UNOFFICIAL MACHINE TRANSLATION

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Financováno Evropskou unií
NextGenerationEU

5G Broadcast

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Contents

List of abbreviations and explanations

Abbreviation	Full text	Explanation
(f∆)	Frequency Shift	Frequency shift
µs	Microseconds	A unit of time equivalent to one millionth of a second
2FA	Two-Factor Authentication	Two-factor authentication
3DES	Triple Data Encryption Standard	An enhanced version of DES, using triple encryption to improve security
3G	Third Generation	Third generation of mobile networks
3GPP	3rd Generation Partnership Project	An organisation developing standards for mobile networks
4G	Fourth Generation	Fourth-generation mobile network technology
4K	Ultra High Definition	Very high image resolution (4K and above)
5G	Fifth Generation	A new generation of mobile technology, offering higher speeds and capacity
5G NR CPE	5G New Radio Customer Premises Equipment	Equipment for end users in 5G NR networks
5GC	5G Core	The core of 5G networks
5G-MAG	5G Media Action Group	A group focused on the development of media services in 5G
5GTN+	5G Test Network Plus	5G test network
5GTNF	5G Test Network Finland	5G test network in Finland
5G-Xcast	5G Broadcast and Multicast Communications	A project focused on the development of multicast and broadcast technologies within 5G networks
8K	8K Resolution	8K resolution
AAA	Authentication, Authorisation, Accounting	Protocols for authentication, authorisation and accounting
ABR	Adaptive Bitrate Streaming	Technology enabling the data rate to be adjusted according to available bandwidth
AES	Advanced Encryption Standard	A symmetric encryption algorithm
AI	Artificial Intelligence	Artificial intelligence
API	Application Programming Interface	Interface for communication between applications
AR	Augmented Reality	Augmented Reality
ARD	Association of Public Service Broadcasters in the Federal Republic of Germany	Association of Public Service Radio and Television Stations in Germany
ARD/SWR Media Library	ARD/SWR Media Library	Media library of the German public service broadcasters ARD and SWR
ARQ	Automatic Repeat Request	Automatic Repeat Request
ATSC	Advanced Television Systems Committee	Organisation for the standardisation of television broadcasting
AVC	Advanced Video Coding	An advanced video compression standard, also known as H.264
AVMSD	Audiovisual Media Services Directive	Audiovisual Media Services Directive
AVOD	Ad-Supported Video on Demand	Ad-supported video-on-demand service
BBC	British Broadcasting Corporation	A public service broadcaster in the UK
Blowfish	An algorithm designed for fast encryption	
BM-SC	Broadcast Multicast Service Centre	Centre for multicast and broadcast services

BS	Base Station	Base stations in mobile networks
BSCC	Broadcast Service & Control Centre	Broadcast Service Management and Control Centre

BSP	Base Station Power	Base station power
BSS/OSS	Business Support System / Operational Support System	Business and Operational Support Systems
CA	Certificate Authority	Certification Authority
CABAC	Context-adaptive binary arithmetic coding	Context-adaptive binary arithmetic coding, an efficient compression method
CAS	Cell Acquisition Subframe	Subframe for cell acquisition
CAS	Conditional Access Systems	Conditional Access Systems
CAVLC	Context-adaptive variable-length coding	Context-adaptive variable-length coding, used in H.264
CDG	Czech Digital Group	A group operating digital broadcasting in the Czech Republic
CDMA2000	Code Division Multiple Access 2000	Code Division Multiple Access 2000
CDN	Content Delivery Network	Content Delivery Network
CDR	China Digital Radio	A digital radio system in China that combines analogue FM broadcasting with modern technologies
CEPT	European Conference of Postal and Telecommunications Administrations	European Conference of Postal and Telecommunications Administrations
CMAF	Common Media Application Format	Standard format for the distribution of streamed video content
CMS	Content Management System	Content management system
CP	Cyclic Prefix	A cyclic prefix ensuring resistance to multipath signal propagation
CRA	Czech Radiocommunications	
C-RAN	Cloud Radio Access Network	Cloud-based radio access network
CSR	Certificate Signing Request	Certificate Signing Request
CR	Czech Republic	
ČT	Czech Television	Czech public service broadcaster
CTU	Czech Telecommunications Office	
DAB	Digital Audio Broadcasting	Digital radio broadcasting
DAB+	Digital Audio Broadcasting Plus	An advanced standard for digital radio broadcasting
DASH	Dynamic Adaptive Streaming over HTTP	Technology for adaptive video streaming over HTTP
DCT	Discrete Cosine Transform	A discrete cosine transform used in video compression
DDoS	Distributed Denial of Service	A denial-of-service attack spread across multiple sources
DES	Data Encryption Standard	Standard for data encryption
DoS	Denial-of-Service	Denial-of-Service attack
DRM	Digital Rights Management	Digital Rights Management
DSA	Digital Signature Algorithm	Algorithm for generating and verifying digital signatures
DST	Discrete Sine Transform	A discrete sine transform used in intra-prediction
DTT	Digital Terrestrial Television	Digital terrestrial television
DTTB	Digital Terrestrial Television Broadcasting	Digital terrestrial television broadcasting
DTV	Digital Television	Digital television
DVB	Digital Video Broadcasting	Standard for digital television broadcasting
DVB-T	Digital Video Broadcasting – Terrestrial	Standard for digital terrestrial broadcasting
DVB-T2	Digital Video Broadcasting – Second Generation Terrestrial	Second generation of the standard for digital terrestrial broadcasting
EAP	Extensible Authentication Protocol	Extensible Authentication Protocol
EAP-PEAP	Protected Extensible Authentication Protocol	Protected EAP
EAP-TLS	Transport Layer Security	Transport Layer Security

EAP-TTLS	Tunneled Transport Layer Security	Tunnelled Transport Layer Security
EBU	European Broadcasting Union	European Broadcasting Union
EDGE	Enhanced Data rates for GSM Evolution	Increased data transmission rates in GSM networks
EIRP	Effective Isotropic Radiated Power	Effective isotropic radiated power
eLAA	Enhanced Licensed Assisted Access	Enhanced access via licensed spectrum
ElGamal	Encryption algorithm	Asymmetric encryption algorithm based on the calculation of the discrete logarithm
eLWA	Enhanced LTE-WLAN Aggregation	Enhanced LTE and Wi-Fi aggregation
eMBMS	Evolved Multimedia Broadcast Multicast Service	Multicast and broadcast technology in LTE networks
eNB	Evolved NodeB	Base station in LTE and 5G networks
EnTV	Enhanced TV	Enhanced television
EPC	Evolved Packet Core	Core of advanced mobile networks
EPC/5GC/NGC	Evolved Packet Core/5G Core/Next Generation Core	Advanced and next-generation mobile cores for 5G networks
ERP	Effective Radiated Power	The effective radiated power of a transmitter, which defines the total transmission power
ETSI	European Telecommunications Standards Institute	European Telecommunications Standards Institute
ETSI TS	European Telecommunications Standards Institute Technical Specification	Technical specification drawn up by the European Telecommunications Standards Institute (ETSI)
EU	European Union	
EuCNC	European Conference on Networks and Communications	Conference on Networks and Communications in Europe
EWBS	Emergency Warning Broadcast System	Emergency Warning Broadcast System
FEC	Forward Error Correction	Transmission error correction
FEFs	Future Extension Frames	Extension frames for DVB-T2 that enable advanced broadcasting features
FeMBMS	Further Evolved Multimedia Broadcast Multicast Service	Enhanced technology for multicast and broadcast in 5G networks
FeMBMS-OMA	Further evolved Multimedia Broadcast Multicast Service – Orthogonal Multiple Access	Enhanced FeMBMS technology with orthogonal multiple access
FeMBSM	Further evolved Multimedia Broadcast Multicast Service	Enhanced technology for multicast and broadcast in 5G networks
FIPS	Federal Information Processing Standards	Federal standard for information processing in the USA
FIPS 186	Federal Information Processing Standard 186	Federal standard for digital signatures in the USA
FM	Frequency Modulation	Frequency Modulation
FTA	Free-to-Air	Free-to-air broadcasting
GHz	Gigahertz	A unit of frequency equivalent to one billion cycles per second
GPS	Global Positioning System	Global Navigation System
GSM	Global System for Mobile Communications	Global standard for mobile communications
H.264	Advanced Video Coding	An advanced standard for video compression
H.265	High Efficiency Video Coding (HEVC)	A highly efficient video compression standard
HARQ	Hybrid Automatic Repeat Request	Hybrid Automatic Repeat Request
HbbTV	Hybrid Broadcast Broadband TV	A hybrid television service combining broadcast television and broadband internet
HD	High Definition	High-definition picture, usually 720p, 1080p or higher
HDR	High Dynamic Range	High dynamic range
HEVC	High Efficiency Video Coding	A highly efficient compression standard, also known as H.265
HLS	HTTP Live Streaming	A protocol for video streaming
HPHT	High-Power High-Tower	Broadcasting technology using high-power transmitters
HTTP	Hypertext Transfer Protocol	A protocol for transferring hypertext and data over the internet

ID	Identifier	Identifier
IDCT	Inverse Discrete Cosine Transform	Inverse discrete cosine transform for video decompression
IDEA	International Data Encryption Algorithm	A symmetric encryption algorithm developed as a replacement for DES
IDS	Intrusion Detection Systems	Network intrusion detection systems
IDS/IPS	Intrusion Detection and Prevention Systems	A combination of intrusion detection and prevention systems
iFN	Intermediate Frequency Network	Intermediate Frequency Network
ILS	Internet Link Service	A service enabling access to internet links
IMB5	Integration of Broadcast and Broadband in LTE/5G	Project for the integration of broadcasting and broadband in LTE/5G
IMT	International Mobile Telecommunications	International Mobile Telecommunications Services
IoT	Internet of Things	A network connecting various devices and sensors via the internet
IP	Internet Protocol	Internet Protocol
IPS	Intrusion Prevention Systems	Network intrusion prevention systems
IPTV	Internet Protocol Television	Television broadcasting via IP networks
ISD	Inter-Site Distance	Distance between transmission sites
ITU	International Telecommunication Union	International Telecommunication Union
JSON	JavaScript Object Notation	A format for exchanging data between systems
kHz	Kilohertz	A unit of frequency equivalent to one thousand cycles per second
km/h	Kilometres per hour	Kilometres per hour
KML	Keyhole Markup Language	A format for displaying geographical data
kW	Kilowatt	A unit of power equivalent to one thousand watts
LDM-NOMA	Layered Division Multiplexing – Non-Orthogonal Multiple Access	Layered Division Multiplexing with non-orthogonal access
LL	Lower Layers	Lower layers in a communication protocol
LP Tx	Low-Power Transmitters	Low-power transmitters
LPLT	Low-Power Low-Tower	Low-power, low-tower transmitter for covering densely populated areas
LTE	Long Term Evolution	4th-generation mobile network technology
LTE enTV	LTE enhanced TV	Technology for distributing television broadcasts via LTE networks
LTE-A	Long Term Evolution Advanced	Advanced LTE mobile network technology
LTE-A+	Long Term Evolution Advanced Plus	An advanced version of LTE with higher capacity
LTE-B	LTE Broadcast	Technology for broadcasting over LTE networks
M&E	Media and Entertainment	Media and Entertainment sector
mABR	Multicast Adaptive Bitrate Streaming	Adaptive multicast streaming
MB	Media Broadcast	Media broadcasting service
MBB	Mobile Broadband	Mobile broadband connection
Mbit/s	Megabits per second	Unit of data transfer rate
MBMS	Multimedia Broadcast Multicast Service	Technology for multicast and broadcast in mobile networks
MBMS-GW	MBMS Gateway	MBMS gateway for multicast and broadcast services
Mbps	Megabits per second	A unit of data transfer rate equivalent to one million bits per second
MBS	Multicast and Broadcast Services	Multicast and broadcast services
MBSFN	Multicast Broadcast Single Frequency Network	Single-frequency network for multicast and broadcast
MCE	Multicast Coordination Entity	Entity for coordinating multicast services
MCS	Modulation and Coding Scheme	Modulation and coding schemes for data transmission

MHz	Megahertz	A unit of frequency equivalent to one million cycles per second (1 MHz = 1,000,000 Hz)
MIMO	Multiple Input, Multiple Output	A technology for data transmission using multiple antennas
MME	Mobility Management Entity	Entity for managing mobility in LTE/5G networks
MNO	Mobile Network Operator	Mobile network operator
MooD	MBMS on Demand	A function enabling the dynamic allocation of resources based on current demand
MPEG-2	Moving Picture Experts Group - 2	An older compression standard for digital video
MPEG-DASH	Dynamic Adaptive Streaming over HTTP	Adaptive video streaming over HTTP
MPMT	Medium-Power Medium-Tower	Medium-power, medium-tower transmitters
NDR	Norddeutscher Rundfunk	North German Broadcasting
NGMN	Next Generation Mobile Networks	A conference focusing on next-generation mobile technologies
NLP	Natural Language Processing	Natural Language Processing
NPN ID	Non-Public Network Identifier	Non-Public Network Identifier
NR	New Radio	New radio access used in 5G networks
NRK	Norsk rikskringkasting	Norwegian public service radio and television broadcaster
NSA	Non-Standalone	5G technology operating in conjunction with 4G networks
OBECA	Open Broadcast Edge Cache Appliance	A device for edge storage of broadcast content
OBS	Olympic Broadcasting Services	Organisations responsible for broadcasting the Olympic Games
OFDM	Orthogonal Frequency Division Multiplexing	Orthogonal frequency division multiplexing technology
OFDMA	Orthogonal Frequency Division Multiple Access	Technology for multi-user access using orthogonal frequency division
OpenSSH	Open Secure Shell	An open protocol for secure connections via SSH
OTT	Over-The-Top	Distribution of content via the internet outside traditional broadcasting networks
OWC	Optical Wireless Communication	Optical wireless communication
PGP	Pretty Good Privacy	Encryption software for secure data transmission
P-GW	Packet Gateway	Gateway for the transmission of data packets
PKI	Public Key Infrastructure	Public Key Infrastructure
PLS	Physical Layer Security	Physical security at the transmission layer
PMCH	Physical Multicast Channel	Physical Multicast Channel
PTM	Point-to-Multipoint	Point-to-multipoint communication
PTP	Point-to-Point	Point-to-point communication
PVV	Pay-Per-View	A service where viewers pay to watch individual programmes
PWS	Public Warning Systems	Public warning system
QAM	Quadrature Amplitude Modulation	A modulation technique that combines amplitude and phase modulation for more efficient data transmission
QoS	Quality of Service	Quality of Service
QPSK	Quadrature Phase Shift Keying	Quadrature phase shift keying
R&S	Rohde & Schwarz	German manufacturer of measurement and transmission equipment
RADIUS	Remote Authentication Dial-In User Service	A service for remote user authentication
RAI	Radiotelevisione Italiana	Italian public service broadcaster
RAN	Radio Access Network	Radio Access Network
RBS	Resource Blocks	Resource blocks for data transmission
ROI	Return on Investment	Return on Investment
ROM	Receive-Only Mode	Receive-Only Mode

RRC	Radio Resource Control	Radio Resource Control
RSA	Rivest-Shamir-Adleman	Asymmetric encryption method
SA	Stand-Alone	Standalone 5G technology
SAO	Sample Adaptive Offset	Adaptive sample adjustment, a tool used in HEVC
SaT5G	Satellite and Terrestrial 5G	A combination of satellite and terrestrial broadcasting for 5G
S-boxes	Substitution boxes	Part of the DES algorithm, which replaces parts of a block with other values
SC-PTM	Single-Cell Point-to-Multipoint	Transmission from a single transmission point to multiple users simultaneously
SCS	Subcarrier Spacing	Subcarrier spacing
SD	Standard Definition	Standard image resolution
SDK	Software Development Kit	Software Development Kit
SDL	Supplemental Downlink	Supplemental downlink in NSA/SA networks
SDR	Software-Defined Radio	Software-defined radio
SEN	Shared eMBMS Network	A shared eMBMS network enabling multiple mobile operators to share the costs associated with content distribution
SFN	Single Frequency Network	A network using a single frequency for broadcasting
S-GW	Serving Gateway	A gateway for providing services in LTE networks
SIM	Subscriber Identity Module	Identification module card for mobile devices
SNPN	Stand-alone Non-Public Network	Stand-alone non-public network
SSL	Secure Sockets Layer	A security protocol, the predecessor to TLS
StatMux	Statistical Multiplexing	Statistical multiplexing
SVOD	Subscription Video on Demand	Subscription video-on-demand service
SWR	Südwestrundfunk	Regional public service radio and television broadcaster for the German federal states of Baden-Württemberg and Rhineland-Palatinate
TDF	Télédiffusion de France	French national broadcasting company
TDM	Time Division Multiplexing	Time-division multiplex
TLS	Transport Layer Security	A security protocol for encrypting data on the internet
TOoL+	Tower Overlay LTE Advanced Plus	A technology that enables data transmission via LTE-A+ using long-range transmitters
TTI	Transmission Time Interval	Time interval for data transmission
TV	Television	
TVOD	Transactional Video on Demand	A video-on-demand service charged on a per-transaction basis
UE	User Equipment	User equipment
UHD	Ultra High Definition	Ultra-high image resolution
UL	Upper Layers	Upper layers in the communication protocol
UMTS	Universal Mobile Telecommunications System	Universal Mobile Telecommunications System
V2V	Vehicle-to-Vehicle	Vehicle-to-vehicle communication
VDCM	Virtual Digital Content Manager	Virtual Digital Content Manager
VHF	Very High Frequency	Very High Frequency
VLC	Variable Length Coding	Variable-length coding used in MPEG-2
VOD	Video on Demand	Video available on demand
VR	Virtual Reality	Virtual Reality
VTT	VTT Technical Research Centre of Finland	Technical Research Centre of Finland
W	Watt	Unit of power
Wavefront	Wavefront Parallel Processing	Wavefront parallel processing, a feature in HEVC for multi-core processors

WCDMA	Wideband Code Division Multiple Access	Technology for wideband code division multiple access
WiFi	Wireless Fidelity	Wireless technology for connecting to the internet
WIVE	Wireless for Verticals	A project focused on the development of 5G technologies for various vertical industries
xMB	xMB Interface	The xMB interface for broadcast services
XR	Extended Reality	Extended Reality
Winter Olympics	Winter Olympic Games	

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Executive Summary

This study focuses on analysing FeMBMS (Further evolved Multimedia Broadcast Multicast Service) technology in current 5G networks and its potential use in the Czech Republic. FeMBMS offers the possibility of more efficient transmission of audiovisual data and mass communications with high efficiency, both for commercial use and for public services, including emergency communications. The study assesses the current state of the technology's implementation, analyses its compatibility with existing systems and explores possible future applications.

Conclusion to Chapter 1:

- FeMBMS introduces a revolutionary model for broadband broadcasting within the 5G framework, which enhances the stability and efficiency of the distribution of multimedia content and emergency communications.
- The 'one-to-many' approach ensures that the technology is capable of handling mass transmissions during events with high concentrations of people or in emergency situations, whilst saving bandwidth compared to unicast.
- Thanks to its support for high-performance transmitters and wide coverage, FeMBMS helps to extend access to multimedia services to remote regions, contributing to the availability of information and safety.

Conclusion to Chapter 2:

- Multimedia broadcasting via 5G provides an effective solution for the distribution of digital content across various sectors, from entertainment to healthcare and education.
- FeMBMS ensures high-quality transmission and low latency, resulting in a smooth and stable user experience even with a large number of connected devices.
- Narrowcasting within this technology facilitates the targeting of content at selected user groups, for example in crisis communication or marketing, where it is necessary to reach a specific audience.
- 5G broadcast guarantees the reliable distribution of emergency messages to the general public, even when conventional networks are overloaded.

Conclusion to Chapter 3:

- FeMBMS expands the possibilities for distributing multimedia content via 5G networks and enables more efficient use of the frequency spectrum, higher-quality transmission and greater geographical coverage.
- The combination of multicast and broadcast approaches helps to optimise bandwidth, whilst the HPHT and LPLT modes adapt the coverage range according to population density, whether in cities or remote areas.
- The separation of transport and service functions improves flexibility and adaptability for digital terrestrial broadcasting, simplifying the integration of the technology into existing infrastructure.
- The deployment of FeMBMS in the Czech Republic requires addressing issues relating to spectrum management, the technical aspects of single-frequency networks and the need for investment in the modernisation of existing transmission equipment.

Conclusion to Chapter 4:

- The AVMSD Directive, updated to take account of digital media, focuses on consumer protection, the promotion of European content, and the regulation of advertising and undesirable content.
- ETSI technical standards support the interoperability of equipment within 5G Broadcast, whilst 3GPP defines specifications for FeMBMS, enabling secure and efficient transmission.

- The legal framework in the Czech Republic comprises laws on electronic communications and broadcasting, which are being adapted to the requirements of modern technologies, including spectrum management and consumer protection.
- The implementation of FeMBMS and 5G Broadcast in the Czech Republic faces technical and legislative challenges that must be overcome in order to fully realise the potential of new features and ensure the secure and efficient use of the spectrum.

Conclusion to Chapter 5:

- FeMBMS deployment strategies vary from country to country; Italy is focusing on rural coverage, whilst France is conducting trials for major events.
- International FeMBMS pilot projects highlight technical and regulatory challenges, data transmission optimisation and user responses to new services.
- Germany emphasises in-vehicle multimedia services and collaboration with the automotive industry, thereby influencing the development of new broadcasting models.
- International experience offers inspiration for adapting FeMBMS deployment strategies in the Czech Republic, where key issues include financial sustainability, content protection, efficient spectrum utilisation and cooperation with other sectors.

Conclusion to Chapter 6:

- FeMBMS supports both standalone (SA) and non-standalone (NSA) modes of 5G networks, with NSA facilitating the transition to 5G using LTE, whilst SA delivers full autonomy, higher capacity and low latency.
- Integration with DVB-T2 adds value by delivering television content to mobile devices, thereby meeting current demands for flexibility in multimedia services.
- The combination of SFN and HPHT architecture ensures extensive coverage and eliminates interference, improving signal stability even in challenging conditions.
- FeMBMS is adapted to a wide range of devices, from mobile phones to infotainment systems; it supports content viewing whilst on the move and expands the possibilities for multimedia consumption.

Conclusion to Chapter 7:

- FeMBMS utilises advanced compression technologies, such as H.265 (HEVC) and AV1, and achieves high image quality whilst consuming low bandwidth.
- Adaptive streaming via MPEG-DASH adjusts the transmission quality to network conditions and ensures a smooth and stable picture even under high network load.
- Single-frequency networks (SFNs) reduce interference and ensure stable transmission, thereby improving signal availability and quality in areas with a high concentration of users or complex terrain.
- FeMBMS optimises spectrum utilisation, thereby ensuring stable distribution of multimedia content even under high load.

Conclusion to Chapter 8:

- FeMBMS incorporates comprehensive security measures to protect multimedia content and prevent unauthorised access, minimising the risk of financial loss and legal issues.
- User and device authentication is supported by a PKI infrastructure for managing encryption keys and certificates, as well as by authentication protocols such as EAP and AAA.
- Protection against DoS attacks and jamming includes detection systems, signal encryption, access rate limiting and spectrum spreading.

- Modern encryption algorithms, such as AES and RSA, create a secure environment for transmission, whilst DRM and CAS systems manage access rights and restrict the unauthorised distribution of content.

Conclusion to Chapter 9:

- FeMBMS enables automatic switching between multicast and unicast and maintains service continuity even during infrastructure outages.
- The choice of backup strategy – full, incremental or differential – is tailored to specific recovery needs and storage capacity.
- Automated backups and geographical data replication minimise the risk of outages and enhance the system's overall resilience.
- OFDM and SFN technologies ensure spectrum efficiency and enhance transmission reliability, contributing to robust digital broadcasting that is resistant to interference and physical attacks.

Conclusion to Chapter 10:

- Implementing FeMBMS requires investment in hardware upgrades, infrastructure and spectrum licences. Costs can be reduced by utilising existing infrastructure elements, particularly in remote areas.
- The costs of spectrum licences, which are essential for operation, may vary depending on regional and regulatory conditions.
- Operating costs include energy consumption, maintenance and spectrum fees. Savings can be achieved through energy-efficient technologies and automated maintenance.
- FeMBMS expands revenue opportunities through new business opportunities, such as targeted advertising and interactive broadcasting, which provide additional monetisation strategies.

Conclusion to Chapter 11:

- The 600 MHz spectrum band offers efficient coverage of large areas with a minimum number of transmitters and ensures stable reception even in urban environments.
- FeMBMS supports efficient content distribution through multicast broadcasting and dynamic bandwidth management, and increases network flexibility in line with current needs.
- Single-frequency networks (SFNs) improve coverage and reduce infrastructure costs by transmitting the same signal from multiple transmitters on a single frequency.
- FeMBMS incorporates transmission control technologies that minimise interference, thereby maintaining transmission quality even under high network load.

Management summary

This study focuses on analysing FeMBMS (Further evolved Multimedia Broadcast Multicast Service) technology in current 5G networks and its potential applications in the Czech Republic. FeMBMS enables the efficient transmission of audiovisual data and mass communications, catering to both commercial use and public services, including emergency communications. The study evaluates the current implementation status, compatibility with existing systems, and potential future applications of the technology.

Summary of Chapter 1:

- FeMBMS introduces a groundbreaking model for broadband broadcasting within 5G, enhancing stability and efficiency in the distribution of multimedia content and emergency notifications.
- Its 'one-to-many' approach ensures robust performance during events with high population density or in crisis scenarios, optimising bandwidth usage compared to unicast.
- High-power transmitters and wide coverage expand access to multimedia services in remote areas, improving the availability of information and safety.

Summary of Chapter 2:

- 5G multimedia broadcasting offers an effective solution for distributing digital content across a range of sectors, from entertainment to healthcare and education.
- FeMBMS ensures high-quality transmissions with low latency, providing a seamless experience for large numbers of connected devices.
- Narrowcasting capabilities enable targeted communication, which is essential for emergency response or marketing to specific audiences.
- 5G broadcasting delivers reliable emergency alerts to the public, even during periods of network congestion.

Summary of Chapter 3:

- FeMBMS enhances multimedia distribution via 5G, maximising spectrum efficiency, improving quality and extending geographical reach.
- Combining multicast and broadcast approaches optimises bandwidth usage, whilst high-power-high-tower (HPHT) and low-power-low-tower (LPLT) modes adapt coverage to urban and rural needs.
- A modular architecture for transport and service functions ensures flexibility and easier integration into existing infrastructures.
- Deployment in the Czech Republic requires addressing frequency management, single-frequency network (SFN) technicalities, and investment in infrastructure upgrades.

Summary of Chapter 4:

- The AVMSD Directive, updated for digital media, focuses on consumer protection, promoting European content, and regulating advertising and harmful material.
- ETSI standards ensure device interoperability for 5G Broadcast, whilst 3GPP specifications support secure and efficient FeMBMS transmissions.
- Czech legal frameworks, including laws on electronic communications and broadcasting, are aligned with modern technological requirements, emphasising spectrum management and consumer protection.
- Implementing FeMBMS and 5G Broadcast presents technical and regulatory challenges that must be resolved to realise their full potential.

Summary of Chapter 5:

- Deployment strategies vary internationally, with Italy focusing on rural coverage and France testing large-scale event applications.
- Pilot projects highlight challenges relating to data transmission, user acceptance and regulatory adjustments.
- Germany prioritises multimedia services for vehicles, collaborating with the automotive industry to shape new broadcasting models.
- Lessons from global experiences highlight the need for sustainable financing, content protection, efficient spectrum usage, and cross-industry collaboration in the Czech Republic.

Summary of Chapter 6:

- FeMBMS supports both standalone (SA) and non-standalone (NSA) 5G modes, with NSA facilitating the transition from LTE whilst SA offers full autonomy, greater capacity and low latency.
- Integration with DVB-T2 enhances value by bringing TV content to mobile devices, meeting modern demands for multimedia flexibility.
- SFN and HPHT architectures ensure extensive coverage, reduced interference and reliable signal delivery in challenging conditions.
- The technology supports a range of devices, from smartphones to in-vehicle systems, enabling multimedia consumption whilst on the move.

Summary of Chapter 7:

- Advanced compression technologies such as H.265 (HEVC) and AV1 deliver high-quality visuals whilst minimising bandwidth usage.
- Adaptive streaming via MPEG-DASH adjusts to network conditions, ensuring smooth playback even during periods of high traffic.
- SFN reduces interference and ensures stable transmissions, enhancing signal availability in densely populated areas or challenging terrains.
- FeMBMS optimises spectrum usage, supporting consistent multimedia distribution under heavy load.

Summary of Chapter 8:

- Comprehensive security measures protect multimedia content, preventing unauthorised access and minimising financial and legal risks.
- PKI-based authentication secures users and devices, complemented by protocols such as EAP and AAA for robust access management.
- Defences against DoS attacks and interference include encryption, traffic rate limiting and spectrum spreading.
- Modern algorithms such as AES and RSA secure transmissions, whilst DRM and CAS systems manage access rights and restrict unauthorised content sharing.

Summary of Chapter 9:

- FeMBMS supports seamless switching between multicast and unicast, maintaining service continuity during infrastructure outages.
- Tailored backup strategies—full, incremental, or differential—address specific recovery needs and storage constraints.
- Automated backups and geographic data replication reduce the risk of downtime and enhance system resilience.
- OFDM and SFN technologies improve spectrum efficiency and ensure robust digital broadcasting, resistant to interference or physical disruption.

Summary of Chapter 10:

- Deploying FeMBMS requires investment in hardware, infrastructure and spectrum licences, with costs mitigated by utilising existing infrastructure, particularly in remote areas.
- Spectrum licence costs depend on regional and regulatory conditions.
- Operational costs include energy consumption, maintenance and spectrum fees, which can be reduced through the use of energy-efficient technologies and automated maintenance.
- FeMBMS opens up new revenue streams through targeted advertising and interactive broadcasting, offering innovative monetisation opportunities.

Summary of Chapter 11:

- The 600 MHz band enables cost-effective coverage of large areas with a minimal number of transmitters, ensuring stable reception even in urban environments.
- FeMBMS supports efficient multicast broadcasting, dynamically adapting bandwidth allocation to network demands.
- SFN enhances coverage and reduces infrastructure costs by broadcasting the same signal from multiple transmitters on a single frequency.
- Advanced transmission management minimises interference, maintaining quality even under high network loads.

1 Introduction

5G technology represents a revolution in the field of mobile networks, with one of its key benefits being the ability to transmit multimedia and bulk messages efficiently. An innovation in this field is the **Further evolved Multimedia Broadcast Multicast Service (FeMBMS)** technology, which enables the provision of high-quality television and audiovisual services over 5G networks. FeMBMS builds on previous technologies, such as eMBMS (Multimedia Broadcast Multicast Service) in the LTE standard, and brings significant improvements to the provision of services to large numbers of users simultaneously.

1.1 Aim of the study

This study provides a detailed analysis of FeMBMS technology and its significance for current 5G networks, with a view to its potential application in the Czech Republic. FeMBMS expands the capabilities of the traditional eMBMS standard and delivers fundamental improvements for the transmission of multimedia content, particularly via single-frequency networks and modes optimised for high performance. Given the growing demands for bandwidth, transmission reliability and minimal latency, this technology offers new possibilities not only for the commercial sector but also for public services, including emergency communications.

However, before FeMBMS can be deployed in the Czech Republic, certain challenges must be overcome, particularly in the areas of spectrum management, compatibility with existing systems and infrastructure funding. The legal framework, including European regulations and national legislation, influences how the technology can be implemented and how its benefits – such as the expansion of multimedia services, targeted broadcasting and mobile television – can be utilised. The study also includes an overview of international projects and experiences that may provide inspiration for addressing the practical and technical aspects of introducing FeMBMS in the local context.

The dynamic development of digital broadcasting and growing technological demands highlight the potential of FeMBMS as a platform capable of transmitting multimedia content more efficiently, with lower bandwidth requirements and greater resilience to network outages. The study therefore not only assesses the current state of FeMBMS implementation but also focuses on its potential future benefits, particularly when combined with traditional systems such as DVB-T2. This opens up new prospects for the development of multimedia services, ensuring higher transmission quality, extended coverage and more flexible content distribution models.

1.2 Definition of key terms

1.2.1 Broadcast

Broadcast, also known as mass transmission, is a method of data transmission in which content is distributed unidirectionally from a single source to a large number of recipients simultaneously. This method of information distribution is traditionally used in television and radio broadcasting, as well as in data broadcasts, and is effective for reaching a large number of users with minimal demands on network infrastructure and bandwidth.

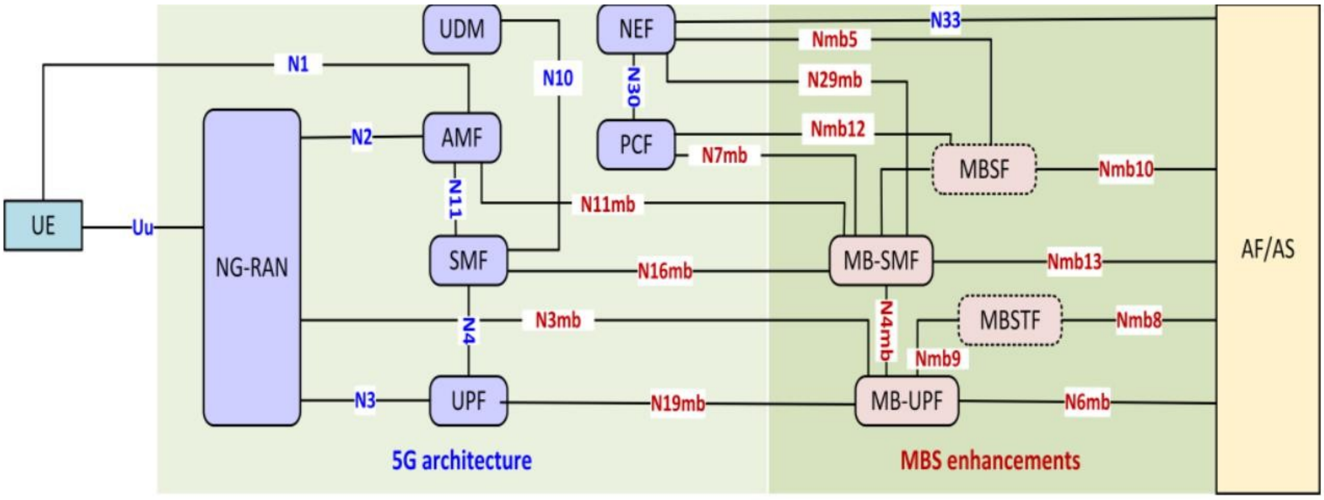

Figure 1: 5G broadcast architecture

Source: https://eujournal.org/index.php/esj/article/view/16888/16758

*The figure illustrates **the architecture of** a **5G Broadcast** system, which enables the efficient distribution of multicast and broadcast content to a large number of users. This process involves several parties:*

- ***End user (UE – User Equipment)**: These are end devices, such as smartphones or tablets, which receive the content.*
- ***Operator (electronic communications provider)**: The mobile operator plays a key role in signal distribution. It provides the radio access network (NG-RAN) and manages the 5G core network, which facilitates communication between end devices and content. The operator is responsible for network management, resource allocation and data transmission, including broadcast content.*
- ***Content provider**: This entity is responsible for creating or acquiring multimedia content, which is subsequently distributed via multicast or broadcast. It communicates with the network architecture via servers and application functions (AF/AS).*

***Multicast/Broadcast server and other network functions**:*

- ***MBSF (Multicast Broadcast Service Function)** manages and organises the distribution of content via multicast/broadcast.*
- ***MB-SMF** and **MB-UPF** ensure the management and transmission of multicast sessions across the network.*
- ***Interfaces such as N3mb and N11mb** connect the individual network components to ensure proper operation and data transmission.*

The main difference between unicast and broadcast (sometimes referred to as multicast in the context of broadcasting) is that unicast transmits data to each user individually. This means that if thousands of users are watching the same content, such as a live broadcast, each receives their own data stream. This model places high demands on bandwidth, as a separate channel is required for each connection. In situations with high viewership, unicast can lead to network congestion, resulting in a deterioration in service quality, such as transmission delays, reduced picture quality or outages.

Broadcast (sometimes also referred to as multicast) operates on a ‘one-to-many’ principle, whereby one or more transmitters distribute the same content to many users simultaneously. In this one-way transmission, all users within the coverage area receive the same data stream without the need to establish separate connections for each individual. This makes broadcast more efficient in terms of bandwidth and allows for better scaling of transmissions during mass events. Whilst unicast networks may fail under heavy load, broadcast provides stable transmission, as the network’s capacity does not depend on the number of connected users.

The practical implications of this difference are evident during the transmission of widely watched events, such as sports matches or live concerts. If an operator were to use unicast, it would have to manage thousands or millions of connections simultaneously, which would place a significant strain on its network and would likely lead to a deterioration in transmission quality. Broadcast, however, transmits a single data stream that all viewers can receive simultaneously without the need to increase network capacity.

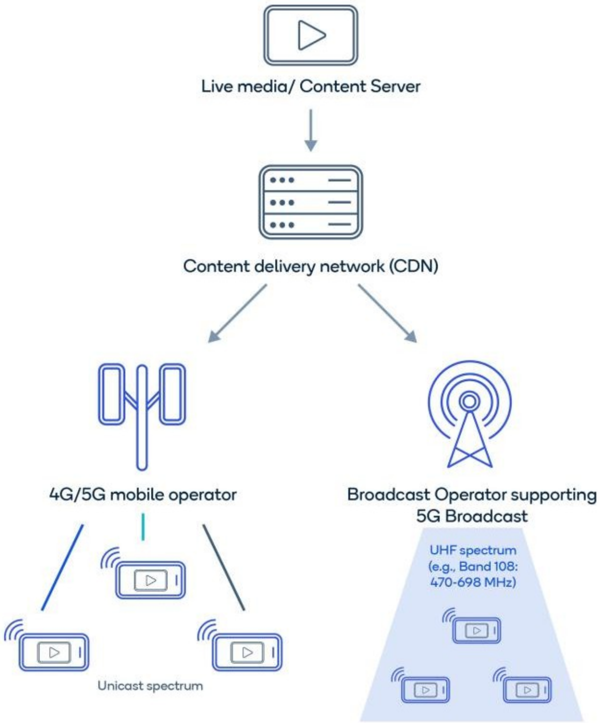

Figure 2: Hybrid content distribution via 5G Broadcast and unicast networks

Source: https://www.qualcomm.com/news/onq/2023/12/5g-broadcast-what-can-consumers-expect

An example of the effective use of a combination of unicast and 5G broadcast can be seen in the diagram below. The content is first stored on a server, which serves as a source for live broadcasts or media files. This content is then distributed via a Content Delivery Network (CDN), which optimises data delivery to operators.

On the one hand, there is a 4G/5G mobile operator using a unicast connection, whereby an individual data stream is sent to each user. In the event of mass viewing, this can lead to network congestion and a reduction in transmission quality, as the operator must manage thousands or even millions of connections simultaneously.

On the other hand, there is an operator supporting 5G broadcast, which transmits content via the UHF spectrum (for example, the 470–698 MHz band). This system allows a single data stream to be broadcast, which all users can receive simultaneously without the need to increase network capacity. This significantly reduces the load on the network and ensures stable transmission even with a high number of viewers.

The combination of these two technologies enables operators to switch dynamically between unicast and broadcast depending on current network conditions.

In mobile networks, where unicast is the primary transmission method, broadcast offers significant capacity savings by eliminating the need to create separate data streams for each user. Broadcast transmits the same data stream to many users simultaneously from one or more transmitters, with all receivers within the transmitter’s coverage area receiving the same content. Unlike unicast, where each user establishes an individual connection with the server, broadcasting offers considerable advantages in terms of saving bandwidth and reducing network load.

Broadcast also plays a vital role in disseminating crisis information and emergency alerts, where there is a need to reach a large number of people quickly without two-way communication with each individual. This one-way transmission enables the efficient and reliable delivery of important messages, particularly in situations where the network is under heavy load or during emergencies.

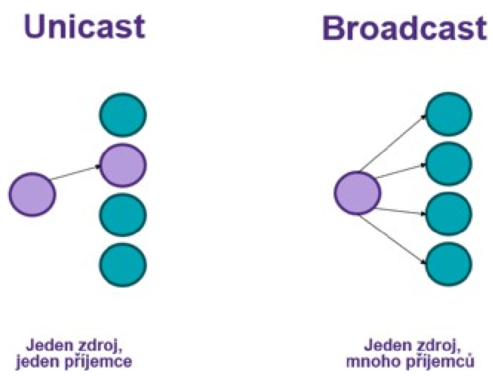

Figure 3: Comparison of unicast and broadcast communication

The figure illustrates the fundamental difference between two methods of data transmission: unicast and broadcast. In the case of unicast communication, data is sent from a single source to a single recipient. In contrast, in broadcast communication, a single source is able to send the same signal to multiple recipients simultaneously.

In mobile networks, the broadcast signal is transmitted unidirectionally, i.e. from a single central transmitter (or multiple transmitters) to many receivers simultaneously. This type of transmission is referred to as 'one-to-many'. The signal can be transmitted from large, high-power towers covering extensive geographical areas, or from smaller cellular transmitters in densely populated urban areas. High-Power High-Tower (HPHT) technology is one of the factors that enables wide signal coverage to be achieved at a lower transmission frequency. This ensures reliable data transmission even in rural and remote areas.

1.2.1.1 Technologies supporting broadcast

In mobile networks, broadcasting is supported by several technologies that must be implemented within the network and which have evolved over the years in response to the growing demand for the efficient distribution of multimedia content. This chapter describes the main technologies that support broadcasting in mobile networks, such as eMBMS and FeMBMS. These technologies are designed primarily for mobile networks, where they enable the efficient distribution of content to a large number of users simultaneously. In addition, variants of DVB (Digital Video Broadcasting) are also utilised; these are commonly used in combination with mobile networks to deliver multimedia content and extend coverage. The individual services and their use in mobile and fixed networks are described in detail below.

eMBMS (Evolved Multimedia Broadcast Multicast Service)

One of the first services to be introduced in 4th-generation (LTE) mobile networks is eMBMS (Evolved Multimedia Broadcast Multicast Service). This technology has enabled the distribution of multimedia content (such as television programmes) to a large number of users simultaneously without the need to establish separate, parallel connections for each user individually. eMBMS has proven its worth during live events and in emergency communications, where the rapid and efficient dissemination of information is crucial without the risk of network congestion.

FeMBMS (Further Evolved Multimedia Broadcast Multicast Service)

With the advent of 5th generation (5G) networks, the FeMBMS service was developed, building on the foundations of eMBMS and delivering significant improvements, particularly in terms of bandwidth, transmission quality and coverage. FeMBMS transmits high-definition content with low latency across large geographical areas.

FeMBMS achieves greater spectrum efficiency and supports higher transmitter power, enabling the provision of multimedia services even in sparsely populated areas or rural locations where traditional mobile networks might have limited coverage.

Table 1: Comparison of eMBMS and FeMBMS technologies

Function	eMBMS (Enhanced MBMS)	FeMBMS (Further evolved MBMS)
Standard	3GPP Release 9–14	3GPP Release 14 and above
Spectrum	Limited to mobile networks (<6 GHz)	Supports multiple mobile bands as well as TV bands (up to 700 MHz)

Coverage	Smaller coverage, dependent on mobile cells	Extended coverage, can utilise a wider bandwidth
Network utilisation	Shares spectrum with unicast services	Dedicated spectrum for broadcast/multicast
Feedback requirement	Feedback from the device is required	Feedback is not required
Transmitters	Usually uses low-power mobile transmitters	May use high-power TV transmitters (HPHT)
Support for SFN (Single Frequency Network)	Supported, but with limited flexibility	Enhanced support for broadband SFN
Signal range	Greater dependence on proximity to the mobile base station	Ability to reach more distant areas
Dynamic switching between unicast and multicast	Limited capability	Improved dynamic switching capability
Target applications	Mobile video, multicast streaming	Mobile video, TV broadcasting, public safety services
Capacity for mass events	Limited capacity with large numbers of users	Designed for higher capacity at mass events

This table compares the differences between eMBMS (enhanced Multimedia Broadcast Multicast Service) and FeMBMS (Further evolved Multimedia Broadcast Multicast Service) technologies, which are used for multicast and broadcast in mobile networks. Whilst eMBMS is an older technology, FeMBMS offers improvements in terms of coverage, spectral flexibility, the use of high-power transmitters and support for broadband networks. FeMBMS enables more efficient media transmission, including public broadcasts, and is designed for mass events with a high concentration of users.

In addition to eMBMS and FeMBMS, other technologies supporting broadcast include various variants of DVB (Digital Video Broadcasting), which are used in combination with mobile networks to deliver multimedia content. DVB broadcasting is often integrated with mobile services, extending coverage and improving transmission quality for users.

1.2.1.2 Advantages of broadcasting

Broadcasting provides operators with the ability to distribute multimedia content, even in situations where unicast transmissions would fail due to high capacity demands. As a next-generation technology, FeMBMS delivers improvements in coverage and transmission quality.

Broadcast also reduces costs for operators thanks to lower bandwidth and infrastructure requirements. It is suitable for scenarios where a large number of users need to be reached simultaneously, whether for entertainment content, news or critical communications during crisis situations.

1.2.1.3 OTT (Over-the-Top)

There are various technologies and services enabling the transmission of multimedia content over digital networks, offering both unicast and broadcast options. OTT (Over-the-Top) is one such technology that enables content delivery via the internet without the need for traditional television or satellite infrastructure.

It utilises **the principle of unicast transmission**, which means that each user receives their own data stream, and content is thus delivered individually according to the user’s requirements. OTT is becoming increasingly popular due to its ability to provide flexible, personalised services that are available anytime and anywhere there is an internet connection.

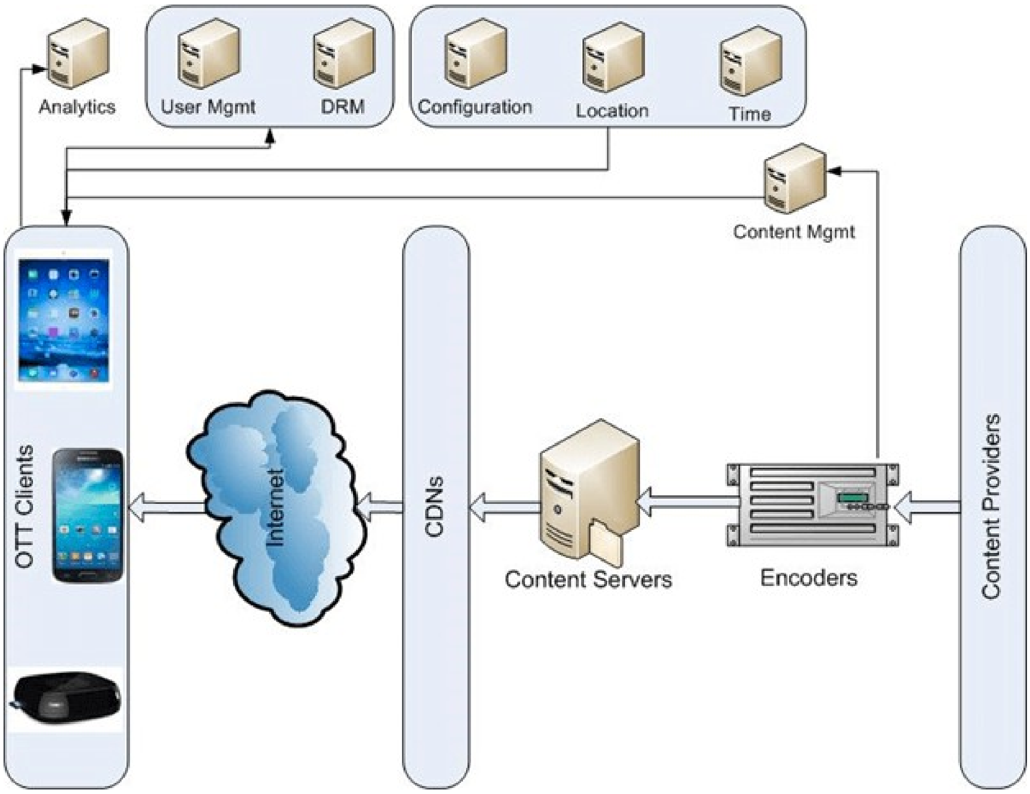

Figure 4: OTT Ecosystem Architecture

Source: https://www.hsc.com/resources/blog/commercial-grade-ott-client-development-an-analysis/

The diagram illustrates the main components of the OTT ecosystem and how they are interconnected, encompassing various modules and technologies for the efficient delivery of multimedia content over the internet. The main components include:

- ***OTT clients**: Devices such as mobile phones, smart TVs or set-top boxes that receive content via the internet. Their role is to play back multimedia content correctly using adaptive streaming techniques.*
- ***Content Delivery Networks (CDNs)**: Content delivery networks optimise the distribution of multimedia content by caching and delivering it from the geographically nearest servers, thereby improving playback quality and reducing latency.*
- ***Content Servers**: These servers store content and stream it to users. The content is received from content providers and then encoded for use by OTT clients.*
- ***Encoders**: Encoders convert multimedia content into formats suitable for efficient playback on OTT clients. In doing so, they balance encoding time against stream quality, particularly during live broadcasts.*
- ***Content Management**: This layer manages information about the programme schedule and content available to OTT clients, including data on live broadcasts and access rights.*
- ***User Management**: This module authorises users based on their subscriptions and grants access only to authorised content.*
- ***DRM (Digital Rights Management)**: This component protects content through encryption and decryption to prevent unauthorised access to multimedia streams.*
- ***Analytics**: Analyses data from OTT clients to monitor service quality, user preferences and system performance. This data is used to further improve the user experience and business strategies.*
- ***Configuration/Location/Time Management**: Provides data for configuring OTT clients, such as regional restrictions, time synchronisation and content customisation based on the user's geographical location.*

The diagram comprehensively illustrates how OTT platforms connect content providers with users via the internet and distribution networks, with an emphasis on the high quality and security of the content delivered.

Key features of OTT:

- **Unicast transmission**: OTT services operate on the unicast principle, whereby each user receives their own data stream intended exclusively for them. Unlike broadcast transmission, where the same signal is sent to all users at once (one-to-many), unicast transmits content on a one-to-one basis, i.e. from a single server to an individual user.

- **On-demand access**: OTT services offer users the option to watch content at any time, which sets them apart fundamentally from traditional broadcast services. Users are not tied to a fixed broadcast schedule and are free to choose programmes or films of their own choosing. Typical examples include platforms such as Netflix, Hulu and Amazon Prime Video, which offer an extensive library of multimedia content.
- **Wide availability across various devices**: OTT services are accessible on a range of devices, such as smart TVs, mobile phones, tablets, laptops and desktop computers. In addition, there are specialised devices such as the Amazon Fire Stick, Apple TV or Google Chromecast, which allow users to watch content comfortably on large screens. This gives users unlimited flexibility, as they can watch content anywhere an internet connection is available.
- **Simpler infrastructure**: OTT services do not require traditional broadcasting or cable infrastructure, as is the case with satellite or terrestrial broadcasting. Instead, these services are distributed via the internet using Content Delivery Networks (CDNs). A CDN is a network of servers located around the world that optimise content distribution based on the user's geographical location, thereby minimising latency and ensuring high-quality streaming.
- **Content personalisation**: OTT platforms offer users the ability to personalise content based on their preferences. Using advanced algorithms, they are able to analyse users' previous behaviour, their ratings and interactions with the platform, and generate recommendations based on this. This increases the likelihood that users will discover content relevant to them and spend more time on the platform.
- **Interactive features**: One of the main advantages of OTT services is the ability to interactively control content. Users can pause, rewind, replay or even download content at any time to watch offline later. This level of control and flexibility is highly appealing to users and significantly enhances the user experience.
- **Monetisation models**: OTT platforms utilise various funding methods, including:
  - Subscription-based: Users pay a regular monthly fee for access to content (e.g. Netflix, Disney+).
  - Advertising (Ad-supported): Content is available free of charge, but users are shown adverts whilst watching (e.g. YouTube, Pluto TV).
  - Pay-Per-View (PPV) models: Users pay for individual programmes or films they wish to watch (e.g. Amazon Prime Video). This flexible approach to monetisation allows providers to adapt to different market segments and user preferences.
- **Adaptive streaming (ABR – Adaptive Bitrate Streaming):** ABR is a technology that dynamically adjusts video quality according to the user's current connection speed. At lower speeds, the system automatically reduces the resolution to prevent interruptions. As soon as the connection speeds up, the resolution increases again, ensuring smooth playback without dropouts.
- **Content Delivery Networks (CDNs):** A CDN is a network of servers that distribute content as close as possible to users. This minimises latency and improves transmission quality, which is essential for streaming high-definition video such as HD or 4K. OTT platforms use CDNs to deliver content quickly and reliably to users worldwide.

Technological aspects of OTT:

- **Data transmission protocols**: OTT platforms use specific protocols for data transmission, such as:
  - HLS (HTTP Live Streaming): This protocol is widely used for video streaming, particularly on Apple devices.
  - MPEG-DASH (Dynamic Adaptive Streaming over HTTP): This protocol adapts the video quality according to the user's current connection conditions.

Advantages of OTT over traditional broadcasting services:

- **Flexibility and accessibility**: OTT services provide content to users anytime and anywhere, which is a key advantage over traditional television broadcasting. Users are not tied to a broadcast schedule and can play content according to their own timetable.
- **Efficient use of the network**: Although OTT technology is unicast, which means it places higher demands on bandwidth than broadcast, it gives users greater control over content and interactivity. This is particularly important today, when viewers demand greater personalisation and instant access to content.
- **High level of personalisation**: Unlike broadcast services, which offer content for the masses, OTT platforms use data on user behaviour to provide personalised recommendations and offers.

OTT vs. IPTV:

OTT and IPTV represent the two main technologies for delivering television and multimedia content via the internet. Although both technologies utilise internet protocols, they differ fundamentally in their approach to content management and distribution. Comparing these two approaches helps to understand the differences in infrastructure, quality of service management and user access. Whilst IPTV requires a controlled network and dedicated service providers, OTT operates independently of the network infrastructure, offering greater flexibility. The following sections therefore compare these two technologies to highlight their advantages and limitations in modern multimedia content delivery.

Video on Demand (VOD)

Video on Demand (VOD) is a service that allows users to watch multimedia content on demand – that is, whenever they wish, according to their needs – without having to follow a fixed broadcast schedule. VOD services provide flexible access to films, television programmes, documentaries and other multimedia material stored on servers and accessible via the internet.

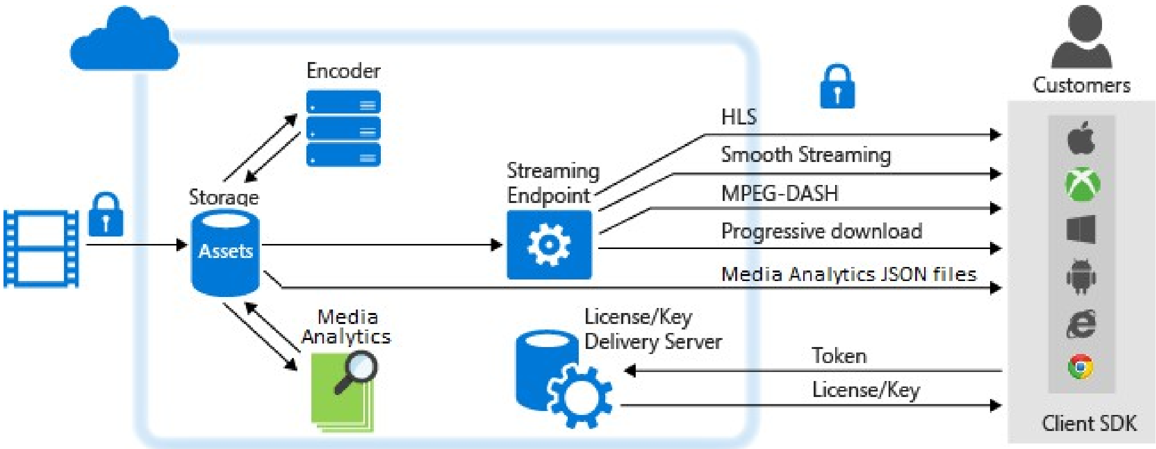

Figure 5: The Video on Demand service delivery process

Source: https://videospace.co/faq-video-ondemand

This diagram illustrates the process of delivering a Video on Demand (VOD) service. Videos are first stored in the asset repository and then encoded by the encoder into formats compatible with various devices. They are subsequently distributed via the streaming endpoint using technologies such as HLS, MPEG-DASH or Progressive Download.

The Licence/Key Delivery Server protects content using DRM and delivers decryption keys. Media Analytics monitors stream quality and provides performance data, whilst CDN networks efficiently distribute content worldwide. Users access content on various devices thanks to an SDK that supports cross-platform compatibility and playback.

Key features of VOD

Unlike traditional linear television broadcasting, where content is broadcast according to a fixed schedule, VOD allows users to select and play any available content whenever they wish.

Typical examples of VOD services include platforms such as Netflix, Amazon Prime Video and **Hulu**, where users can choose from a vast library of programmes and films and play them at their leisure. These platforms usually offer content via streaming, which means there is no need to download the entire content in advance; instead, the video is played in real time over the internet.

Key features of VOD:

- **On-demand access**: VOD gives users the ability to access content at any time. This allows users to watch any programme or film according to their own schedule, without being tied to broadcast times.
- **Content personalisation**: VOD platforms use advanced algorithms to analyse users' preferences and viewing habits. Based on this data, users are recommended films or series that match their interests.
- **Wide range** of **devices**: Users can access content via various devices, such as smart TVs, mobile phones, tablets or computers. This aspect makes VOD platforms flexible, as users can watch content at any time and from anywhere they have internet access.

- **Interactive features**: VOD platforms often include various interactive elements, such as pausing, rewinding or saving content to watch offline later. These features allow users to tailor their viewing experience to their current needs, representing a significant advantage over linear broadcasting.
- **Monetisation**: VOD platforms typically operate on a subscription basis (Subscription Video on Demand – SVOD), through advertising (Ad-Supported Video on Demand – AVOD) or on a pay-per-view basis (Transactional Video on Demand – TVOD). Thanks to this flexible business model, content providers can tailor their services to different markets and users.

Technological aspects of VOD:

- **CDN (Content Delivery Network)**: Content delivery networks (CDNs) are a key technology in the VOD sector, as they ensure the efficient delivery of content to users. CDN servers are located in various locations around the world and deliver data to the nearest user, ensuring smooth streaming without delays.
- **Adaptive Bitrate Streaming (ABR)**: ABR dynamically adjusts video quality according to the user's current bandwidth. This means that even with a slower internet connection, users can still watch content, with the video quality automatically adapting to the available connection.
- **Support for various devices**: VOD platforms must be compatible with various types of devices and operating systems, ranging from smart TVs and games consoles to mobile devices. This requires a flexible user interface that is optimised for different screens and controls.

The difference between VOD and OTT

VOD (Video on Demand) is a subset of OTT (Over-the-Top), where VOD refers to a specific service enabling users to watch videos on demand. OTT, as a broader term, encompasses all services that deliver content via the internet, including VOD, live broadcasting and other streaming services. Whilst OTT covers the full range of content delivered via the internet, VOD focuses specifically on videos that users can watch at any time according to their preferences.

Challenges and limitations of VOD:

- **Dependence on bandwidth**: The quality of VOD services depends directly on the quality and speed of the internet connection. If the connection is slow, frequent buffering or a reduction in video quality may occur.
- **Content licensing**: VOD platforms often face challenges with content licensing in the global market. Different countries have different regulations regarding copyright and licensing, which can limit the availability of certain content in some regions.
- **Network congestion**: As the number of users grows, network congestion may occur, particularly during peak times, which can lead to a drop in streaming quality or a complete service outage.

Video on Demand is revolutionising the way people consume multimedia content. It offers users the chance to watch their favourite programmes and films according to their own schedule, providing maximum flexibility and convenience. The combination of high-quality streaming, personalised content and access across various devices makes VOD one of the most popular technologies for modern media consumption.

1.2.2 Mobile technologies/5G and LTE networks

5G and LTE represent two generations of mobile networks that differ significantly in terms of technological capabilities, speed and the scope of services provided, including support for broadcasting. Within these technologies, there have been significant developments in the field of multicast and broadcast – that is, the mass distribution of content, where a single data stream is shared by many users simultaneously.

LTE, often referred to as 4th-generation (4G) technology, introduced eMBMS, which was the first implementation of multicast and broadcast in mobile networks. This technology effectively distributed television programmes, videos and other multimedia services to a large number of users simultaneously. The main advantage of eMBMS in LTE networks was its ability to deliver content to the masses without overloading the network, particularly during live events or the distribution of emergency messages.

However, 5G brings even more significant advances in this area. FeMBMS technology expands the possibilities of broadcasting, particularly in terms of coverage, capacity and efficient spectrum utilisation. FeMBMS delivers high-quality content with minimal latency across a wide geographical area.

Whilst LTE networks already provided multicast and broadcast services via eMBMS, 5G networks with FeMBMS offer greater capabilities in terms of quality and coverage, including support for more advanced multimedia services and greater flexibility in deploying broadcast services in both urban and rural areas.

1.2.2.1 LTE (Long Term Evolution)

LTE is a fourth-generation technology introduced to improve data transmission speeds, network efficiency and quality of service in mobile networks. One of the key features of LTE is its support for broadband applications, such as video streaming and high-definition data transmission. LTE introduced eMBMS, the first technology for multicast and broadcast in mobile networks. This technology delivered television broadcasts and other multimedia content to a large number of users simultaneously; however, its deployment was limited by the low demand for multimedia content on mobile devices at that time.

1.2.2.2 5G (Fifth-generation mobile networks)

5G is the successor to LTE and represents the fifth generation of mobile networks. This technology brings significant improvements in areas such as data transfer speeds, reduced latency (network response times), connection reliability and network capacity. 5G offers much greater bandwidth and is designed to handle a massive number of connected devices and support future applications such as the Internet of Things (IoT), autonomous vehicles, industrial automation and advanced multimedia services.

One of the benefits of 5G is support for MBS (Multicast and Broadcast Services), which was implemented in versions 16 and 17 of the 3GPP standard. Unlike LTE, 5G provides more advanced capabilities for multicast and broadcast, ensuring more efficient use of the network when distributing multimedia content to a large number of users. FeMBMS (Further evolved Multimedia Broadcast Multicast Service) technology, which forms part of 5G, brings significant improvements over older technologies such as eMBMS, and provides higher quality and reliability when distributing content, even in densely populated areas.

1.2.2.3 Key differences between LTE and 5G

Whilst LTE focused on increasing speed and capacity for individual users, 5G offers a much wider range of services, including support for critical communication systems (e.g. healthcare or emergency services), large-scale IoT networks and high-quality real-time multimedia streaming. Furthermore, 5G improves network efficiency and enables the simultaneous delivery of broadcast services to a large number of users, resulting in an uninterrupted flow of data even under demanding conditions, such as major sporting events or concerts.

2 Types of Broadcast

2.1 Multimedia Broadcasting

Multimedia broadcasting is one of the most significant and widespread methods of content distribution in the digital world. Thanks to the development of technologies such as television, radio, the internet and mobile networks, multimedia broadcasting has become an effective means of disseminating a wide range of content, including videos, audio, images and other multimedia data.

In recent years, demand for multimedia content has grown rapidly. With the advent of 5G networks, the expansion of network capacity and the development of technologies such as FeMBMS, multimedia broadcasting has become an important tool for content providers, operators and marketing companies. This system enables the delivery of high-definition content with low latency, ensuring a consistent, high-quality experience for all users, regardless of their location or the number of connected devices.

Multimedia broadcasting is characterised not only by its efficient use of bandwidth but also by a wide range of applications, which include not only entertainment but also education, marketing, healthcare and other sectors. Traditional media, such as television and radio, remain popular, but digital and mobile platforms have introduced new forms of distribution, such as podcasts, webinars and live streaming, which enable interaction and direct feedback from users.

With technological advances, multimedia broadcasting can be used not only for the general public but also for narrowly targeted audiences (narrowcasting). This type of broadcasting focuses on specific market segments or user groups and is becoming an effective tool for communication, education and marketing.

Multimedia broadcasting encompasses several types of broadcast, which differ in both form and content, but all share a common goal – the dissemination of multimedia data to a wide audience. In this chapter, we will focus on three main forms of broadcasting, which are described in more detail below:

- **Audio broadcasting** – traditional radio as well as modern formats such as podcasting and internet radio.
- **Video broadcasting** – both traditional television broadcasting and online video streaming via platforms such as YouTube or Netflix.
- **Web broadcasting** – live streaming and the playback of recorded content on websites or social media.

Narrowcasting in multimedia broadcasting

Narrowcasting is a personalised model of content distribution that targets specific audiences, in contrast to the mass reach of traditional broadcasting. This approach focuses on delivering content tailored to the preferences, behaviour or geographical location of smaller user segments.

In the context of 5G networks and the convergence of broadcasting and broadband technologies, narrowcasting plays a role in providing a better user experience through personalised services. As noted in research on the convergence of broadcasting and broadband networks in the 5G era, narrowcasting offers content providers the opportunity to tailor services to individual users, for example through targeted advertising, on-demand content and interactive features such as voting or polls.

2.1.1 Audio broadcasting

Audio broadcasting is the oldest form of multimedia broadcasting, focused on the transmission of audio content. It is traditionally carried out via radio, which transmits sound over long distances using radio waves.

2.1.1.1 Traditional radio

Broadcasting via radio waves remains a widely used form of broadcasting, particularly for the distribution of music, news and radio programmes. Radio is particularly effective in emergency situations, when information needs to be disseminated rapidly across large areas.

2.1.1.2 Podcasting

A modern format of audio broadcasting that enables content creators to record and distribute audio files to subscribers via online platforms.

2.1.2 Video broadcasting

Video broadcasting involves the transmission of audiovisual content, such as television programmes, films, sporting events or live broadcasts. This format provides viewers with both picture and sound simultaneously.

2.1.2.1 Television broadcasting

Traditional television uses radio waves to transmit audiovisual content. Television stations can broadcast content to millions of viewers at once. Television broadcasting utilises technologies such as DVB-T and satellite broadcasting.

2.1.2.2 Internet video broadcasting

With the rise of streaming services such as YouTube, Netflix and Twitch, video broadcasting has also moved to online platforms, allowing users to watch content on demand or in real time via an internet connection.

2.1.3 Web broadcasting

Web broadcasting is a form of broadcasting that uses internet technologies to distribute content, both in real time and in the form of recorded multimedia. It includes live streaming and the distribution of recorded content via websites or social media.

2.1.3.1 Live streaming

Live streaming allows users to watch events in real time over the internet. Popular platforms such as Facebook Live, Instagram Live and YouTube Live offer this feature to a wide audience, creating a space for immediate interaction between the creator and the viewers.

2.1.3.2 Web broadcasting

In addition to live streaming, web broadcasting also includes the playback of recorded content, such as webinars, video tutorials and other formats. Companies often use this format for marketing purposes, presentations and communication with clients.

2.1.4 Technologies and platforms

Multimedia broadcasting utilises several technologies focused on distributing content across various platforms. The main ones include:

- Satellite broadcasting: Technology for transmitting television and radio signals via satellite, widely used in areas with limited coverage from terrestrial transmitters.
- Cable broadcasting: Cable companies provide content via cable networks, where customers subscribe to access a wide range of channels and programmes.
- Mobile broadcasting: 5G networks support multimedia broadcasting on mobile devices, allowing users to watch content such as live broadcasts, videos and podcasts on their phones and tablets.

2.2 Broadcasting for security purposes

Broadcasting for public safety is part of modern communications infrastructure, designed to rapidly disseminate critical information during emergencies such as natural disasters, terrorist attacks or other threats to public safety. This type of broadcasting is designed to ensure that warning messages reach the widest possible audience, regardless of their geographical location or access to the internet or mobile services. Using broadband broadcasting, safety announcements are able to immediately inform the public of an imminent danger and provide the necessary instructions to protect lives and property.

2.2.1 The role of broadcasting in emergency situations

In times of crisis, rapid and reliable communication is essential to minimise loss of life and damage to property. Regardless of the nature of the crisis – be it natural disasters, terrorist attacks or technological accidents – it is vital to ensure that critical information reaches the public as quickly as possible. Broadcast technologies play an irreplaceable role in such situations, as they enable warning messages to be disseminated to a wide audience simultaneously without overloading communication networks.

In crisis situations, unicast transmission – where a separate data stream is sent to each user – can cause network congestion, leading to delays or even the failure of the entire communications system. When using broadcast transmission, content – such as warning messages – is transmitted as a single data stream to many users at once, significantly reducing the load on the network infrastructure and ensuring that critical information reaches the widest possible audience in the shortest possible time. This one-to-many transmission is effective because it delivers the same information to all recipients simultaneously, regardless of their number or geographical location.

Emergency broadcasts are designed to utilise reliable and widely available technologies, such as radio and television signals. These technologies have one key advantage over mobile or internet networks – wider coverage. Whilst mobile networks may be limited by insufficient coverage or congestion in densely populated areas, radio and television signals can be transmitted across vast geographical areas with minimal infrastructure. This means that even users who are not connected to the internet or do not have access to a mobile network can be quickly informed of the situation.

Radio broadcasting is one of the most reliable media for disseminating emergency messages, as it continues to function even during power cuts or when other communication channels fail. In many countries, radio stations are required to interrupt their regular programming and broadcast emergency warning messages immediately, thereby ensuring that, even in the event of an internet or mobile network outage, the general public is informed of an imminent danger. Television broadcasting also plays a significant role, particularly in situations where visual information, such as maps of evacuation zones or safety instructions, needs to be provided.

2.2.1.1 China Digital Radio (CDR)

One example of the effective use of broadcasting in crisis situations is the China Digital Radio (CDR) system, which combines traditional analogue FM broadcasting with modern digital technologies. This system disseminates emergency messages via both conventional radio signals and digital channels. CDR enables government bodies and emergency services to quickly send out warning signals to the general public, even in areas without mobile or internet services. As a result, residents are kept informed of the current situation in real time. This system is used, for example, during evacuations, to warn of dangerous areas, or to provide instructions on how to protect oneself from imminent danger. CDR has proved particularly effective during floods and earthquakes, when traditional communications infrastructure fails.

2.2.1.2 The importance of broadcasting for real-time warnings

One of the most important aspects of emergency broadcasting is the ability to transmit warning messages in real time. The speed of message delivery is crucial, as in many crisis situations, delayed information can have fatal consequences. For example, during an earthquake, a tsunami or an industrial explosion.

Emergency broadcast systems enable emergency services to immediately trigger an emergency broadcast that interrupts all other programmes. The EWBS forms part of television and radio networks and transmits not only audio warnings but also visual instructions and maps of evacuation zones. These systems are designed to operate even in situations where other communication channels are overloaded or out of service.

Another advantage of emergency broadcasting is the ability to target specific areas. Emergency messages can be broadcast only in specific regions that are most at risk. This means that, for example, during floods, residents of low-lying areas can be warned to evacuate, whilst people in safer locations receive less urgent information.

2.3 Mass messaging

Mass messaging is another emergency broadcast tool that disseminates information to the general public. This type of broadcast is used not only to issue warnings in crisis situations, but also to distribute information relevant to society, politics, the economy or other areas of public importance. Mass messages may include official government announcements, evacuation orders, health warnings or information on changes to legislation.

Mass messages can be disseminated via various communication channels, such as television, radio, the internet, social media and mobile networks. The aim is to ensure that the message reaches as many people as possible simultaneously, even when traditional communication channels are limited. To ensure maximum reach, mass messages are often broadcast across multiple platforms, i.e. via several media simultaneously. This makes it possible to reach the widest possible audience, including those who only have access to one type of media (such as radio stations or mobile networks).

Figure 6: The process of sending alerts via broadcast Source:

https://www.alertus.com/cell-broadcasting

The figure illustrates the process of disseminating alerts via the mass broadcasting system in mobile networks. First, the alert is triggered from a central system (step 1). The message is then sent to a specialised unit, which verifies that the sender is authorised and subsequently forwards the alert to mobile network operators (step 2). Mobile operators receive the alert at their transmission centres and forward it to the relevant transmitters (step 3). Finally, the alert is delivered to users' mobile phones in the designated area (step 4). This procedure enables the rapid and reliable dissemination of information without placing a burden on mobile networks or requiring the installation of special applications.

2.3.1 Types of mass messages

Mass messages can be divided into several categories depending on their purpose and the content they convey:

2.3.1.1 Political and government messages

These relate to official government announcements, such as changes to laws, regulations or policies. They also include declarations of states of emergency, nationwide events or political elections.

2.3.1.2 Economic news

The dissemination of information on important economic changes, such as new fiscal policies, changes to interest rates, new trade agreements or announcements regarding major projects.

2.3.1.3 Social announcements

Information relating to public services, such as health alerts, vaccination campaigns, training programmes or cultural events. This type of mass communication is also used to inform citizens about public gatherings, demonstrations or important social changes.

2.3.1.4 Emergency messages

Although emergency messages are a specific category within emergency broadcasting, they may also be classified as mass messaging when they constitute warnings affecting the entire population, for example during a pandemic or other health crisis.

2.3.2 Technology for disseminating mass messages

As with emergency messages, mass messaging utilises various technologies to reach a wide audience. Mobile network operators can use Cell Broadcast technology to send messages to mobile users in specific geographical areas, and this is particularly effective for disseminating locally relevant information.

Systems for disseminating mass messages are designed to function even when the communications infrastructure is under increased strain. Mobile networks and internet platforms are often the first channels to become overloaded during crisis situations; therefore, mass messages are also broadcast via radio and television stations, which provide reliable channels for message delivery.

Mass messaging offers a wide range of options for effective communication with the public. With advances in 5G and other communication technologies, mass messaging systems will be able to deliver targeted and personalised messages based on users' locations, interests and specific needs. This will enable mass messages to be better tailored to specific situations and to provide relevant information in real time.

In the future, mass messaging systems are expected to make increasing use of artificial intelligence and machine learning to analyse large volumes of data and determine what information is most relevant to the public. This will improve the ability of governments and other institutions to communicate effectively with citizens both during and outside times of crisis.

3 Description of the FeMBMS service

FeMBMS is an advanced technology that forms an integral part of the 5G standard and is designed for the efficient distribution of multimedia content to a large number of users simultaneously. This technology is the result of the evolution of the previous eMBMS standard used in LTE (4G) networks and brings significant improvements in terms of performance, efficiency and spectrum utilisation. Thanks to these improvements, FeMBMS is capable of supporting the delivery of content in higher resolution and with greater reliability.

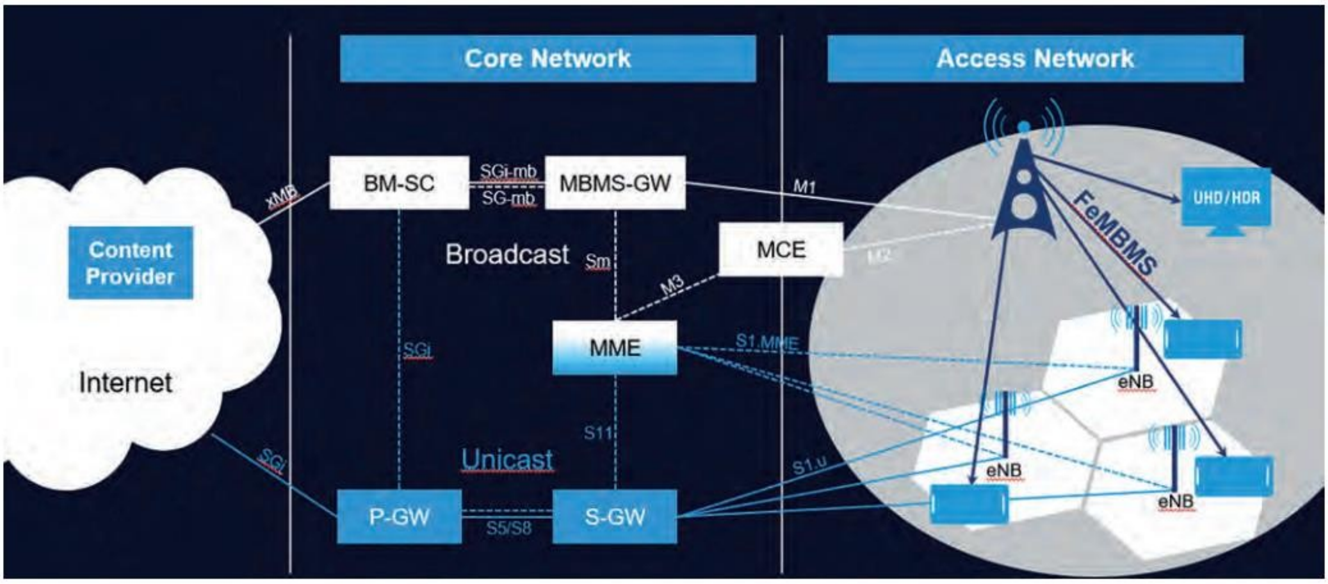

Figure 7: Broadcast architecture

Source: https://cdn.rohde-schwarz.com/pws/solution/broadcasting/content_distribution/5g_broadcast/ieee_broadcast_technology__________5g_broadcast.pdf

This figure illustrates the service architecture and shows how this technology works in 5G networks. The architecture is divided into two main parts: the Core Network and the Access Network.

Core Network:

- ***BM-SC (Broadcast Multicast Service Centre):*** *Manages membership, sessions, transmission and content security. It provides MBMS services, establishes e-MBMS sessions and ensures the distribution of content from the provider through the core network to users.*
- ***MBMS-GW (MBMS Gateway):*** *Distributes MBMS data to eNBs (evolved NodeBs) using IP multicast and manages MBMS signalling at the user plane.*
- ***MME (Mobility Management Entity):*** *Manages mobility control and administers MBMS sessions between the MBMS-GW and the access network.*

Access Network:

- ***MCE (Multicast Coordination Entity):*** *Manages MBMS content and resources for efficient broadcasting. It cooperates with eNBs to deliver content to users.*
- ***eNB (evolved NodeBs):*** *Access points that provide both unicast and multicast services and transmit content to users via FeMBMS.*

Overall, this diagram illustrates how FeMBMS operates in a 5G network, where a content provider delivers data via various entities (BM-SC, MBMS-GW, MME, eNBs) to receivers, which may be, for example, mobile phones or televisions supporting UHD/HDR resolution. The system combines both unicast and broadcast functions for the efficient distribution of multimedia content.

3.1.1 Features of FeMBMS

FeMBMS incorporates several innovations that enhance its efficiency and ability to deliver high-quality services:

- **Combination of Multicast and Broadcast:** FeMBMS effectively combines multicast (one-way transmission of content to a group of users) and broadcast (transmission of content to a wide audience). This combination optimises the use of available bandwidth, reduces network load and increases the efficiency of data transmission. Unlike unicast, which transmits a data stream to each user individually and can lead to network congestion during periods of high demand, FeMBMS transmits a single data stream to many users simultaneously.

- **Support for Extensive Geographical Areas:** FeMBMS is designed for broadcasting over extensive geographical areas. This is achieved through the use of high-power, long-range transmitters that can cover a wide area without the need for a dense network of transmission points, which is particularly advantageous in rural or mountainous areas where traditional transmission technologies may not be as effective.

- **HPHT and LPLT Modes:** FeMBMS supports HPHT (High-Power High-Tower) and LPLT (Low-Power Low-Tower) modes, ensuring flexible deployment in various environments. The HPHT mode is ideal for covering large, sparsely populated areas, whilst the LPLT mode is suitable for densely populated urban areas where a stable, high-quality signal is required.
- **Transport and Services Separation:** FeMBMS implements transport and services separation via an API (Application Programming Interface), which allows the mobile system to transmit television content in its native format. The entire mobile platform can thus function as a fully-fledged Digital Terrestrial Television Broadcasting (DTTB) system, ensuring high flexibility and compatibility with existing multimedia formats and services.
- **Increased Spectral Efficiency:** FeMBMS achieves high spectral efficiency of up to 97.5 per cent, which is a significant improvement on previous technologies. This efficiency stems from a newly designed frame structure, which allows almost 100 per cent of carrier resources to be allocated to broadcasting, thereby maximising bandwidth utilisation and increasing the network's data transmission capacity.

3.1.1.1 Technical Structure of FeMBMS

FeMBMS utilises an extended Cyclic Prefix (CP) with a length of 200 μs, enabling the system to better withstand multipath interference and implement a Single Frequency Network (SFN) over large areas. The FeMBMS frame structure is designed for high spectral efficiency and robust data transmission.

- **FeMBMS Numerology:** FeMBMS extends traditional eMBMS by adding two new CP lengths – 33.3 μs and 200 μs – and supports a maximum inter-site distance (ISD) of up to 60 km. This enhanced numerology ensures wider coverage and better performance in various environments. FeMBMS adapts to the specific requirements of transmission scenarios by supporting bandwidths ranging from 1.25 kHz to 200 kHz.
- **Frame Structure:** There are two main solutions in the FeMBMS physical layer: MBSFN (Multicast Broadcast Single Frequency Network) and SC-PTM (Single-Cell Point-to-Multipoint). MBSFN coordinates broadcasting on the same frequency from multiple transmission points, thereby improving coverage and signal quality. SC-PTM, designed for single-transmission-point scenarios, is not compatible with SFN; consequently, in practice, FeMBMS is often used in conjunction with MBSFN to achieve wider coverage and efficient spectrum utilisation.
- **Modulation and Coding Schemes (MCS):** FeMBMS offers various MCS indices, which determine coding rates and modulation techniques. With 35 MCS indices, FeMBMS dynamically adapts transmission parameters to current network conditions and quality-of-service requirements. Higher MCS indices provide higher data rates and are used for the transmission of high-definition content, such as 4K video.

3.1.1.2 Various solutions for efficient content distribution

FeMBMS technology offers three main solutions for efficient content distribution in different environments. These solutions vary according to the characteristics of the area in which they are deployed and the specific requirements for signal distribution.

NSA/SA Overlay for rural and suburban areas

An NSA (Non-Stand-Alone) or SA (Stand-Alone) overlay is ideal for covering rural and suburban areas with available line-of-sight. In these areas, the use of high-power and medium-power transmitters (HPHT/MPMT) is recommended, as they ensure wide coverage and greater signal range. This overlay model operates either with an existing network based on non-standalone architecture or on a completely standalone architecture, thereby providing efficient and cost-effective content distribution in less densely populated areas.

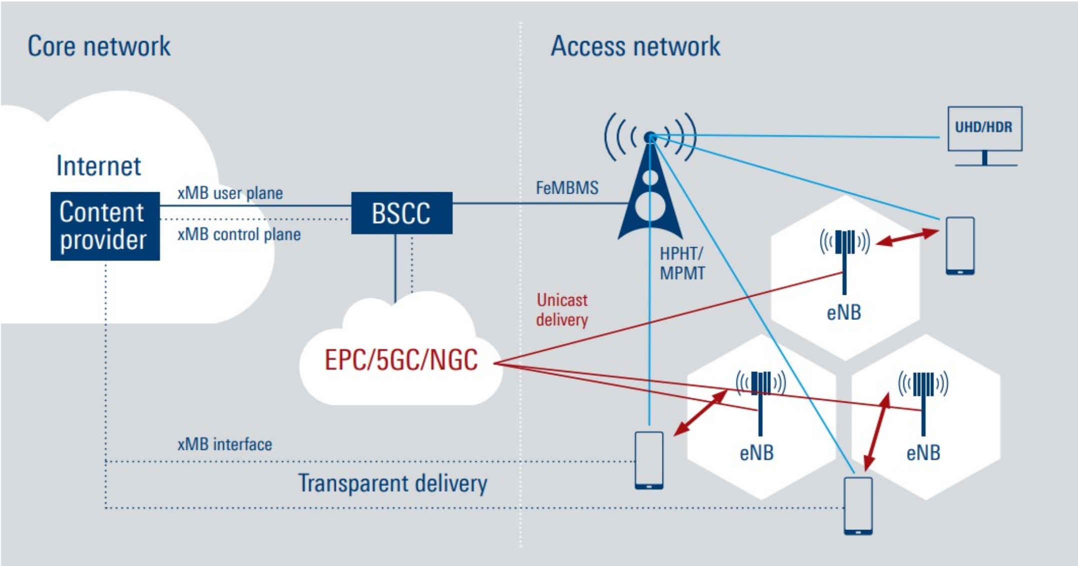

Figure 8: NSA/SA overlay architecture for rural and suburban areas

Source: https://scdn.rohde-schwarz.com/ur/pws/dl_downloads/dl_common_library/dl_brochures_and_datasheets/pdf_1/Rohde-Schwarz_5G-Broadcast-Multicast_bro_3609_6135_92_v0100.pdf

The figure above illustrates the NSA/SA (Non-Standalone/Standalone) overlay architecture designed for use in rural and suburban areas. This model utilises HPHT/MPMT (High-Power High-Tower/Medium-Power Medium-Tower) transmitters, which provide wide coverage via FeMBMS (Further evolved Multimedia Broadcast Multicast Service) for the efficient distribution of content to many users simultaneously.

The key elements of the architecture include:

- A Content Provider, which supplies multimedia content. This content is delivered via the xMB interface to the BSCC (Broadcast Service and Control Centre), where content transmissions are managed.
- The EPC/5GC/NGC (Evolved Packet Core/5G Core/Next Generation Core) forms the core of the network, ensuring delivery
- The access network comprises eNB (evolved NodeB) base stations, which provide both unicast and multicast content transmission.
- FeMBMS technology ensures the delivery of high-quality content (e.g. UHD/HDR) directly to mobile devices and other receivers with minimal latency.

This model is ideal for areas where a direct connection is available and long-range transmitters can be utilised, reducing the need for a dense network of transmission points. This ensures efficient and cost-effective coverage of large geographical areas.

SDL NSA/SA for densely populated areas

For areas with high population density, such as city centres, the Supplemental Downlink (SDL) NSA/SA solution is suitable. This solution provides localised coverage within existing cellular networks by adding low-power transmitters (LP Tx) to existing base stations. This model makes efficient use of existing infrastructure at minimal cost, as it is based on software integration into a cloud-based RAN (C-RAN) without the need for additional hardware.

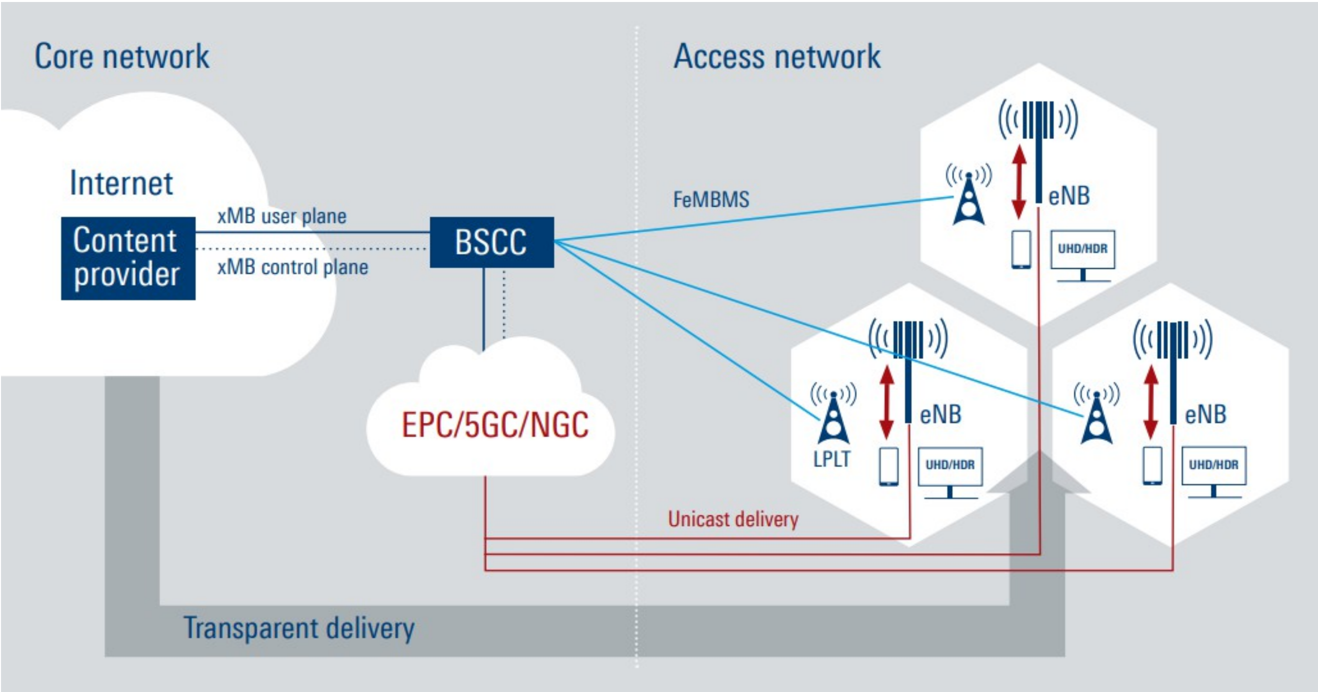

Figure 9: SDL NSA/SA architecture for densely populated areas

Source: https://scdn.rohde-schwarz.com/ur/pws/dl_downloads/dl_common_library/dl_brochures_and_datasheets/pdf_1/Rohde-Schwarz_5G-Broadcast-Multicast_bro_3609_6135_92_v0100.pdf

This diagram illustrates the Supplemental Downlink (SDL) NSA/SA architecture, which is designed for densely populated urban areas. This model utilises low-power transmitters that are integrated into existing mobile cells at minimal cost, primarily through software integration into a cloud-based RAN (C-RAN).

The key elements of the architecture include:

- A Content Provider, which supplies multimedia content that is delivered via the xMB interface to the BSCC (Broadcast Service and Control Centre), where data transmission is managed.
- The EPC/5GC/NGC (Evolved Packet Core/5G Core/Next Generation Core) forms the core of the network, ensuring the transparent delivery of content to access points.
- The access network comprises eNB (evolved NodeB) base stations, which ensure the delivery of content via both unicast and multicast.
- FeMBMS technology enables the delivery of high-quality content, such as UHD/HDR, to mobile devices and other receivers with low latency.

This model is ideal for urban environments where a high-quality, stable signal needs to be guaranteed in very densely populated areas. Thanks to its low-power transmitters, this model can be easily deployed within existing mobile network infrastructure without the need for extensive modifications or the addition of physical equipment. This ensures efficient and cost-effective coverage with high capacity and reliability, which is essential for mass media events or broadcasts.

Combining both solutions for nationwide coverage

The combination of Overlay NSA/SA and SDL NSA/SA represents an effective strategy for achieving comprehensive coverage. This combination ensures high-quality broadcasting in densely populated areas, whilst simultaneously providing extensive coverage in rural and suburban regions. This approach delivers optimal distribution of multimedia content at minimal cost and with maximum efficiency, whilst providing high quality of service (QoS) and transmission reliability in all types of environments.

3.2 From the user's perspective

FeMBMS technology offers end-users a range of benefits that improve service quality and the overall user experience when receiving multimedia content. At the same time, however, it is important to mention some potential drawbacks or challenges that users may encounter. In this section, we will focus on the key aspects that affect users when utilising services provided via FeMBMS, including both the positives and negatives.

- **Service quality and user experience** – FeMBMS transmits high-definition audiovisual content, including support for 4K and 8K formats. Thanks to the efficient use of the spectrum and advanced compression techniques, high picture and sound quality is ensured with minimal latency. Users can watch live broadcasts or on-demand content without interruptions or delays.
- **Availability and coverage in various areas –** One of the main advantages of FeMBMS is its ability to provide services in various geographical areas, including rural and remote locations. The use of HPHT (High-Power High-Tower) and LPLT (Low-Power Low-Tower) modes ensures wide signal coverage even in areas with challenging conditions. Users in these areas have access to the same content and service quality as in urban areas.
- **Energy savings and efficient use of devices** – FeMBMS supports Receive Only Mode (ROM), in which devices receive broadcasts without needing to send return signals. This leads to lower energy consumption and extended battery life for mobile devices. Users can use their smartphones or tablets for longer without needing to recharge frequently.
- **Independence from internet connectivity** – Thanks to the broadcast nature of FeMBMS, users are not dependent on the availability of mobile data or Wi-Fi connections. Content is distributed via broadband broadcasting, ensuring services are available even in areas with limited or no internet coverage.
- **Interactive and personalised services** – FeMBMS can be combined with unicast services to deliver interactive and personalised content. Users can access features such as language track selection, access to supplementary information or interactive adverts, where such integration enhances the value of the services provided and opens up new possibilities for interacting with the content.
- **Emergency and crisis information** – FeMBMS is an effective tool for disseminating emergency alerts and crisis information to the general public. In the event of emergencies, users can quickly receive important messages and instructions. The reliability and wide coverage of the technology ensure that this information reaches even areas with limited access to traditional communication channels.
- **Compatibility with existing devices** – Although FeMBMS is designed to be compatible with modern mobile devices, in practice it is necessary to have a device that supports this technology. Some users will need to invest in new phones or tablets capable of receiving the FeMBMS signal. Older or more affordable devices may not support this feature.
- **The need for software and app updates** – In addition to hardware compatibility, it may be necessary to update the operating system or install specialised apps to receive FeMBMS broadcasts.
- **Potential costs associated with accessing services** – Although FeMBMS transmits content without using mobile data, providers may charge fees for access to premium content or special features.
- **Dependence on FeMBMS signal coverage** – Although the technology aims to provide wide coverage, in the early stages of deployment there may be areas where the FeMBMS signal is not available. Users in these areas will not be able to use the service.
- **Security and data protection** – FeMBMS incorporates advanced encryption and authentication mechanisms that protect content from unauthorised access and ensure the integrity of transmitted data. However, users should exercise caution when sharing personal data, particularly where services are combined with interactive features requiring registration or login.

3.3 From the content provider’s perspective

FeMBMS technology represents a significant step forward for content providers in the field of multimedia service distribution. More efficient distribution of content to a wide audience, reduced distribution costs and new service opportunities are just some of the benefits of this technology. We will now focus on the key aspects that affect content providers when using it.

- **Efficient content distribution** – FeMBMS enables the simultaneous transmission of audiovisual content to a large number of users without placing an increased load on the network. Thanks to the technology’s multicast and broadcast capabilities, content providers can efficiently distribute live broadcasts, sporting events, news and other high-demand content, eliminating the need for repeated unicast transmission to each user individually.
- **Reduced distribution costs** – The use of FeMBMS leads to the optimisation of costs associated with content distribution. Broadcasting content once to many users simultaneously minimises operational costs and contributes to a more efficient use of available resources.
- **Expanding reach and market penetration** – FeMBMS enables content providers to extend their reach into rural and remote areas where it was previously difficult or uneconomical to provide services. Thanks to its wide coverage and ability to overcome geographical barriers, providers can reach new market segments and increase their user base.

- **Ensuring high quality of service (QoS)** – FeMBMS technology ensures consistent, high-quality transmission, including support for high-definition (HD, 4K) and high dynamic range (HDR) content. Minimal latency and resilience to network congestion contribute to a better user experience.
- **Content protection and security** – Security is crucial for content providers, particularly when it comes to protecting intellectual property and preventing piracy. FeMBMS utilises advanced encryption and authentication mechanisms to ensure that content is accessible only to authorised users. The implementation of DRM (Digital Rights Management) systems provides control over content distribution and ensures compliance with licensing terms.
- **Integration with existing infrastructures** – FeMBMS is designed to be compatible with current standards and technologies in the fields of broadcasting and mobile networks. This facilitates integration into existing workflows and content management systems (CMS). Providers can leverage their existing infrastructure investments and minimise the costs of implementing new technology.
- **Personalisation and interactivity options** – Although FeMBMS is primarily a broadcast technology, it can be combined with unicast services to deliver personalised and interactive content. Providers can offer hybrid services that allow users to access supplementary information, choose different camera angles or view interactive adverts. This opens up new opportunities for user engagement and for enhancing the value of the services on offer.
- **Compliance with regulatory requirements and standards** – FeMBMS is being developed in accordance with international standards (e.g. 3GPP, ETSI) and takes into account legislative requirements relating to broadcasting and telecommunications. Content providers can be confident that the technology complies with the relevant licensing policies and regulatory frameworks.
- **Challenges in implementing FeMBMS** – When rolling out FeMBMS, content providers must consider several challenges:
  - End-device compatibility: Not all devices on the market support FeMBMS. Providers must take into account the penetration of compatible devices amongst users.
  - Cooperation with operators: Successful deployment of FeMBMS requires close cooperation with mobile operators and, where applicable, other stakeholders in the ecosystem.
  - Investment in infrastructure: Although FeMBMS is compatible with existing systems, investment may be required to upgrade transmission technology and software platforms.
- **Strategic benefits and future prospects** – FeMBMS presents a strategic opportunity for content providers to expand their services, increase efficiency and tap into new sources of revenue. The technology is poised to support future innovations such as virtual reality (VR), augmented reality (AR) and the Internet of Things (IoT), which can further expand the range of services on offer and strengthen providers' market position.

3.4 From the signal distributor's perspective

FeMBMS technology represents an innovation for signal distributors, i.e. the entities responsible for distributing the broadcast signal to users. FeMBMS makes more efficient use of the frequency spectrum, improves the quality of services provided and opens up new possibilities for covering various geographical areas. In this section, we will focus on the key aspects that affect signal distributors when implementing and operating FeMBMS.

- **Efficient spectrum utilisation and increased network capacity** – FeMBMS optimises the use of the available frequency spectrum thanks to its high spectral efficiency of up to 97.5 per cent. The technology allocates almost all carrier resources to content transmission, thereby increasing network capacity and enabling the transmission of more data streams within the same bandwidth.
- **Support for HPHT and LPLT modes for different areas** – FeMBMS supports both high-power transmitters with tall masts (HPHT) and low-power transmitters with low masts (LPLT). This flexibility allows signal providers to adapt their infrastructure to the specific characteristics of a given geographical area:
  - HPHT: Suitable for rural and remote areas where there is a need to cover a large area with fewer transmitters. High-power transmitters provide wide coverage and are capable of overcoming geographical obstacles.
  - LPLT: Ideal for densely populated urban areas where high network capacity is required and interference between transmitters needs to be minimised. Low-power transmitters can be strategically deployed to optimise coverage.

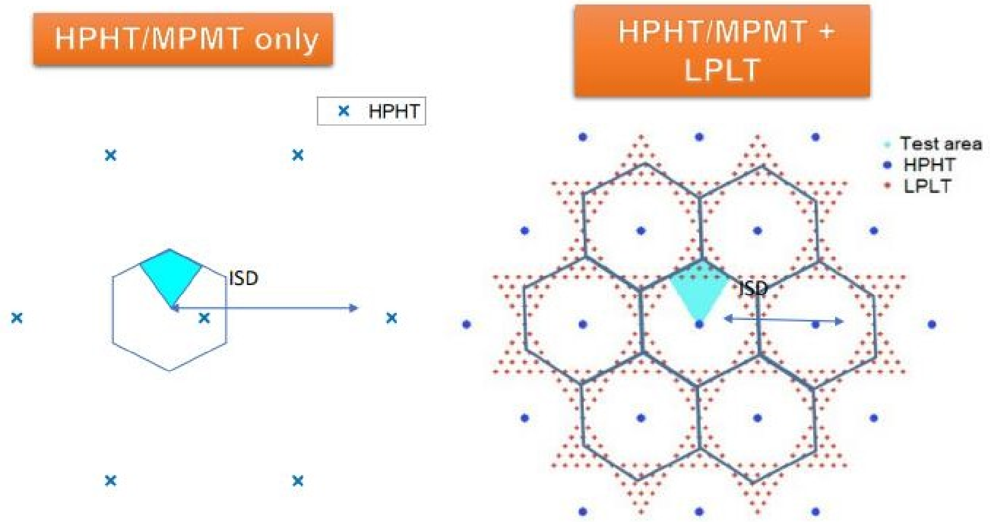

Figure 10: Area coverage using HPHT/MPMT and LPLT transmitters in FeMBMS networks

Source: https://tech.ebu.ch/files/live/sites/tech/files/shared/events/webinar2020_5GDistribution/presentations/Webinar_5G_for_distribution_AssuntaDeVita.p df

This figure illustrates two different approaches to area coverage using HPHT/MPMT technologies and their combination with LPLT.

***HPHT/MPMT only** (left diagram): This model depicts high-power transmitters (HPHT/MPMT) that cover extensive areas with a minimum number of transmitters. It is ideal for rural or remote areas where there is a need to cover large geographical areas with a lower population density. The transmitters have a wide range (ISD – Inter-Site Distance), which ensures coverage despite greater distances between transmitters.*

***HPHT/MPMT + LPLT** (right-hand diagram): This diagram illustrates a combination of high-power (HPHT/MPMT) and low-power (LPLT) transmitters. This approach is suitable for urban and densely populated areas where higher network capacity and better coverage are required. Low-power transmitters are deployed amongst the high-power transmitters, which allows for optimised coverage, improved signal quality and minimised interference between transmitters.*

The fundamental difference between these two approaches lies in the effective use of different types of transmitters according to the specific needs of the area being served.

- **Integration with existing infrastructure and networks** – FeMBMS is designed to be fully compatible with existing LTE and 5G (SA/NSA) mobile networks, allowing signal providers to integrate this technology into current systems without the need for a complete overhaul of the infrastructure. FeMBMS can be implemented as a software upgrade in existing base stations.
- **Support for Single Frequency Network (SFN)** – FeMBMS enables a single-frequency network (SFN), where multiple transmitters synchronously broadcast the same signal on the same frequency. This improves coverage and signal quality, particularly in areas with challenging terrain. SFN also optimises spectrum utilisation, as it eliminates the need for different frequencies for individual transmitters.
- **Ensuring Quality of Service (QoS) and transmission reliability** – It is essential for signal broadcasters to maintain high quality of service and transmission reliability, particularly during periods of high network load. FeMBMS provides mechanisms for Quality of Service (QoS) management, ensuring data stream prioritisation and minimal latency, which is essential for services such as live broadcasting or critical information services.
- **Network security and protection** – Broadcasters must ensure the security of transmitted content and protect the network against unauthorised access. FeMBMS supports advanced encryption and authentication protocols that protect content from piracy and ensure data integrity. The implementation of security measures is essential for compliance with legal and licensing requirements.
- **Interference management and spectrum coordination** – When implementing FeMBMS, it is important to minimise interference with other services and optimise the use of the allocated spectrum. Broadcasters must carefully plan frequency allocations and coordinate transmissions with other operators and services. The use of advanced modulation and coding techniques, as well as adaptive transmission parameters, helps to reduce interference and improves network efficiency.
- **Implementation and operational costs** – The implementation of FeMBMS delivers cost savings through more efficient use of infrastructure and spectrum, but requires an initial investment in upgrading networks and equipment. Signal providers must carry out a financial analysis covering:

– Capital costs: Upgrading transmitters, base stations, software and network elements.

– Operating costs: Network maintenance, energy consumption, licence and spectrum fees.

– Potential revenue: New services, increased capacity, expanded coverage.

- **Legislative and regulatory requirements** – Signal providers must comply with the applicable legal and regulatory frameworks governing the use of frequencies and broadcasting. The implementation of FeMBMS requires the acquisition of the relevant licences and authorisations from regulatory authorities, such as the Czech Telecommunications Office (ČTÚ). It is also important to ensure compatibility with international standards (e.g. 3GPP, ETSI) and to comply with spectrum management principles in the Czech Republic.
- **Data backup and recovery planning** – To ensure service continuity, signal providers must plan mechanisms for data backup and recovery in the event of an outage or failure. This includes redundant network elements, backup power supplies and procedures for rapid restoration of service. Effective planning minimises the impact of outages on users and ensures high service availability.
- **Technical support and maintenance** – Regular infrastructure maintenance and software updates are also essential for the reliable operation of FeMBMS. Signal distributors must ensure that technical staff are properly trained, that network performance is monitored, and that technical issues are addressed promptly. A proactive approach to maintenance extends the service life of equipment and reduces the risk of unplanned outages.
- **Innovation and future development** – FeMBMS is a platform for future innovation in broadcasting and telecommunications. Signal distributors can develop new services, such as interactive television, data transmission for IoT devices, or support for autonomous systems. Investment in FeMBMS ensures a flexible response to technological progress and changing market needs.

3.4.1 The expected transition to 5G for the distribution of television content

Survey results among broadcasters and content providers suggest that 5G technology has the potential to become the dominant platform for television content distribution in the coming years. The development of 5G broadcasting, and FeMBMS technology in particular, is increasing the pressure to replace traditional broadcasting methods such as DTT/DTV and satellite broadcasting. FeMBMS, with its ability to utilise bandwidth efficiently, its higher spectral efficiency and its capacity to serve a large number of users simultaneously whilst maintaining high quality of service, represents a key element in this anticipated transition to 5G.

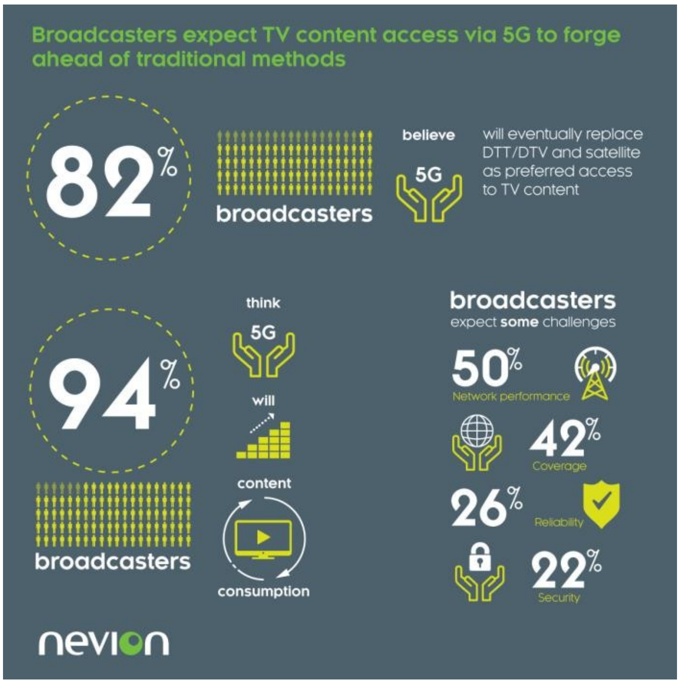

Figure 11: Broadcasters' expectations regarding the transition to 5G and its challenges for TV content distribution Source: https://nevion.com/news/press-releases/survey-5g-to-be-preferred-access-to-tv/

According to a global survey of broadcasters and signal providers, 82 per cent of respondents believe that 5G technology will eventually replace traditional broadcasting methods, such as DTT/DTV and satellite, as the preferred means of accessing television content. Furthermore, 94% of them expect that the arrival of 5G will lead to an increase in content consumption, particularly due to growing demand for streaming on mobile devices. However, as many as 50% of respondents consider network performance to be the biggest challenge, with a further 42% citing coverage. Reliability and security issues are cited by 26 per cent, whilst 22 per cent of broadcasters describe security as a challenge.

However, the current broadcasting infrastructure, in particular the DVB-T2 system, remains the most efficient solution for distributing linear video content to large audiences with fixed reception. This is primarily due to the high efficiency of resource and infrastructure utilisation, which involves an optimal balance between the useful data bitrate, the number and power of transmitters, and the required frequency resources. It is therefore questionable whether 5G technology, in its current form, can fully replace existing distribution systems.

The 5G Broadcast standard should therefore not be regarded as a direct successor to the existing DVB-T2 broadcasting standard, but rather as a complementary technology that enables the distribution of video content to mobile receiving devices. This method of use differs fundamentally from the traditional distribution of linear content and remains, to a certain extent, in an experimental phase, where the target groups of potential users are not yet fully defined, and it is not clear who will receive what content and when. This uncertainty is also reflected in the absence of a clear business model that would provide an economic justification for the roll-out of 5G Broadcast.

The transition to 5G is not without challenges, particularly in terms of network performance, coverage and ensuring sufficient reliability. These aspects must be thoroughly addressed so that 5G technology can truly assume the role of the dominant medium for content distribution in the future. Whilst FeMBMS does offer some innovative solutions that can mitigate these problems – such as broadcasting over vast geographical areas at low cost and with high efficiency – its role in the distribution of linear video content remains largely supplementary and cannot currently be regarded as a fully-fledged replacement.

3.5 A comparison of terrestrial and satellite broadcasting

3.5.1 Terrestrial broadcasting

Terrestrial broadcasting, also known as ground-based broadcasting, is a method of transmitting television and radio signals using electromagnetic waves transmitted from ground-based transmitters. This form of broadcasting is central to the widespread distribution of information and entertainment without the need for cable infrastructure or satellite transmission. Terrestrial broadcasting currently relies on advanced technologies that ensure efficient, high-quality and secure signal transmission.

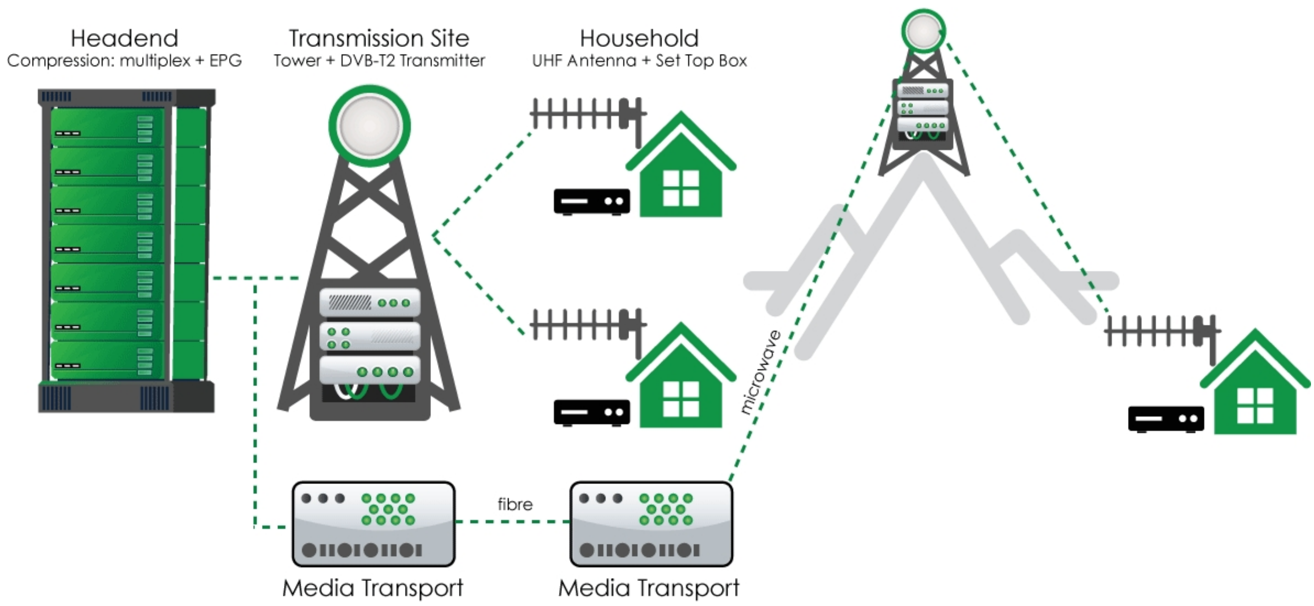

Figure 12: Diagram of terrestrial broadcasting

Source: https://www.techtel.com.au/digital-terrestrial-tv-distribution

This diagram illustrates the process of distributing a digital terrestrial television (DTT) signal. The process begins at the headend, where television channels are compressed, multiplexed and electronic programme guides (EPGs) are added. The signal is then transmitted via fibre-optic cables or microwave links to a transmission site, where it is modulated for broadcast via transmitters (DVB-T2). From the transmitter, the signal is broadcast to target households, which use UHF antennas and set-top boxes to receive the signal.

Technological aspects of terrestrial broadcasting

Modern terrestrial broadcasting utilises several technologies that improve its performance and security. Among the most significant are Orthogonal Frequency Division Multiplexing (OFDM) and Single Frequency Networks (SFN).

3.5.1.1 Orthogonal Frequency Division Multiplexing (OFDM)

OFDM is an advanced digital modulation technique that divides the data stream into several parallel narrowband channels or carrier frequencies. These carriers are orthogonal, meaning that they are independent of one another and do not interfere with each other, even though they overlap in the frequency domain.

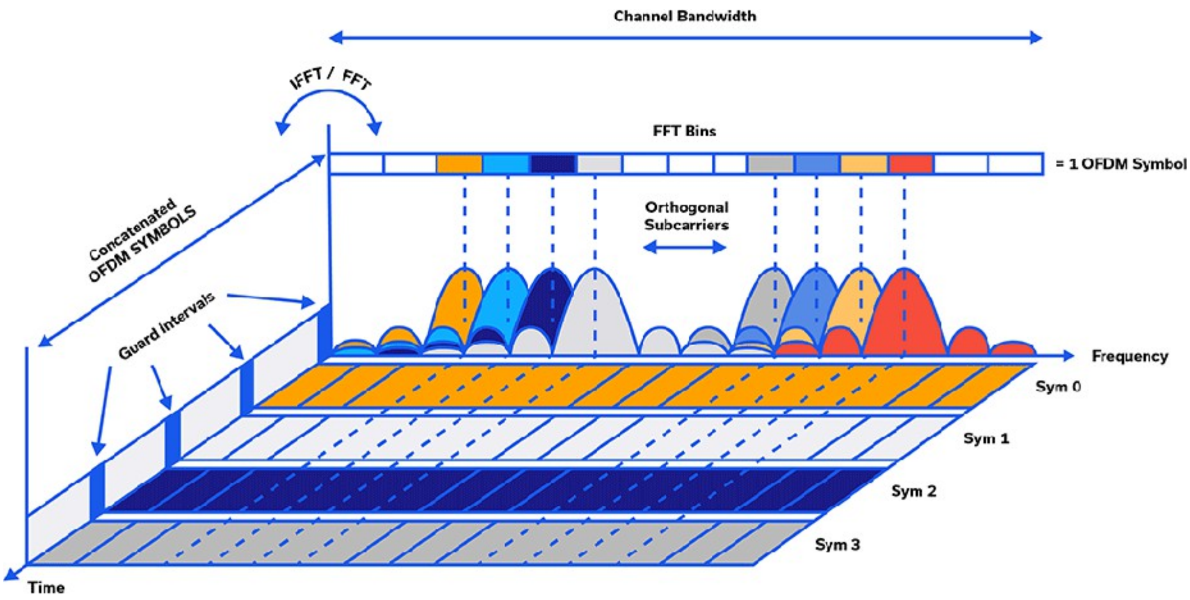

Figure 13: Diagram of OFDM (Orthogonal Frequency Division Multiplexing)

Source: https://blog.minicircuits.com/the-basics-of-orthogonal-frequency-division-multiplexing-ofdm/

This diagram illustrates the basic principles of Orthogonal Frequency Division Multiplexing (OFDM), a technology used in modern wireless communication systems such as 4G, 5G and Wi-Fi. The figure shows how the individual subcarriers are arranged orthogonally, meaning that their peaks lie at the zero-crossing points of neighbouring subcarriers, thereby minimising interference.

OFDM operates on the basis of the Fast Fourier Transform (FFT), which converts data between the time and frequency domains. Each OFDM symbol consists of several subcarriers, which can transmit different parts of the data stream in parallel. This orthogonal structure enables efficient use of bandwidth, as the subcarriers can partially overlap without interfering with one another.

The diagram also shows guard intervals, which are placed between individual symbols to prevent problems caused by multipath interference – a situation where the signal reaches the receiver via several different paths. This system ensures high resistance to intersymbol interference (ISI), which is a key advantage of OFDM over other technologies.

Features of OFDM:

- Spectral efficiency: OFDM maximises the utilisation of the available frequency spectrum by minimising the gap between individual carriers.
- Resistance to multipath propagation: In terrestrial environments, the signal is often reflected off buildings, terrain and other obstacles, causing multipath propagation. OFDM is designed to minimise the effects of this phenomenon, resulting in better signal quality.
- Flexibility: OFDM allows for easy adaptation to different transmission conditions and is compatible with various bandwidths and data rates.

The role of OFDM in transmission security:

- Resilience to interference: Thanks to its ability to spread data across many subcarriers, OFDM is less susceptible to interference on individual frequencies.
- Data redundancy: By dividing the data stream across multiple subcarriers, OFDM can maintain transmission integrity even if some subcarriers are affected by interference.

- Integration of security mechanisms: OFDM enables the implementation of advanced encryption and authentication methods directly at the physical layer of transmission.

3.5.1.2 Single Frequency Networks (SFN)

An SFN is a concept in which multiple transmitters broadcast the same signal on the same frequency simultaneously. This is the opposite of traditional networks, where each transmitter uses a different frequency to prevent interference between them.

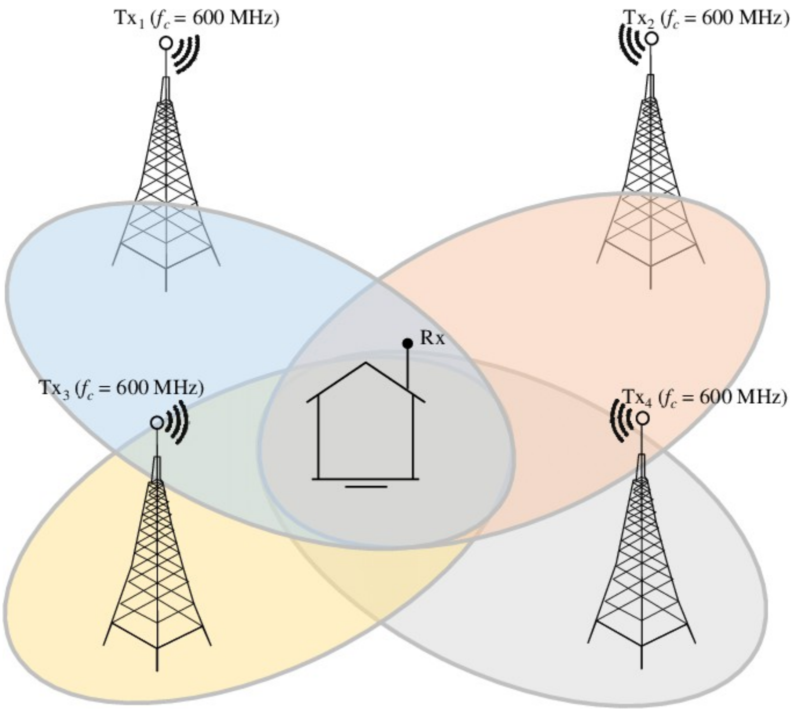

Figure 14: Single Frequency Network (SFN) with four transmitters

Source: https://www.researchgate.net/figure/Single-Frequency-Network-SFN-constituted-by-four-transmitters-that-use-the-same-RF_fig1_324659350

This diagram illustrates the principle of a Single Frequency Network (SFN), where four transmitters (Tx1, Tx2, Tx3, Tx4) transmit on the same frequency (600 MHz) simultaneously. All transmitters are synchronised and cover overlapping areas, enabling a receiver (Rx) within the coverage area to receive signals from all transmitters simultaneously.

SFN utilises a single frequency for multiple transmitters, which optimises spectrum utilisation and improves signal quality at the edges of the coverage area thanks to the combined signals from multiple transmitters. This concept minimises interference and increases the efficiency of broadcast distribution. If one of the transmitters in the network fails, the remaining transmitters can continue to provide a stable signal, which increases the network's resilience to outages and technical problems.

SFN features:

- Efficient use of the spectrum: Using a single frequency across the entire network optimises the use of the available frequency spectrum.
- Improved coverage and signal quality: Signals from different transmitters can reinforce one another, leading to better coverage and signal quality, particularly at the edges of coverage areas.
- Reduced interference: The synchronisation of transmitters minimises interference issues between them.

The role of SFN in transmission security:

- Resilience to outages: If one transmitter fails or is compromised, the other transmitters in the network can continue to provide a signal, thereby increasing overall reliability.
- More complex attack for attackers: To disrupt the entire broadcast, an attacker would have to attack multiple transmitters simultaneously, which is technically more challenging.
- Redundancy: SFN provides natural redundancy, which increases the network's resilience against various types of attacks and interference.

3.5.1.3 Security challenges

Terrestrial broadcasting faces several security challenges that can affect the quality and availability of services. The main issues include interference and localised attacks.

Interference – Interference is one of the most common problems affecting the quality of terrestrial broadcasting.

- It can be caused by various factors:
  - Natural phenomena: Atmospheric conditions, such as thunderstorms, solar flares or geomagnetic storms, can affect the propagation of electromagnetic waves.
  - Human activity: Unintentional interference may arise from electronic devices that emit electromagnetic noise, or from incorrectly configured transmitters.
  - Deliberate interference: Attackers may deliberately transmit signals on the same frequency with the aim of disrupting transmission.
- Effects of interference:
  - Deterioration in signal quality: Loss of picture or sound, pixelation, dropouts.
  - Reduced coverage: Users in certain areas may lose access to broadcasts.
  - Service disruption: Critical information services, such as emergency alerts, may be affected.
- Measures against interference:
  - Spectrum management: Monitoring and regulating the use of frequencies to minimise unintentional interference.
  - Technical solutions: Use of technologies such as OFDM and SFN, which are inherently more resistant to interference.
  - Training and awareness-raising: Informing the public and technicians about the correct use of equipment and compliance with standards.
  - Legal measures: Enforcement of laws against deliberate interference, including fines and criminal prosecution.

Local attacks – Local attacks are targeted actions designed to disrupt or take control of broadcasting in a specific area. They can have serious implications for public safety and confidence.

- Types of local attacks:
  - Jamming: The attacker transmits a strong signal on the same frequency to block the original broadcast.
  - Spoofing: Transmitting a fake signal with the aim of deceiving receivers and replacing legitimate content.
  - Infrastructure sabotage: Physical damage to transmitters, antennas or transmission paths.
- Impacts of local attacks:
  - Spread of disinformation: False reports may cause panic or confusion amongst the public.
  - Security risks: Disruption of critical communications, particularly in emergency situations.
  - Economic losses: The cost of repairing infrastructure and the loss of advertising revenue.
- Measures against local attacks:
  - Technical protection:
    - Signal encryption: Implementation of encryption algorithms to prevent unauthorised access to and modification of the signal.
    - Digital signatures: Verification of the authenticity of broadcast content using cryptographic methods.
    - Device authentication: Use of security protocols to verify the legitimacy of transmitters and receivers.
  - Physical security:
    - Protection of transmission equipment: Installation of security systems, cameras and alarms on transmitters and antennas.
    - Access controls: Restricting physical access to sensitive parts of the infrastructure.
  - Monitoring and detection:
    - Spectral analysis: Continuous monitoring of the frequency spectrum to detect unusual signals or interference.
    - Early warning systems: Automated systems that alert operators to potential attacks or signal anomalies.
  - Legal and regulatory measures:
    - Cooperation with law enforcement agencies: Rapid response to incidents and investigation of attacks.

– International cooperation: Sharing of information and procedures between countries to address cross-border threats.

Terrestrial broadcasting remains an important medium for the dissemination of information and entertainment. Technological advances, such as the introduction of OFDM and SFN, bring significant improvements in transmission efficiency and security. However, these benefits are accompanied by new security challenges.

It is essential that service providers, regulatory bodies and other stakeholders work together to implement comprehensive security measures. These measures should include technical solutions, legal frameworks and public awareness campaigns.

Ensuring the security of terrestrial broadcasting is essential for maintaining public confidence and for protecting critical communication services. Continued investment in research and development in the field of security technologies, together with a proactive approach to identifying and addressing threats, is vital for maintaining the integrity and availability of terrestrial broadcasting in the future.

3.5.2 Satellite broadcasting

Satellite broadcasting plays a vital role in global communications, providing broadband access to information and enabling data transmission over long distances, often to remote or hard-to-reach areas. This technology utilises artificial satellites orbiting the Earth to transmit signals between ground stations. Satellites are positioned in various orbital paths, with GEO (Geostationary Earth Orbit) and LEO (Low Earth Orbit) satellites being the most commonly used.

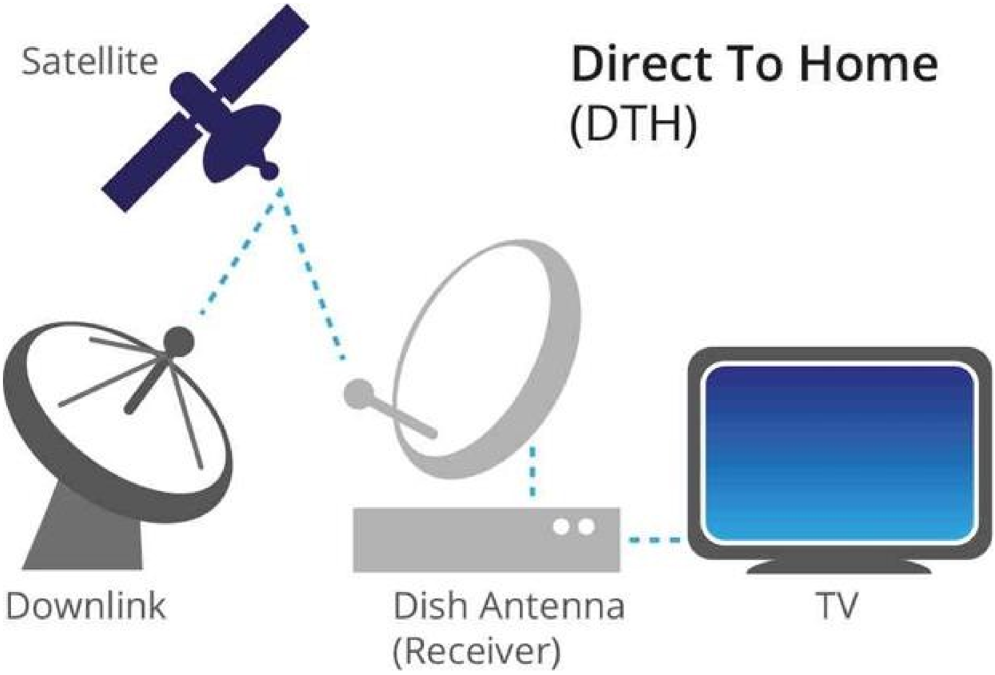

Figure 15: Satellite broadcasting

Source: https://www.orbofleet.com/satellite-broadcasting-market-meeting-the-demands-of-the-new-decade/

This diagram illustrates the basic process of satellite broadcasting, which is one of the main methods of transmitting television and radio signals over vast geographical areas. Satellite broadcasting involves the transmission of a signal from a satellite to receiving antennas on the ground; this can either be direct delivery to households, known as Direct-to-Home (DTH), or transmission to relay stations, which then distribute the signal via terrestrial or cable networks

The signal is first transmitted from a ground-based transmitting station (uplink) to a satellite located in geostationary orbit. The satellite amplifies this signal and returns it to Earth (downlink), where it is received by an antenna. This signal can be processed by a receiver and subsequently displayed on a television screen.

3.5.2.1 GEO (Geostationary Earth Orbit)

Geostationary satellites are located in orbit at an altitude of approximately 35,786 kilometres above the equator. At this altitude, they orbit the Earth at the same speed as the Earth rotates on its axis, which means that, from the perspective of an observer on Earth, they appear to be stationary.

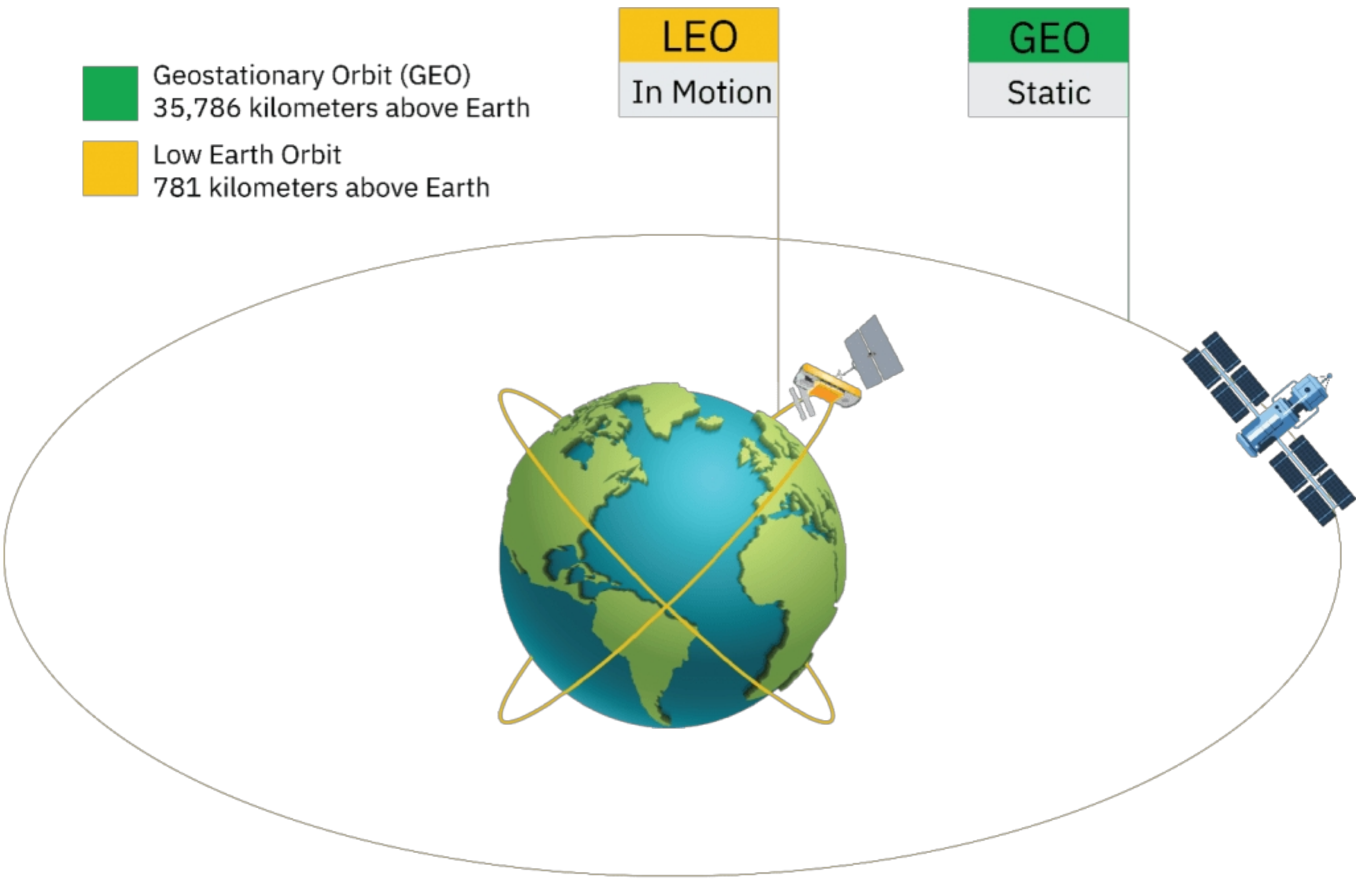

Figure 16: Satellites in geostationary (GEO) and low Earth orbit (LEO)

Source: https://www.skytrac.ca/resources/magazine/skytrac-satcomseries-the-differences-strengths-and-weaknesses-of-leo-and-geo-satellites/

This diagram illustrates the differences between geostationary satellites (GEO) and low Earth orbit (LEO) satellites. A geostationary satellite (GEO) is located at an altitude of approximately 35,786 kilometres above the Earth and remains stationary relative to the Earth's surface, meaning that, from the perspective of an observer on the ground, it appears to be in one place. This type of satellite is ideal for long-term communications, such as television broadcasting, as it provides continuous coverage of a single area.

In contrast, a low Earth orbit (LEO) satellite orbits the Earth at an altitude of around 784 kilometres and is in constant motion relative to the Earth's surface. LEO satellites have lower latency and are often used for services requiring a rapid response, such as the internet or Earth monitoring and observation.

GEO satellites provide wide coverage but suffer from higher latency due to their distance from Earth, whilst LEO satellites have lower latency but require more satellites to ensure continuous global coverage. These two orbits have different advantages and disadvantages depending on their intended use.

Characteristics of GEO satellites

Geostationary satellites (GEO) are characterised by several features that make them ideal for specific communication purposes. Thanks to their stationary position in orbit, they provide stable and continuous coverage of a specific area on Earth. This stability means that, from the perspective of an observer on the ground, the satellite appears as a fixed point in the sky, which facilitates communication without the need to constantly track its movement.

One of the most significant attributes of GEO satellites is their ability to provide wide coverage. A single such satellite can cover up to a third of the Earth's surface, enabling global communication using just three satellites positioned above the equator. This extensive coverage is particularly advantageous for applications that require the transmission of information over long distances without interruption.

GEO satellites are also ideal for various forms of broadcasting. They are widely used for television and radio broadcasting, where they ensure the distribution of signals to households and businesses around the world. In addition, they are used by meteorological services to collect and transmit important meteorological data, which is vital for weather forecasting and monitoring climatic phenomena.

Use in data transmission

GEO satellites play a vital role in data transmission. They provide signals for satellite television and radio, enabling viewers and listeners to receive a wide range of programmes regardless of their geographical location. In telecommunications, they support international calls and data services, thereby facilitating global business communication and connectivity between different parts of the world. They also provide internet access in areas where terrestrial infrastructure is inadequate or non-existent.

In meteorology, GEO satellites are indispensable for the collection and transmission of meteorological data. They enable continuous monitoring of atmospheric conditions, which is essential for accurate weather forecasts, early warnings of extreme weather events and research into climate change.

Advantages of GEO satellites

One of the main advantages of GEO satellites is the constant communication they provide. Thanks to their fixed position relative to the Earth, they enable uninterrupted connection with fixed antennas without the need to track the satellite's movement. This greatly simplifies the design and operation of receiving equipment and increases the reliability of communications.

Another significant advantage is their wide coverage. GEO satellites are effective at covering large geographical areas, making them ideal for global broadcasting and communications. This feature enables service providers to reach a large number of users with a minimum number of satellites, which is economically advantageous.

Disadvantages of GEO satellites

Despite their advantages, GEO satellites also have several disadvantages. One of these is high latency caused by the great distance the signal must travel between the Earth and the satellite. The signal travels approximately 35,786 kilometres one way, causing a delay of around 250 milliseconds. This delay can be problematic for time-sensitive applications, such as interactive video conferencing or online gaming.

Another limitation is the high cost associated with launching and maintaining satellites in high orbits. The process of placing a satellite into geostationary orbit is technically demanding and financially costly. Furthermore, maintaining these satellites is complex, as any repairs or upgrades either require expensive space missions or are entirely impossible.

GEO satellites also face the challenge of a weaker signal. Given their great distance from Earth, they require powerful transmitters on the satellite side and sensitive receivers on the user side. This can increase equipment costs and energy consumption, and thus the overall operating costs of the system.

3.5.2.2 LEO (Low Earth Orbit)

Low Earth orbits are situated at an altitude of between 160 and 2,000 kilometres above the Earth's surface. Satellites at this altitude orbit the Earth more quickly and, from the perspective of an observer on the ground, appear to move across the sky.

Characteristics of LEO satellites

Satellites in low Earth orbit (LEO) have several distinctive characteristics that set them apart from satellites in higher orbits. One such characteristic is their rapid movement around the Earth; these satellites orbit our planet in approximately 90 to 120 minutes. This rapid orbit means that, from the perspective of an observer on the ground, the satellites are constantly moving across the sky, which requires dynamic tracking to maintain communication.

Another important feature is the smaller coverage area of individual LEO satellites. Each satellite covers a relatively small area of the Earth's surface, which means that a constellation of many satellites operating in synchronisation is required to ensure continuous global coverage. This network of satellites works together to provide connectivity anywhere on Earth.

One of the significant advantages of LEO satellites is lower communication latency. Due to the shorter distance between the satellite and Earth, signal delay is reduced, enabling faster data transmission. This feature is particularly important for time-sensitive applications such as video conferencing, online gaming or other interactive services.

Use in data transmission

LEO satellites are widely used in various areas of data transmission. One of the main applications is satellite internet, where they provide high-speed internet access in remote or hard-to-reach areas. Projects such as SpaceX's Starlink are examples of the use of large constellations of LEO satellites to achieve global internet coverage.

Another significant area is Earth observation and monitoring. LEO satellites are ideal for environmental monitoring, mapping and scientific research, as their proximity to Earth enables the collection of high-resolution data. This data is essential for monitoring climate change, natural disasters and other phenomena affecting our planet.

In the field of communications, LEO satellites support mobile and data services, including Internet of Things (IoT) devices. They enable the interconnection of devices on a global scale, which is crucial for the development of smart cities, autonomous vehicles and other advanced technologies.

Advantages of LEO satellites

The main advantages of LEO satellites include low latency, which enables faster communication suitable for interactive applications. This improves the user experience and opens up new possibilities in telemedicine, remote working and other areas requiring an immediate response.

Another advantage is lower launch costs. Thanks to their smaller size and weight, LEO satellites can be launched at a lower cost compared to satellites in higher orbits. This enables faster renewal and modernisation of satellite networks.

A better signal is also a significant advantage. Proximity to Earth means the signal is stronger and suffers less signal loss, which improves transmission quality and reduces the energy requirements of transmitting equipment.

Disadvantages of LEO satellites

On the other hand, LEO satellites also have their disadvantages. One of these is the complexity of the network. Continuous global coverage requires a large number of satellites, which increases the complexity of managing and coordinating the entire network. Maintaining synchronisation between satellites and ensuring seamless data transmission presents a technical challenge.

A short lifespan is another limitation. LEO satellites are subject to greater wear and tear due to atmospheric drag and radiation, leading to faster ageing. This means they need to be replaced more frequently, which can increase the long-term costs of operating the network.

Furthermore, ground stations must constantly track the movement of satellites due to their rapid orbit around the Earth. This requirement for continuous tracking demands sophisticated technology and can complicate the operation of ground infrastructure.

3.5.2.3 Advantages and disadvantages of satellite broadcasting in the context of security

Satellite broadcasting offers several significant advantages in the field of security. The first of these is global coverage, which enables communication services to be provided in areas without existing infrastructure. As a result, remote or isolated regions can be connected to the rest of the world, which is essential for humanitarian aid, emergency situations or development projects.

Another significant advantage is its resilience to terrestrial disasters. Satellites, being located outside the Earth’s atmosphere, are not directly affected by terrestrial events such as earthquakes, floods or volcanic eruptions. This ensures uninterrupted communication even if terrestrial infrastructure has been destroyed or damaged, which is vital for coordinating rescue and recovery operations.

Satellite technology also enables broadband transmission, i.e. the ability to transmit large volumes of data over long distances. This capacity is essential for modern applications such as high-speed internet, high-definition video streaming, or complex data services for businesses and government institutions.

However, satellite broadcasting also has its drawbacks in terms of security. One of these is the vulnerability of the signal. Satellite signals can be intercepted or jammed during transmission, posing a risk to the confidentiality and integrity of data. Attackers can exploit techniques such as eavesdropping, jamming or signal spoofing, which necessitates the implementation of advanced encryption and authentication methods to protect communications.

Another challenge is cyber threats. Satellites and their ground stations may be targeted by cyber attacks, which can disrupt their functionality, gain unauthorised access to systems or steal sensitive data. Securing against these attacks requires a comprehensive approach encompassing network security, access control, regular software updates and staff training.

Finally, satellites also face physical threats. They may be endangered by space debris, which, in the event of a collision, can cause serious damage or destruction to the satellite. Furthermore, there is a risk of deliberate attacks, such as the use of anti-satellite weapons by other states or non-state actors. These threats require monitoring of the space environment, international cooperation in space traffic management, and the development of defence technologies.

Overall, satellite broadcasting offers immense benefits for global communication and security, but at the same time presents specific challenges that must be addressed through technical, organisational and legal measures.

3.5.2.4 Security challenges of satellite broadcasting

Satellite broadcasting faces specific security challenges arising from the nature of the technology and the environment in which it operates. As satellite signals are transmitted across vast geographical areas, they become vulnerable to various types of attacks and unauthorised access.

One of the main issues is signal interception. Signals transmitted by satellites can be easily intercepted, as they are broadcast over large areas and can be picked up even by unauthorised parties. Without adequate encryption, attackers can decrypt these signals and obtain sensitive information, posing a serious risk to the security of the transmitted data.

Another challenge is interference and jamming. Attackers can transmit signals on the same frequency as legitimate communications in order to disrupt transmission and cause signal interference. Jamming involves deliberately saturating a frequency with a strong signal in order to block communications. These attacks can lead to service outages and the disruption of vital communication channels.

Spoofing, or signal forgery, is another security threat. Attackers can transmit fake signals to deceive receivers and gain unauthorised access to systems or spread disinformation. This type of attack can have serious consequences, particularly if it affects critical infrastructure or emergency communication systems.

To protect satellite signals from these threats, it is essential to implement effective security measures. Encrypting communications is one such approach. End-to-end encryption ensures that data is encrypted from the transmitter to the receiver, making it impossible for attackers to access the content of the communication. The deployment of advanced encryption algorithms, such as AES (Advanced Encryption Standard), enhances the level of security and resilience against decryption attempts.

Authentication and authorisation are further key elements of security. The use of digital certificates enables the identity of communicating parties to be verified and ensures that only authorised entities have access to the system. The implementation of security protocols, such as IPsec or TLS, helps to secure data transmissions and protect against unauthorised access.

The detection and prevention of interference are also essential for maintaining the integrity of satellite transmissions. Spectrum monitoring enables continuous surveillance of the frequency spectrum to detect anomalies or suspicious activity. Should interference be detected, the system can utilise adaptive frequency hopping – that is, the ability to change communication frequencies – to avoid interference and maintain service continuity.

Physical protection of satellites is also important. Satellites must be designed to be resistant to radiation and space conditions so that they can withstand the extreme environment in which they operate. Countermeasures include technologies for detecting and responding to physical attacks, such as anti-satellite weapons. This may include, for example, satellite manoeuvring capabilities or protective shields.

Finally, the cyber security of ground stations is essential. The use of firewalls and anti-virus systems protects ground infrastructure from cyber attacks that could compromise communications or allow unauthorised access to systems. Software updates and patches are essential for eliminating known vulnerabilities and maintaining a high level of security.

Overall, satellite broadcasting requires a comprehensive approach to security, encompassing technical, organisational and physical measures. Addressing these challenges is essential for ensuring the reliability and security of communications on a global scale.

3.5.3 A comparison of the security aspects of terrestrial and satellite broadcasting

Data transmission security is a key element in both terrestrial and satellite broadcasting. Both technologies are used to disseminate information, but they differ in their methods of implementing encryption and authentication, and in their resilience to various types of attacks. The following comparison focuses on these aspects to clarify the differences and similarities between the two technologies.

3.5.3.1 Encryption and Authentication

In terrestrial broadcasting, encryption is often implemented using the DVB (Digital Video Broadcasting) standard, which utilises the Common Scrambling Algorithm (CSA). CSA is a symmetric encryption algorithm designed for the efficient encryption of audiovisual content in real time. User and device authentication in terrestrial broadcasting is usually handled via Conditional Access Systems (CAS). CAS enables service providers to control access to content using encryption and decryption keys, often implemented via smart cards or Common Interface (CI) modules.

Satellite broadcasting, on the other hand, utilising standards such as DVB-S and DVB-S2, implements more advanced encryption methods due to its wider geographical coverage and the higher risk of signal interception. The Advanced Encryption Standard (AES) is frequently used for its high level of security and its ability to withstand known cryptographic attacks. Authentication protocols in satellite broadcasting are also more complex and may include Digital Rights Management (DRM) systems for managing and protecting copyright in digital content. DRM allows for detailed control over who can play, copy or share content, and how.

The differences in encryption methods and authentication protocols between terrestrial and satellite broadcasting are primarily due to the technical limitations and requirements of each technology. Terrestrial broadcasting, which is predominantly one-way and covers smaller areas, can use simpler encryption algorithms without significantly compromising security. In contrast, satellite broadcasting, which covers global areas and is more susceptible to signal interception, requires stronger encryption algorithms and more complex authentication protocols to ensure the integrity and confidentiality of the transmitted data.

3.5.3.2 Resilience to attacks

The vulnerability of terrestrial and satellite broadcasting to different types of attacks varies significantly due to the differing nature of these technologies.

In the case of terrestrial broadcasting, physical attacks on infrastructure, such as transmitters and antennas, pose a real threat. These devices are often located in accessible areas and may be targets of vandalism or sabotage. Signal jamming is another issue, whereby an attacker may deliberately transmit on the same frequency and cause interference, leading to signal degradation or complete loss. However, terrestrial broadcasting utilises technologies such as OFDM (Orthogonal Frequency Division Multiplexing), which increases resilience to multipath propagation and interference, and SFN (Single Frequency Networks), which enables synchronised broadcasting on the same frequency from multiple transmitters, thereby improving coverage and resilience to local attacks.

Satellite broadcasting is less susceptible to physical attacks on the satellites themselves, as they orbit at high altitudes above the Earth. However, ground stations and control centres can be targets of both physical and cyber attacks. Satellite signal jamming is a serious threat that can affect large geographical areas. As the satellite signal has to travel long distances, it is more susceptible to jamming and requires sensitive receivers. Denial-of-Service (DoS) attacks can be carried out by flooding communication channels or by attacking the network infrastructure of ground stations. Satellite systems therefore often implement advanced detection mechanisms and protocols to mitigate these threats, such as spectral monitoring and adaptive frequency planning.

Overall, terrestrial broadcasting is generally less susceptible to DoS attacks, as the one-way nature of the transmission and the absence of a need for the receiver to acknowledge the sender limit the attacker’s options. Satellite broadcasting, which may involve two-way communication, is more vulnerable to such attacks and requires more sophisticated defence mechanisms.

3.6 Assessment of the potential for providing FeMBMS services in the Czech Republic

3.6.1 Current status of broadcasting and mobile networks in the Czech Republic

The Czech Republic has a well-developed digital terrestrial broadcasting (DVB-T2) infrastructure and a gradually expanding 5G network. DVB-T2 is currently the most widespread platform for receiving television broadcasts, used by approximately 57.4 per cent of Czech households. Mobile operators are continuing to roll out 5G networks, creating favourable conditions for the integration of new technologies such as FeMBMS.

3.6.2 FeMBMS testing in the Czech Republic

The roll-out of FeMBMS technology in the Czech Republic is taking place in line with national strategies for radio spectrum management and the roll-out of digital broadcasting networks. České Radiokomunikace (ČRa) is playing a significant role in the testing and implementation of 5G Broadcast technology, which offers significant advantages over traditional broadcasting technologies.

In 2024, ČRa launched the second phase of testing 5G Broadcast transmission from the Žižkov and Strahov transmitters in Prague. The tests are being conducted within a single-frequency network (SFN) and aim to optimise signal coverage and ensure high-quality mobile reception of television broadcasts. Broadcasting takes place on the 746 MHz frequency (channel 55) in the 700 MHz band, specifically in the duplex gap, which allows for the efficient use of the spectrum without interference from other services. The Žižkov transmitter has a power output of 32 kW and the Strahov transmitter 2 kW. Both transmitters, Žižkov and Strahov, use vertical polarisation. This means that the electromagnetic waves transmitted by these transmitters oscillate in a vertical plane, which is particularly advantageous in urban areas where the signal needs to penetrate buildings and other obstacles. Vertical polarisation ensures better coverage in densely populated areas, as it enables more stable signal reception whilst on the move, for example with mobile devices, which are often equipped with antennas optimised specifically for vertical polarisation. This type of polarisation also minimises interference with other broadcasting services that may use horizontal polarisation.

Figure 17: Coverage map of the Prague – Strahov and Prague – Žižkov transmitters for 5G Broadcast testing Source: https://i-day.cz/admin/fileGet.aspx?f=ilzbgpsos

The map shows the area of Prague where the two transmitters involved in testing 5G Broadcast technology are located. The transmitters are situated in Strahov and Žižkov, with a distance of approximately 5.4 km between them. The Strahov transmitter is shown on the left and the Žižkov television transmitter on the right. These transmitters are part of a single-frequency network (SFN) and are being used to test signal coverage and broadcast quality in urban areas.

The aim of these tests is to gain practical experience in the operation and optimisation of technology that would enable the widespread use of 5G Broadcast for the distribution of television content to mobile devices such as phones and tablets. This technology is not only more cost-effective but also more environmentally friendly than traditional technologies, as it does not require the use of mobile data networks to receive broadcasts.

3.6.2.1 Next steps and outlook for the future

České Radiokomunikace continues to develop digital broadcasting not only in the field of television but also in radio broadcasting. One example is the launch of DAB+ (digital radio) network development, where spectrum auctions for two nationwide and 27 regional networks were completed in 2024. The nationwide 'B' network was awarded to CDG (Czech Digital Group), a subsidiary of ČRa. The auction results generated proceeds of 80 million CZK, of which CDG secured the frequencies for 26.35 million CZK.

However, investment in the roll-out of these digital networks will significantly exceed the costs of spectrum auctions. Nationwide network coverage is expected to reach 50 per cent of the population and motorways by the end of 2025, and 80 per cent by the end of the first quarter of 2026. Regional networks are then to be extended to cover 40 per cent of the population in the relevant regions by 2026 and 70 per cent by 2028.

3.6.2.2 International cooperation and development

The Czech Republic is not the only country where 5G Broadcast technology is being tested. Similar tests are also taking place in Germany, Austria and Italy, where pilot projects focusing on the use of this technology are also being carried out.

5G Broadcast technology has the potential to significantly influence the way in which television content is distributed, particularly when combined with hybrid technologies such as HbbTV, which enable interactive features and targeted advertising. In the Czech Republic, digital terrestrial television (DTT) remains the dominant platform, used by more than 57 per cent of households. With the transition to DVB-T2 and the introduction of further interactive services, ČRa is establishing itself as a leader in digital broadcasting and innovation.

The implementation of FeMBMS technology presents a suitable opportunity for the Czech Republic to modernise television and radio broadcasting, particularly in the context of 5G networks. In this chapter, we will focus on assessing the current possibilities for providing FeMBMS services in the Czech Republic, taking into account recent testing, identified challenges and prospects for future development.

3.6.2.3 Test results and identified challenges

The testing yielded valuable insights but also revealed technical challenges. One of the main obstacles was the problematic decoding of the so-called Cell Acquisition Subframe (CAS) within the SFN. This systemic issue relates to the use of different numerologies (older LTE numerology with 15 kHz SCS for CAS and newer ones for MBSFN subframes). The CRA is collaborating with international partners to resolve this complication.

Another finding was that signal quality and coverage did not meet initial expectations, which requires further optimisation of transmission parameters and network configurations.

3.6.3 Prospects and planned development of FeMBMS in the Czech Republic

Despite the challenges identified, the potential for FeMBMS in the Czech Republic is significant. The CRA plans to continue testing and developing the technology with the aim of preparing it for commercial deployment within a few years, with a possible launch around 2027.

Areas of development include:

- **Resolving technical issues**: Ongoing work to address broadcasting issues within the SFN and optimise the network architecture.
- **Integration with the internet**: Developing applications that link 5G Broadcast with internet services, such as implementing HbbTV-like functionality (‘red button’) on mobile devices.
- **Availability of compatible devices**: Collaboration with chip and mobile device manufacturers, such as Qualcomm, to ensure support for FeMBMS in new models of smartphones and tablets.
- **Business models**: Identification of sustainable business strategies, including options for monetising services, delivering content at sporting or cultural events, and utilising the technology for content production.

3.6.4 Potential benefits and advantages of FeMBMS in the Czech Republic

The implementation of FeMBMS brings a number of significant benefits to the Czech Republic. One of the main benefits is ensuring independence from mobile networks. Thanks to this technology, users can receive linear television and radio broadcasts directly, without needing access to mobile data or a SIM card. This not only reduces the load on mobile networks but also eliminates the use of users’ data allowances.

Another advantage is the system’s high scalability. An unlimited number of viewers can watch broadcasts simultaneously without this having a negative impact on the quality of the services provided. This feature is important at times of high demand for multimedia content, when traditional networks may become overloaded.

In crisis situations, FeMBMS proves to be more reliable than traditional mobile networks. Broadcasts from high-power transmitters are less prone to outages caused by network congestion or damage to infrastructure. This ensures continuous access to vital information for the public during emergencies.

3.6.5 Challenges and limitations of FeMBMS implementation in the Czech Republic

Although FeMBMS offers many advantages, its introduction in the Czech Republic also presents several challenges. One of the main challenges is the need for new devices, as current mobile phones and tablets are unable to receive the FeMBMS signal. Users would therefore need to purchase new, compatible devices.

Another issue is technical complications. Resolving issues related to broadcasting in single-frequency networks (SFN) and the integration of different numbering plans requires further research and development. These technical challenges may prolong the time needed for full implementation and require specialised expertise.

Regulatory aspects also play an important role. It is necessary to obtain the required licences for the use of the frequency spectrum. To this end, international standards set by organisations such as 3GPP and ETSI must be adhered to.

The financial costs of implementing FeMBMS can be substantial and represent a significant challenge. Investment in new infrastructure and development requires thorough planning and the efficient allocation of resources. To cover these expenses and ensure the successful roll-out of FeMBMS technology in the Czech Republic, support from the state or the use of European funds may be necessary.

4 5G Broadcast Legislation

4.1 EU Directive on Audiovisual Content

The Audiovisual Media Services Directive (AVMSD) is the European Union's most important legislative instrument governing the provision of audiovisual content across Member States. The Directive was originally adopted in 2010 as Directive 2010/13/EU and was subsequently significantly updated by Directive (EU) 2018/1808 to reflect the rapidly changing landscape of digital media and technological innovation. The aim of this Directive is to ensure a single market for audiovisual services within the EU and to promote cultural diversity, consumer protection and, in particular, the protection of minors.

4.1.1 Definition of Audiovisual Media Services

Audiovisual media services are defined according to a set of cumulative criteria: they are usually provided for a fee; they provide programmes under the editorial responsibility of the provider (i.e. the provider determines the selection of content and its organisation); they inform, entertain and educate the general public; and they are provided via electronic communications networks.

Audiovisual media services may be linear television broadcasting (for watching programmes in real time according to a programme schedule) or non-linear/on-demand (for viewing at a time chosen by the user and at their individual request based on a catalogue).

4.1.2 Key points of the Directive

The AVMSD covers both traditional television broadcasting and on-demand audiovisual services (Video-on-Demand, VoD). The fundamental principles of the Directive can be divided into several areas:

- **Coordination of legislation**: The Directive ensures a minimum level of harmonisation of legislation in the field of audiovisual media services. EU Member States are obliged to transpose this Directive into their legal systems and to ensure that audiovisual content provided within their territory meets common standards for consumer protection and content provision.
- **Freedom of reception and cross-border transmissions**: Member States must respect the principle of freedom of reception, which means that audiovisual content lawfully broadcast from one Member State must be freely available in other EU Member States. However, there are situations in which Member States may temporarily restrict the dissemination of certain content if it infringes their national legislation, for example in the areas of the protection of minors or the prevention of hate speech.
- **Protection of minors and consumers**: The Directive emphasises the protection of minors from harmful content. Audiovisual services must put in place measures such as age verification and broadcasting time limits for content that could adversely affect the physical, mental or moral development of minors. Particular attention is paid to online video-sharing platforms, which must adopt stricter measures to protect children from inappropriate content.
- **Promotion of European works**: The Directive introduces quotas for on-demand audiovisual services, which must ensure that at least 30 per cent of their catalogue consists of European works. Furthermore, these services are required to ensure the visibility and promotion of European works, thereby supporting cultural diversity and strengthening the position of European production in the digital market.
- **Regulation of audiovisual advertising**: Advertising in audiovisual services must be easily recognisable and must not encourage discrimination, undermine human dignity or promote behaviour that is harmful to health or the environment. The Directive also lays down strict rules for advertising aimed at minors, particularly in relation to the promotion of foods high in fat, salt or sugar.
- **Hate speech and terrorism**: Audiovisual services must not contain content that incites violence, hatred or terrorism. These provisions are in line with the Charter of Fundamental Rights of the European Union and aim to protect the public from dangerous and extremist content.

- **Accessibility of services for people with disabilities**: The Directive requires providers of audiovisual media services to gradually make their services accessible to people with disabilities. This includes, for example, the accessibility of emergency information or support in developing plans to improve accessibility.

4.1.3 Updates

The latest update to the Directive introduced a number of new provisions applicable to providers of video-sharing platforms, such as YouTube, to improve the protection of minors and the public from harmful content. Member States were required to transpose the Directive into their national legislation by September 2020, although implementation continued beyond that date. Key changes introduced by Directive (EU) 2018/1808 of the European Parliament and of the Council:

- Extension of scope to video-sharing platforms – Platforms such as YouTube and social media sites are now subject to the Directive’s rules.
- Enhanced protection for minors – Stricter measures to control minors’ access to harmful content, including mandatory age verification.
- Combating hate speech – Introduction of measures against content inciting violence, hatred or terrorism.
- Flexibility in advertising placement – Greater flexibility in advertising rules, including a limit of 20 per cent of daily broadcasting time.
- Promotion of European works – VoD service providers must ensure that at least 30 per cent of their content consists of European works.
- Accessibility for people with disabilities – Providers are obliged to improve the accessibility of audiovisual content.

The Audiovisual Content Directive therefore not only harmonises the legal framework for the provision of audiovisual services in Europe, but also reflects technological innovations such as digital platforms and strengthens rules on consumer protection and cultural diversity.

4.2 ETSI’s role in telecommunications standards

ETSI (European Telecommunications Standards Institute) is an independent European standardisation organisation in the field of telecommunications, information technology and other communication services. ETSI develops internationally recognised technical standards covering a wide range of areas, such as mobile and wireless networks, the Internet of Things (IoT), cyber security, artificial intelligence and many other technologies. ETSI’s main objective is to ensure interoperability between devices and systems, to improve efficiency and service quality, and to promote innovation in the rapidly evolving digital environment.

In the context of 5G technologies, ETSI plays a significant role in defining standards that enable broadcasters to utilise the capabilities of 5G networks for the distribution of linear television and radio broadcasts. ETSI develops technical specifications that set out the basic parameters for the implementation and operation of 5G Broadcast systems. These standards support the effective deployment of 5G Broadcast services in practice and ensure that different manufacturers and providers can create interoperable systems that meet the technical requirements for modern broadcasting over 5G networks.

4.2.1 ETSI TS 103 720 – Technical Specification for LTE-based 5G Broadcast Systems

This document is one of the ETSI technical specifications for 5G Broadcast systems. This technical standard defines the architecture and implementation profiles for an LTE-based 5G Broadcast system, which is designed to deliver linear television and radio services via 5G networks.

The key elements of the system defined in the specification:

- **Support for Free-to-Air (FTA) broadcasting**: This system provides freely accessible television and radio broadcasts that do not require a subscription from mobile network operators.
- **Receive-Only Mode (ROM)**: Devices can receive broadcasts without the need for back-to-back communication with the mobile network. This is particularly useful for devices intended solely for receiving broadcasts, such as televisions or radio receivers.

- **Deployment in Single Frequency Network (SFN) mode:** This system supports SFN deployments with large distances between transmission points (ISD > 100 km). This ensures more efficient coverage of large areas, which is important for linear television or radio broadcasting, particularly in less densely populated areas.
- **Mobility support**: The system is designed to support mobile scenarios, including broadcast reception at speeds of up to 250 km/h, making it suitable, for example, for fast-moving vehicles with external antennas.
- **Support for standard streaming formats**: The specification includes support for common streaming formats such as **Dynamic Adaptive Streaming over HTTP (DASH)**, **HTTP Live Streaming (HLS)** and **Common Media Application Format (CMAF)**. This ensures flexibility in content delivery and optimisation of broadcast quality according to available bandwidth.
- **Combination of unicast and broadcast methods:** The 5G Broadcast system supports a hybrid approach that combines unicast and broadcast methods of content delivery. This means that services can be delivered via both one-way (broadcast) and two-way (unicast) transmission.
- **Emergency announcements and public warnings:** The specification includes support for Public Warning Systems (PWS), which disseminate emergency announcements via broadcast systems, for example by utilising Cell Broadcast services for natural disaster warnings.
- **Interoperability with IPTV and other IP-based services**: The system is designed to support IP services such as IPTV or multicast content delivery, enabling broadcasters and telecoms operators to integrate 5G Broadcast with various digital platforms.

4.2.1.1 Architecture and deployment of 5G Broadcast systems

The **ETSI TS 103 720** technical specification also describes the system's reference architecture. The architecture comprises:

- **A TV and radio content service provider** (TV/Radio Content Service Provider), which operates a 'head-end' for the provision of linear TV and radio services.
- A Broadcast TV/Radio Service Application on user devices, which communicates with the broadcast receiver via an API.
- **A** Broadcast System Operator, which manages 5G Broadcast transmitters and infrastructure (ETSI-TS-103-720-V1-2-1-…).

4.3 The role of 3GPP in the development of telecommunications standards

3GPP (3rd Generation Partnership Project) is an international collaboration between six regional standardisation organisations, established in 1998. Its main objective is to develop global telecommunications standards to ensure the interoperability of mobile networks and technologies on a global scale. 3GPP is involved in developing specifications for mobile communication systems, including 3G (UMTS), 4G (LTE) and 5G technologies.

The 3GPP organisation plays a vital role in the development of modern telecommunications networks, from the radio layer through to the underlying infrastructure and applications. Its aim is to deliver not only high-speed data transmission but also efficient voice services, secure data transmission and support for new technologies such as the Internet of Things (IoT) and autonomous systems.

4.3.1 The main tasks and objectives of 3GPP

3GPP develops technical specifications for mobile technologies that are essential to the global communications ecosystem. The aim is to achieve compatibility and interoperability between different devices, networks and services, thereby supporting their global deployment.

- Standardisation of mobile networks: 3GPP establishes a unified framework for the development of mobile communication systems, encompassing radio access technologies, networks and application layers. This framework covers not only 3G and 4G technologies, but above all the current development of 5G, which brings new possibilities such as high speed, low latency and support for billions of connected devices, including the Internet of Things (IoT).
- Support for innovation and new services: 3GPP is constantly expanding its standards to support new technologies and applications, such as the Internet of Things (IoT), autonomous systems, smart cities and industrial applications. The standards are designed to be flexible and adaptable to further technological developments.
- Global interoperability: Thanks to 3GPP, mobile devices and networks from different manufacturers are compatible across countries and continents, making global roaming and the unified provision of services possible in various regions of the world.

- Security and privacy: 3GPP also focuses on establishing robust security measures within mobile networks. These specifications ensure the protection of user data and the secure transmission of information. These aspects are particularly essential in the current environment of growing cyber threats.

4.3.2 Development of 5G Broadcast within 3GPP Releases

3GPP plays a role in the development of standards for 5G Broadcast, also known as FeMBMS (Further evolved Multimedia Broadcast Multicast Service). The development of this technology takes place through successive versions (Releases) of the 3GPP specifications, which progressively add new features and enhancements to support 5G Broadcast services.

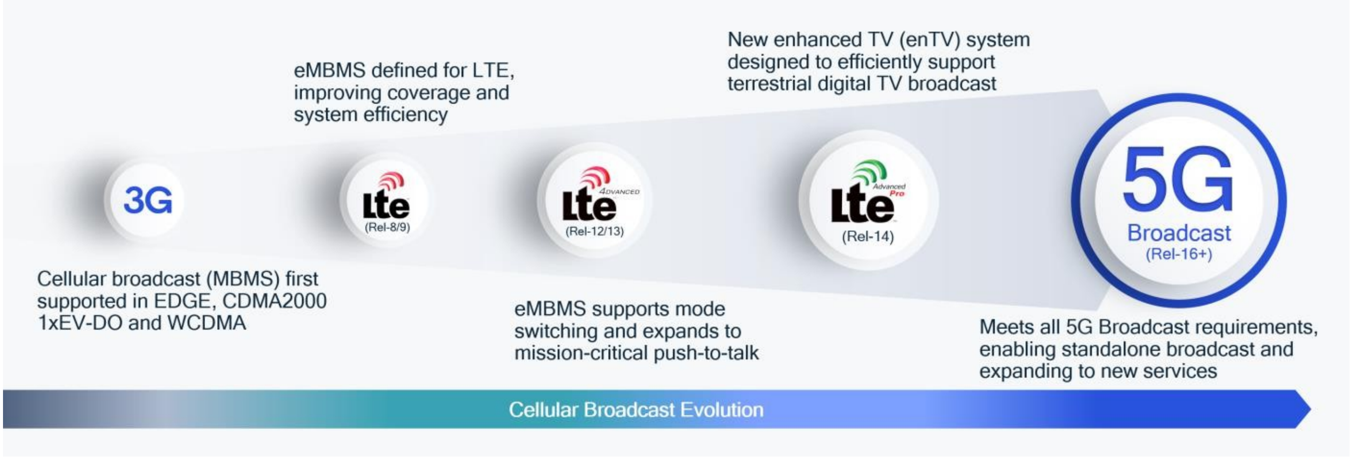

Figure 18: The evolution of broadcast from 3G to 5G in 3GPP releases

Source: https://www.qualcomm.com/content/dam/qcomm-martech/dm-assets/images/blog/managed-images/image_1_20.png

This figure illustrates the development of Cellular Broadcast technology, which has undergone several phases and 3GPP releases from 3G to 5G, with each release bringing new improvements and expanding capabilities.

4.3.2.1 Release 14

- Introduction of FeMBMS: Release 14, finalised in 2017, introduced the concept of FeMBMS as an evolution of the previous eMBMS used in LTE networks. FeMBMS enables the simultaneous broadcasting of multimedia content to a large number of users via mobile networks.
- Extended coverage and efficiency: Release 14 introduced support for large coverage areas through the use of a Single Frequency Network (SFN), which synchronises transmissions from multiple transmitters on the same frequency. Extending the cyclic prefix (CP) length to 200 μs allows for coverage of larger geographical areas.
- Release 14 brought significant improvements to LTE-Advanced Pro. These include enhanced LAA (eLAA), which expands the use of unlicensed spectrum through uplink support, enabling more efficient utilisation of available frequencies. Further enhancements include enhanced LWA (eLWA), which adds uplink via WLAN and support for the 60 GHz band. V2V (vehicle-to-vehicle) communication enables direct communication between vehicles, supporting the development of autonomous systems. Latency improvements, a reduction in TTI and the new Light Connection intermediate state in RRC optimise transitions between active and inactive states and improve efficiency for small data transfers. Multi-connectivity adds support for multiple radio connections per user, increasing network reliability and capacity.

4.3.2.2 Release 16

- FeMBMS enhancements: Release 16, finalised in 2020, brought further enhancements to FeMBMS technology. New features were introduced to improve spectrum efficiency and quality of service, including support for higher modulation schemes and coding techniques.
- Receive Only Mode (ROM): One of the features was the introduction of Receive Only Mode (ROM), which ensures that devices can receive transmissions without needing to send return signals to the network. This is important for energy saving and allows transmissions to be received without the need to log into the network or use a SIM card.

4.3.2.3 Release 17

- Further optimisations to 5G Broadcast: Release 17, finalised in 2022, brought further improvements to 5G Broadcast. New numerology was introduced and support was extended to a wider range of frequency bands. Support for moving receivers (e.g. in vehicles) was also improved, along with optimisations for energy efficiency.
- Support for new services: Release 17 includes support for new types of services, such as the broadcasting of software updates for vehicles, public information services and support for critical communication applications.
- Architecture and mobility: Release 17 also emphasised the need for dynamic switching between Point-to-Multipoint (PTM) and Point-to-Point (PTP) modes, which improves transmission reliability. Advanced feedback mechanisms, such as HARQ (Hybrid Automatic Repeat Request), and support for error-free handover between base stations have been introduced.

The figure below shows the comprehensive 5G Broadcast/Multicast (MBS) architecture, which was developed as part of 3GPP Release 17. This figure illustrates how the technology has evolved from previous versions of LTE and covers the key aspects of 5G MBS that have been progressively enhanced. The architecture reflects the involvement of base stations (eNBs) and the core network, for both unicast, multicast and broadcast services.

Features of the standardised 5G MBS include a group scheduling mechanism, which enables user equipment (UE) to receive MBS services even whilst simultaneously receiving unicast data. Furthermore, content delivery within the 5G Core (5GC) is supported via shared delivery, which enhances the efficiency of content distribution. Delivery reliability is ensured by dynamic switching between Point-to-Multipoint (PTM) and Point-to-Point (PTP) delivery, including support for mechanisms such as Automatic Repeat Request (ARQ) and Hybrid Automatic Repeat Request (HARQ), which ensure error correction and improved data transmission reliability.

The architecture also supports mobility and seamless handover, which is important for transmission in mobile networks. Another significant feature is the ability to receive broadcast data regardless of the device's Radio Resource Control (RRC) state. This system is designed to be compatible with earlier networks, such as those from Releases 15 and 16.

The aim of 5G MBS is to improve the efficiency, reliability and flexibility of transmission, so that content can be broadcast to many users simultaneously without causing network congestion. This technology will find applications, for example, in the delivery of software updates for vehicles, in public safety services or in critical infrastructure applications.

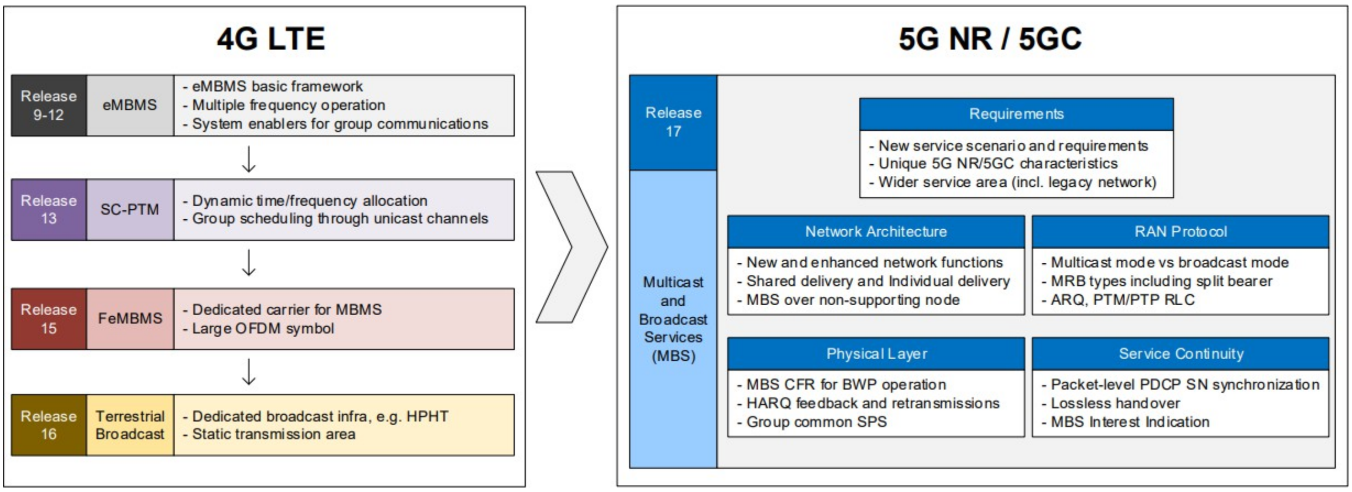

Figure 19: Multicast/broadcast services and their development for LTE and 5G MBS, along with some technical aspects.

Source: https://www.techrxiv.org/users/681071/articles/677413-5g-evolution-for-multicast-and-broadcast-services-in-3gpp-release-17

4.3.3 Contributions of 3GPP Releases to 5G Broadcast

- Standardisation and compatibility: Thanks to 3GPP specifications, 5G Broadcast technologies are standardised, ensuring compatibility between different devices and networks. This enables the global deployment and interoperability of services.
- Innovation and new features: Successive releases introduce new features and enhancements that improve the efficiency, reliability and quality of services. This enables content providers and operators to offer advanced services tailored to the needs of modern users.

- Efficient use of spectrum: Updates in the Releases include optimisations for better utilisation of the frequency spectrum, which is essential for providing high-capacity services within a limited spectrum.
- Security and content protection: The 3GPP specifications include advanced security mechanisms that protect content from unauthorised access, which is essential for copyright protection and compliance with licensing terms.

Enhancements to 5G services in Release 17

This release continues to optimise key areas such as capacity, coverage, latency and energy efficiency, thereby supporting the expansion of 5G technologies into new devices and applications.

Key enhancements include:

- Extension of massive MIMO: Release 17 introduces improvements in the areas of multi-TRP (transmit and receive) and multi-beam steering. The improvements also focus on SRS (sounding reference signals) and CSI (channel state information) measurement and reporting.
- Coverage improvements: Release 17 introduces enhancements to uplink channels for greater reliability across various frequency bands (sub-7 GHz, mmWave) and support for non-terrestrial networks.
- Power savings for devices: New techniques to reduce power consumption include optimising the paging system and simplifying radio signal measurement, which extends battery life both during calls and in idle mode.
- Spectrum expansion: Release 17 extends 5G NR support to the new FR2-2 band (24.25–71 GHz), including the global unlicensed 60 GHz band, opening up new possibilities for deployment and applications.
- Enhanced support for URLLC and private networks: New enhancements ensure better support for ultra-reliable, low-latency communication (URLLC) services, particularly in Industrial Internet of Things (IIoT) applications, including optimisation of the physical layer and device multiplexing.

4.3.4 Changes in 3GPP Releases and their impact on 5G Broadcast legislation

Gradual changes and updates to 3GPP Releases have a direct impact on legislation and regulatory frameworks:

- Adapting legislation to new technologies: As new features are developed in each release, it is essential to update legislative frameworks to enable the deployment of these technologies. This includes, for example, authorisation for the use of new frequency bands or the implementation of new safety standards.
- Ensuring compatibility with international standards: National legislation must comply with the international standards defined in 3GPP Releases to ensure the interoperability and compatibility of services at a global level.
- Protection of consumers and content providers: Updates in Releases may introduce new mechanisms for data and content protection. Legislation must reflect these changes and ensure that the rights of users and providers are protected.

4.4 The legal framework in the Czech Republic

The legal framework for electronic communications and telecommunications in the Czech Republic is based on national legislation and European Union regulations, which together create a comprehensive regulatory environment for the implementation of modern telecommunications technologies, including 5G networks. These regulations ensure the transparent and efficient functioning of the telecommunications market, protect consumers' rights and ensure data and network security. In connection with the deployment of FeMBMS (Further evolved Multimedia Broadcast Multicast Service) technology in 5G networks, it is important to be familiar not only with the general regulations on electronic communications, but also with the specific technical and licensing requirements applicable to this technology.

4.4.1 Act No. 127/2005 Coll., on Electronic Communications

Act No. 127/2005 Coll., on Electronic Communications, constitutes the fundamental legal framework for telecommunications and electronic communications in the Czech Republic. This Act regulates a wide range of activities, including the operation of telecommunications networks, the management and allocation of radio frequencies, and the conditions for the granting of licences and access to infrastructure. It also defines the rights and obligations of telecommunications service providers and their relationship with customers. A central aspect of the Act is ensuring the protection of personal data and the security of telecommunications networks. These measures are particularly crucial when deploying modern technologies that require secure and reliable connections. The Czech Telecommunications Office (ČTÚ) oversees the implementation of the Act, the allocation of frequencies and market regulation, thereby ensuring a competitive environment and the efficient use of telecommunications infrastructure.

The amendment to Act No. 202/2023, which came into force in 2023, introduces a number of changes reflecting the advent of 5G networks and related advanced technologies. The amendment facilitates the construction and expansion of electronic communications networks by simplifying the legislative conditions for their operators. This is of fundamental importance for accelerating the roll-out of 5G infrastructure, which is becoming the foundation for the provision of modern telecommunications services. The update also focuses on enhancing the protection of telecommunications networks against cyber threats and attacks, which is becoming increasingly important with the expansion of digital services and the growing use of networks in critical sectors such as healthcare, transport and energy.

Another key aspect of the amendment is more flexible radio spectrum management, which enables more efficient use of frequencies for a wide range of telecommunications applications, including 5G and the Internet of Things. Access to frequencies is now better coordinated, which promotes competition and innovation in the telecommunications sector. At the same time, the amendment introduces new rules for consumer protection, particularly with regard to access to emergency services and the transparency of contractual terms.

4.4.2 Act No. 231/2001 Coll., on the Operation of Radio and Television Broadcasting

Act No. 231/2001 Coll., on the Operation of Radio and Television Broadcasting, is a piece of legislation governing the conditions for radio and television broadcasting within the Czech Republic. This Act sets out the rights and obligations of natural and legal persons operating broadcasting services, as well as the conditions for granting the licences necessary for the operation of radio or television broadcasting.

The Act also addresses issues relating to the protection of pluralism of information, ensuring access to information for different schools of thought, and the protection of minors from inappropriate content. It regulates the rights of broadcasters in the distribution of content and specifies what content is suitable for broadcast.

The Act specifies the procedures for the Czech Telecommunications Office and the Council for Radio and Television Broadcasting, which are involved in the granting of licences and the supervision of compliance with these conditions. Particular emphasis is placed on ensuring that licences are granted transparently and that conditions for fair competition between individual operators are guaranteed.

In the context of 5G broadcasting, the Act is important because it sets out the conditions for the granting of broadcasting licences and the rules governing the distribution of multimedia content. 5G broadcasting enables television or radio content to be distributed directly to mobile devices and other terminals; it is therefore essential that these providers comply with the requirements laid down by this Act, particularly in the areas of content and licensing. This Act thus remains a key document for 5G broadcast operators wishing to provide legal and regulated broadcasting in accordance with national regulations.

4.4.3 Act No. 132/2010 Coll., on on-demand audiovisual media services

Act No. 132/2010 Coll. regulates the provision of on-demand audiovisual media services in the Czech Republic. This Act implements the relevant European Union regulations and sets out the conditions under which natural or legal persons may provide these services. The Act focuses on defining on-demand audiovisual services, the obligations of providers and the conditions that must be met for lawful operation.

On-demand audiovisual media services primarily involve the provision of video content, such as films, series or other programmes, which users can watch at any time according to their needs. The main feature of these services is that they are offered on the basis of a catalogue compiled by the provider and are accessible at a time chosen by the user. The provider bears editorial responsibility for the content offered.

The Act includes rules on advertising, sponsorship and product placement in programmes, which providers of audiovisual media services must comply with. The aim of these rules is to ensure the protection of consumers, particularly children, and transparency in the provision of content. Sponsored programmes must always be clearly identified.

Furthermore, the Act focuses on the protection of minors, requiring providers to ensure that content which could impair their physical, mental or moral development is not easily accessible. This includes the use of measures such as age verification.

Part of the Act also addresses the accessibility of audiovisual services for people with hearing and visual impairments, including the obligation to provide subtitles or audio descriptions where appropriate.

The Act on On-Demand Audiovisual Media Services forms an important part of the legislative framework for media content in the digital environment in the Czech Republic and ensures that the provision of these services takes place transparently and in accordance with consumers' rights.

4.4.4 Act No. 483/1991 Coll., on Czech Television, and Act No. 484/1991 Coll., on Czech Radio

The Act on Czech Television sets out the rules governing the operation of Czech Television (a public service broadcaster) as a legal entity with its registered office in Prague. This Act establishes Czech Television with the aim of serving the public by producing and broadcasting television programmes and other multimedia content throughout the Czech Republic.

The main objectives of the public service include providing objective and verified information, contributing to citizens' legal awareness, developing cultural identity and promoting social cohesion. Czech Television is obliged to produce a balanced range of programmes for various sections of the population, including minorities, and to operate terrestrial digital broadcasting of at least four television channels.

With regard to 5G broadcasting, Czech Television is obliged to ensure the operation of a public service multiplex, which enables the transmission of television and radio programmes using digital technologies, with radio frequencies allocated to Czech Television by the frequency management authority in accordance with the Electronic Communications Act. These rules support the introduction of modern technologies and broadcasting formats, including new media services and on-demand audiovisual content.

The Act on Czech Radio sets out similar rules governing the operation of Czech Radio as a public service broadcaster. Czech Radio aims to provide proper and balanced content in the form of radio broadcasting, to promote cultural identity, and to ensure the production of news, cultural and educational programmes. In the context of broadcasting, Czech Radio is obliged to provide its programmes via the public service multiplex, alongside Czech Television.

4.4.5 Act No. 194/2017 Coll., on measures to ensure the security and integrity of electronic communications

Act No. 194/2017 Coll., also known as the Act on Measures to Reduce the Costs of Deploying High-Speed Electronic Communications Networks, is an important piece of legislation in the Czech legal system focused on the development of modern telecommunications infrastructure. This Act sets out the rules for the roll-out of high-speed networks and establishes conditions that lead to more efficient construction and operation of electronic communications networks.

The aim of this Act is to ensure the availability of high-speed electronic communications networks across the Czech Republic. The Act contains measures to reduce the costs of infrastructure development, including better coordination of construction work, the use of existing physical infrastructure and more efficient access to information on ongoing construction projects.

An important part of the Act is the role of the Czech Telecommunications Office (ČTÚ), which acts as a single point of contact for information on physical infrastructure and construction works. The Act allows authorised persons access to this information in order to facilitate the roll-out of high-speed networks. Furthermore, the Act includes rules on infrastructure sharing between individual providers, with the aim of reducing duplication of infrastructure and making investments more efficient.

In the context of 5G and broadcast transmission, it is worth noting that the Act includes measures that may contribute to the development of the infrastructure required for the provision of high-quality media services, including 5G broadcasting. The roll-out of high-speed networks enables better transmission of data and multimedia content, which can support new forms of broadcasting, such as public service broadcasting or the distribution of content to a wide audience.

4.4.6 Act No. 202/2023 Coll., an amendment to the Act on Electronic Communications

Act No. 202/2023 Coll. amends Act No. 127/2005 Coll., on electronic communications and amending certain related acts. This amendment came into force on 30 June 2023 and took effect on 1 July 2023. The aim of the amendment is to ensure the responsible and effective functioning of electronic communications in line with current market needs and to ensure maximum protection of consumer rights.

The amendment introduced various measures, including changes to the management of access to subscriber identification cards (SIM cards), which involves blocking them or preventing network access in specific cases. Protection for people with special social needs has also been strengthened, including preferential tariffs and obligations for universal service providers.

The amendment also includes updates for the Czech Telecommunications Office (ČTÚ), which will collect information on small wireless access points and provide this information to the European Commission, with a view to ensuring better record-keeping and data availability for both the Czech and European markets.

From the perspective of broadcasting, the amendment includes changes relating to amendments to the Act on the Operation of Radio and Television Broadcasting, which may directly affect the availability of media content via 5G broadcasts and other new forms of content distribution that are in the public interest and in line with modern technologies.

5 International benchmark

International projects and pilot tests provide valuable insights into the practical aspects of deploying FeMBMS and 5G Broadcast. They address the technical challenges that had to be overcome, optimisation strategies for data transmission, methods of ensuring compatibility with existing infrastructure and equipment, as well as user responses to the new services.

Different countries are approaching the implementation of FeMBMS and 5G Broadcast in different ways, reflecting their specific technical, economic and regulatory conditions. For example, Italy is focusing on integrating this technology into existing broadcasting networks with the aim of improving coverage in remote areas, whilst France is testing the possibilities during major cultural and sporting events in Paris.

Analysing these diverse approaches makes it possible to identify best practices and strategies that can be adapted to the Czech context. International experience highlights potential obstacles, such as regulatory constraints or technical difficulties, and offers solutions to overcome them. Implementations abroad often involve collaboration between various stakeholders, including telecoms operators, broadcasters, content providers and regulatory authorities.

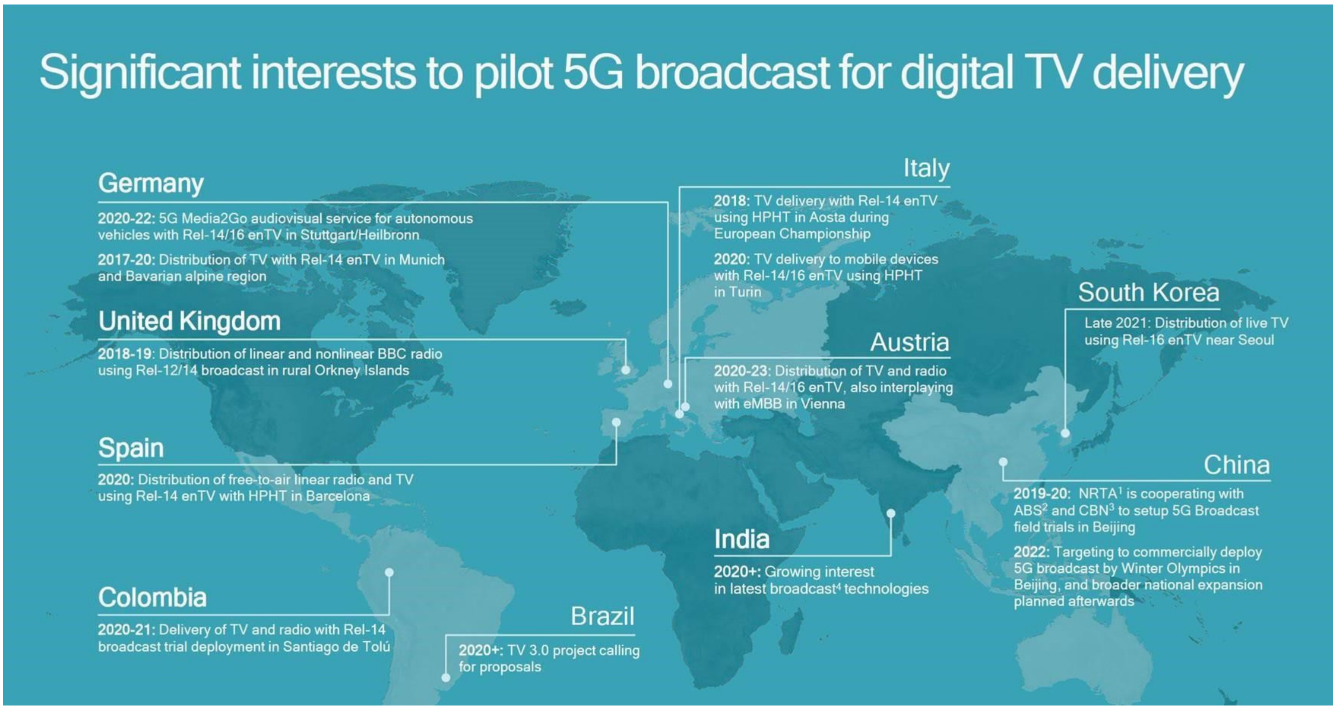

Figure 20: Global 5G Broadcast pilot projects and trials for digital TV broadcasting Source: https://www.qualcomm.com/content/dam/qcomm-martech/dm-assets/images/blog/managed-images/image3new2.jpg The map shows some international 5G broadcast projects and pilot trials for digital TV broadcasting.

Some examples from abroad are listed and described below.

5.1 Germany

Germany plays a significant role in the development and roll-out of 5G technology for multimedia services, particularly through the FeMBMS projects and its integration into 5G networks. These initiatives include testing and optimising the distribution of television and radio programmes, as well as the provision of interactive multimedia services via mobile networks. Key German projects include 5G Media2Go, 5G Broadcast in Hamburg and the 5G Today project, which focus on coverage of various geographical areas, verifying transmission quality and the possibilities for interaction with mobile devices whilst on the move.

The projects emphasise financial sustainability, content protection, efficient spectrum utilisation and collaboration with the automotive industry. They also explore future applications of 5G technology for multimedia services whilst on the move and in urban environments. In this way, Germany is helping to shape the future of multimedia broadcasting within the 5G infrastructure, with a focus on high-quality transmission and personalised user experiences.

5.1.1 5G Media2Go

The 5G Media2Go project began on 1 October 2020 and ended on 30 September 2022. It took place in the wider Stuttgart and Heilbronn areas in Germany. The aim was to investigate how to utilise FeMBMS technology in 5G networks to distribute audiovisual content to mobile devices and vehicles. The project focused on the delivery of linear television and radio programmes, access to media libraries (ARD/SWR Mediathek) and geo-referenced content recommendations whilst travelling.

The diagram below illustrates the entire media distribution process, from content selection at the SWR playout centre in Baden-Baden to its reception in the car's infotainment system. Linear television and radio programmes are converted into a suitable transport format and sent to the Broadcast System & Control Centre (BSCC), which acts as an interface to the 5G Broadcast network. The signals are transmitted to individual transmitters via fibre-optic cable. Antennas in the car receive the signal, which is then connected to the car's infotainment system via an SDR receiver and a Wi-Fi hotspot. Users also have the option to access on-demand content from the ARD/SWR Mediathek either manually or via recommendations from the Travelguide app, which utilises geo-sensitive data. The content is delivered via the mobile network through a CDN.

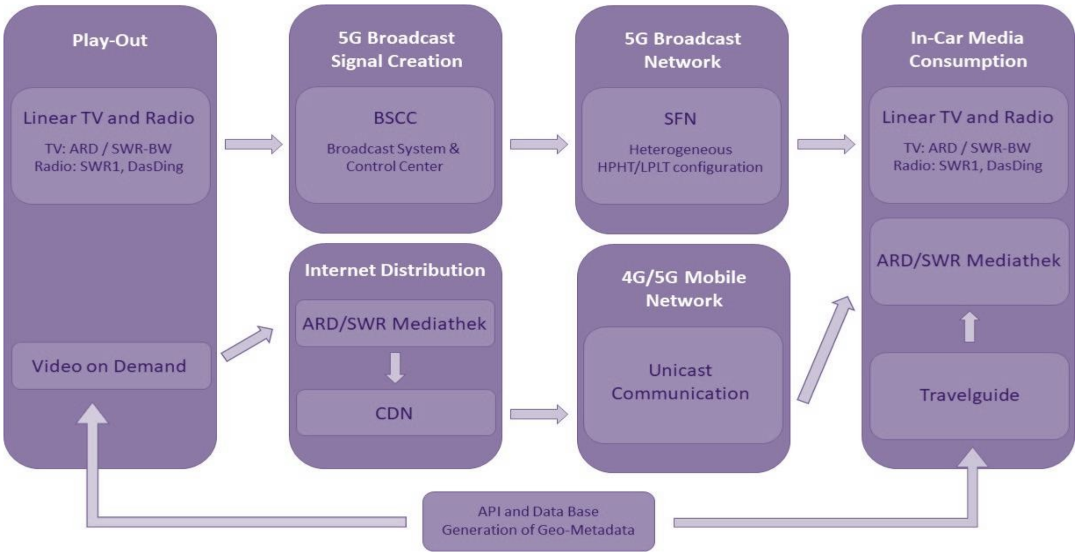

Figure 21: Overview of the entire distribution and usage chain.

Source: https://drive.google.com/file/d/1CznXRhhNboNVvXVI6oTqiF2f6brlONxb/view

The 5G Media2Go project had several objectives:

- **Assessment of service provision capabilities:** Testing the ability of FeMBMS technology to provide television and audiovisual services in various geographical areas, including rural and remote areas. Ensuring a reliable and high standard of picture and sound quality even under high network load.
- **Compatibility and interoperability:** Assessing the compatibility of FeMBMS technology with the architecture and infrastructure of existing 5G networks (SA/NSA) and ensuring its seamless integration. Considering the possibility of integration with existing television broadcasting networks and ensuring compatibility with various devices.
- **Data transmission optimisation:** Designing scenarios to optimise the transmission of television and audiovisual data, including the selection of suitable compression and encoding techniques.
- **Ensuring reliability:** Planning mechanisms for data backup and recovery in the event of an outage or failure.
- **Content security:** Investigating options for securing content broadcast using FeMBMS technology and protecting it against unauthorised access and piracy.

- **Analysis of legal and regulatory aspects:** Analysing the legal and regulatory requirements associated with the use of FeMBMS technology and ensuring compliance with relevant licensing policies.
- **Financial sustainability:** Determining the estimated costs associated with the deployment and operation of FeMBMS technology and ensuring the financial sustainability of the investment.
- **Spectrum utilisation optimisation:** Assessment of the possibilities and benefits of using the 600 MHz frequency band for TV broadcasting and simultaneous optimisation of its use within 5G networks (FeMBMS service).

5.1.1.1 Services provided

The following services were provided as part of the project:

- **Linear television programmes:** Distribution of two 24/7 live TV programmes, ARD and SWR Baden-Württemberg, via the 5G Broadcast network.
- **Linear radio programmes:** Addition of various SWR radio programmes to the range of linear services.
- **ARD/SWR Mediathek:** Access to on-demand content via a mobile network.
- **Geo-referenced recommendations ("Travelguide"):** Development of an app providing users with content recommendations based on their current location or planned route.

5.1.1.2 Technology

The project utilised a combination of technologies:

- FeMBMS (Release 14) and LTE-based 5G Terrestrial Broadcast (Release 16) for the efficient broadcasting of multimedia content.
- LTE Unicast for access to the ARD/SWR Mediathek and interactive services.

5.1.1.3 Equipment and infrastructure

The following infrastructure was used to implement the project:

- **Transmitters:**
  - 2 HPHT transmitters in Stuttgart and Heilbronn with an effective radiated power (ERP) of approximately 73 kW and 20 kW, which covered large areas and provided the main signal.
  - 4 LPLT transmitters located on mobile base stations, serving as repeaters to improve coverage in areas with weaker signals, particularly in urban and rural environments.
- **Antenna systems:** Circularly polarised antennas were used, which significantly improved signal reception in mobile devices and vehicles. This technology increases resistance to multipath propagation and reflections, contributing to reliable reception whilst on the move.
- **Signal transmission system:**
  - An SWR signal contribution system for HPHT transmitters, which ensured high-capacity and reliable transmission of content to the main transmission points.
  - On-channel repeaters for LPLT transmitters, which enabled signal repetition and amplification in areas with weaker coverage without the need for additional frequency resources.
- **LTE mobile network:** This was utilised for unicast services and access to on-demand content via the ARD/SWR Mediathek. This ensured the integration of traditional broadcasting with interactive services and applications.

5.1.1.4 Spectrum and frequencies

- **Bandwidth:** To optimise coverage and transmission quality, 5 MHz and 8 MHz bandwidth carriers were used on TV channel 40 (622–630 MHz). The increased bandwidth made it possible to boost data throughput and the quality of services provided to users.
- **Commercial LTE spectrum:** This was utilised for unicast services and access to the ARD/SWR Mediathek, enabling the provision of interactive and on-demand content alongside linear broadcasting.

5.1.1.5 Travelguide service

The development of the innovative Travelguide service demonstrated the potential for new forms of interaction with users via geo-referenced content. The aim of this service is to provide users with relevant content based on their location or route, thereby enhancing personalisation and the experience of using media services whilst travelling. The implementation involved the use of NLP algorithms to analyse audio tracks and video metadata from the ARD/SWR Mediathek, extract geodata and store it in a database accessible via an API. The service was integrated into vehicle infotainment systems, providing users with real-time recommendations. Users were thus able to access content related to their current location or planned route via the app.

The figure below shows a simplified block diagram of the information flow within the infotainment system. It illustrates how the Travelguide app, based on GPS and navigation data, recommends content from the ARD/SWR Mediathek that corresponds to the car's route, and how the Media2Go app suggests this content for playback on the car's infotainment system.

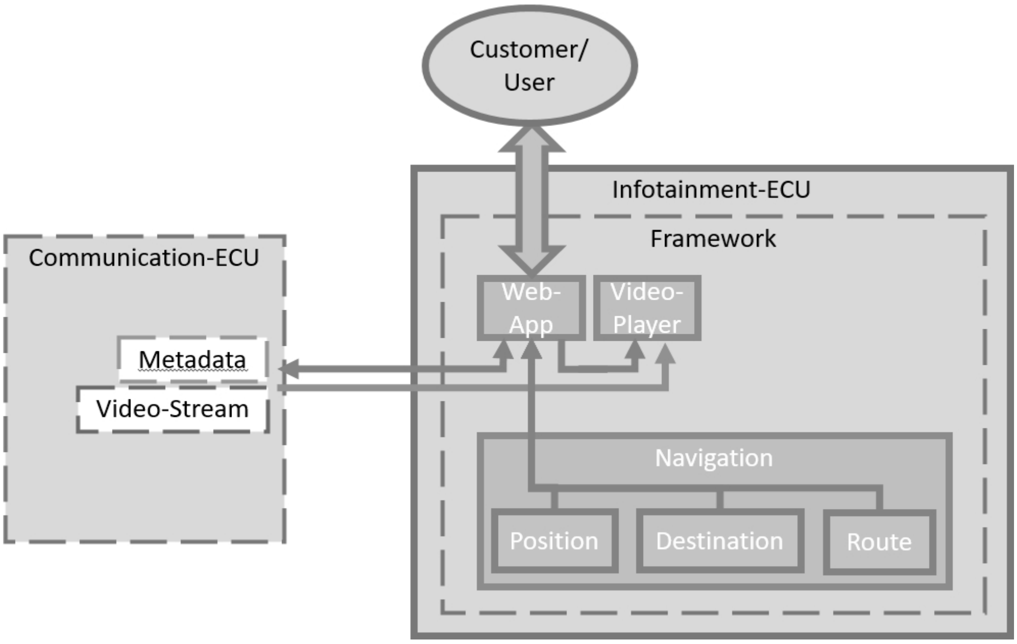

Figure 22: Simplified block diagram of the infotainment information flow Source:
https://drive.google.com/file/d/1CznXRhhNboNVvXVI6oTqiF2f6brlONxb/view

5.1.1.6 Summary and conclusions

During the 5G Media2Go project, extensive measurement campaigns were carried out, confirming the ability of FeMBMS technology to deliver high-quality content even at high speeds and under various geographical conditions. Stationary measurements were carried out at 18 locations, covering various geographical areas, and confirmed stable, high-quality signal transmission in a variety of environments. Mobile measurements included test drives on the A81 motorway between Stuttgart and Heilbronn, where transmission reliability was tested at speeds of up to 180 km/h. The results showed that FeMBMS technology is capable of providing uninterrupted, high-quality transmission even at high speeds.

Through an analysis of network parameters, various configurations – such as modulation and coding schemes (MCS), subcarrier spacing and bandwidth – were tested to optimise transmission and coverage. Optimal configurations for efficient data transmission were identified, including the selection of suitable compression and coding techniques, which led to the optimisation of transmission efficiency.

The 5G Media2Go project has thus successfully demonstrated the potential for using FeMBMS technology in 5G networks to deliver television and audiovisual services. The ability to deliver high-quality content even at high speeds and under various geographical conditions has been verified, confirming the reliability of transmission using FeMBMS technology. The successful integration of FeMBMS technology with existing 5G networks and devices confirmed its compatibility and interoperability.

The development of the innovative Travelguide service demonstrated the potential for new forms of user interaction through geo-referenced content, which opens up new possibilities for personalisation and enhances the value of the services provided.

The project has yielded valuable insights for the future deployment of FeMBMS technology in 5G networks, particularly in the provision of media services in mobile environments. The experience gained and the measurement results will be crucial for the planning and implementation of similar projects in other regions and may contribute to the further development of technologies for media content distribution.

5.1.2 5G Broadcast in Hamburg

The 5G Broadcast pilot project in Hamburg focuses on testing LTE-based 5G Broadcast technology in an urban environment. The project is led by the German public broadcaster Norddeutscher Rundfunk (NDR) in collaboration with Media Broadcast (MB). Two transmitters operating in Single Frequency Network (SFN) mode provide a signal for analysing the impact of network parameters on reception quality.

The 5G Broadcast project in Hamburg has several objectives. The first is to assess urban coverage, i.e. to test the provision of television and radio services using FeMBMS technology in densely populated urban areas. It also focuses on analysing network parameters, examining the impact of parameters such as modulation and coding schemes (MCS) and cyclic prefix length on reception quality, thereby providing important information for future network planning. The project also tests the compatibility of devices – namely FeMBMS-enabled receivers and terminals – to ensure interoperability and compatibility with various devices. Furthermore, it serves as an open platform for the development and testing of applications, enabling further testing and development in the field of video distribution and multimedia services for broadcasters.

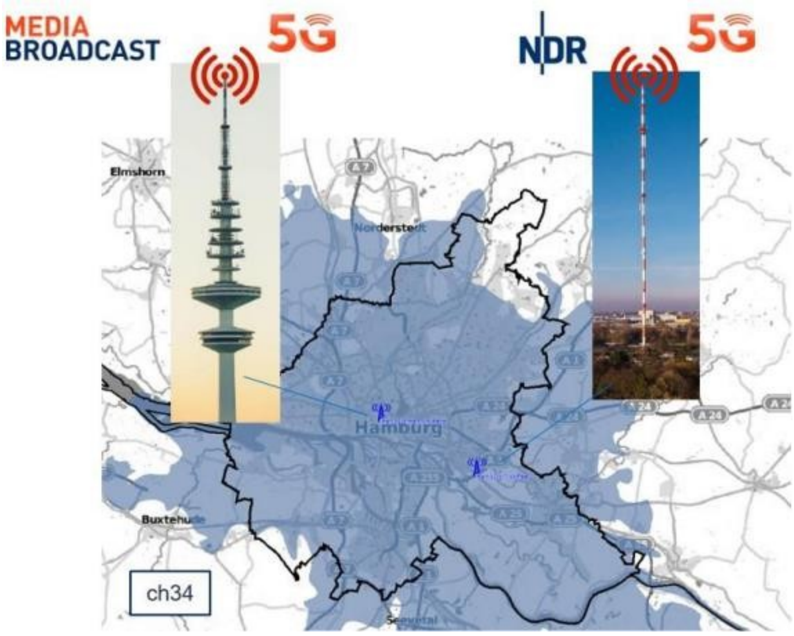

Figure 23: Coverage area

Source: https://tech.ebu.ch/docs/techreports/tr044.pdf

5.1.2.1 Services provided

The following services are provided as part of the project:

- 1 television service: Distribution of live television content.
- 2 radio services: Transmission of radio programmes via 5G Broadcast.
- Internet Link Service (ILS): A service enabling access to internet links.
- HbbTV: A hybrid television service combining broadcasting and broadband internet.

5.1.2.2 Technology

- LTE-based 5G Broadcast (FeMBMS): Technology enabling the efficient broadcasting of multimedia content over 5G networks.
- Single Frequency Network (SFN): The use of two transmitters in SFN mode to optimise spectrum utilisation and improve coverage.
- Virtual Digital Content Manager (VDCM) from Synamedia for content management and distribution.

- Broadcast Service & Control Centre (BSCC) from Rohde & Schwarz (R&S) and Enensys for broadcast network management.
- Transmitters from Rohde & Schwarz (R&S).

5.1.2.3 Equipment and infrastructure

The following infrastructure is being used to implement the project:

- **Transmitters:** Two transmitters with an effective radiated power (ERP) of 5 kW and 10 kW, located at the Hamburg-Moorfleet and Heinrich-Hertz-Turm transmission sites.
- **Playout centre:** Content is generated and processed at the NDR playout centre in Hamburg-Lokstedt.

5.1.2.4 Spectrum and frequencies

Broadcasting takes place on channel K34 (578 MHz) with a bandwidth of 5 MHz, with a planned expansion to 8 MHz to increase data throughput and service quality.

5.1.3 The 5G Today Project

The 5G Today project focuses on the distribution of media content via broadcast mode using mobile technologies. The aim of the project is to explore the possibilities for the efficient distribution of television and radio content via FeMBMS technology in 5G networks.

The 5G Today project successfully demonstrated the potential for distributing television content via FeMBMS technology in 5G networks. Prototypes of transmitters and receivers were developed and deployed, and a test site with high-power transmitters was established. Field measurements confirmed the ability of FeMBMS technology to provide high-quality mobile TV reception across large parts of the measured area. The project has yielded new insights into network parameters, antenna design and signal propagation models. The project results show that FeMBMS can achieve the performance characteristics of a conventional broadcasting system and offers an efficient and cost-effective solution for content distribution in 5G networks.

One of the objectives is the development and deployment of FeMBMS transmitters and receivers, which involves creating prototypes of these devices based on FeMBMS technology. Furthermore, the project aims to establish a FeMBMS-based transmission network in Upper Bavaria, which entails setting up a test bed utilising high-power transmitters to cover extensive areas. The third objective is to gain new insights into network parameters, antenna design and signal propagation models by analysing the impact of various parameters on reception quality and optimising the transmission network. The project also provides an open platform for the development and testing of applications, enabling broadcasters to further test and develop solutions in the field of video distribution and multimedia services.

5.1.3.1 Technology

FeMBMS was specified as part of 3GPP Release 14 in 2017 and enables:

- Support for greater distances between transmitters (200 μs cyclic prefix).
- A combination of MBMS/unicast transmission and dedicated MBMS transmission.
- A new subframe type for more efficient broadcasting.
- Receive-only mode and free-to-air capability.

5.1.3.2 Equipment and infrastructure

The following infrastructure was used to implement the project:

- **Transmitters:** Two high-power transmitters with an ERP of 100 kW, located in Ismaning and on Mount Wendelstein in Bavaria. The transmitters operate as a Single Frequency Network (SFN) on channels 56/57 (750–760 MHz).
- **Antenna systems:** Kathrein antennas optimised for mobile reception, integrated at the transmission sites.
- **Receivers:** Development of FeMBMS receivers based on Software-Defined Radio (SDR) technology using the Open Air Interface Toolkit.

5.1.3.3 Spectrum and frequencies

Broadcasting takes place on channel 56/57 (750–760 MHz).

5.1.4 IMB5

The Integration of Broadcast and Broadband in LTE/5G (IMB5) project focused on testing the capabilities and limitations of current LTE eMBMS technology for nationwide broadcast coverage. The project was funded by the Bavarian Research Foundation and took place in Munich and Erlangen, Germany.

The objectives of the IMB5 project were to test the capabilities and limitations of current LTE eMBMS technology for nationwide broadcast coverage in Germany, to develop an optimised system architecture for eMBMS-based networks, and to define proposals for amendments to the eMBMS standardisation within 3GPP.

5.1.4.1 Technology and test infrastructure

The project investigated the eMBMS broadcasting mode in LTE via two detailed SFN (Single Frequency Network) test networks in Erlangen and Munich. Potential improvements to existing broadcasting functions with a view to 4G/5G technologies were identified.

On the user equipment (UE) side, terminals from Qualcomm and Samsung, based on commercial chipsets, were used, primarily for tests at the application layer. For detailed tests at the physical layer, two different LTE SDR (Software Defined Radio) platforms from OpenAirInterface and National Instruments were deployed. These platforms enabled detailed experiments to be carried out with existing and future extended eMBMS waveforms beyond the scope of the standardised waveforms in 3GPP Release 12.

5.1.4.2 Project results

At the application layer, it was demonstrated that LTE eMBMS can be used to provide a flexible mix of unicast mobile broadband (MBB) and linear television broadcasting. For the nationwide deployment of eMBMS SFN networks, extensions to waveforms at the physical layer were recommended, such as increasing the cyclic prefix compared to currently standardised LTE signals. Another significant result of the project was the successful demonstration of the coexistence of LTE eMBMS with spectrally adjacent digital terrestrial television (DTT).

The IMB5 project successfully investigated the capabilities and limitations of current LTE eMBMS technology for nationwide broadcast coverage. Through detailed experiments at the physical and application layers, opportunities for optimising the system architecture of eMBMS networks were identified. The project provided important input for future revisions to the eMBMS standardisation within 3GPP, which may lead to improved performance and efficiency of networks for the distribution of broadcast content in LTE and future 5G networks.

5.1.5 Tower Overlay improving mobile network

During the NGMN Industry Conference & Exhibition in Frankfurt in October 2016, a demonstration was presented showing the benefits of using High Tower LTE Broadcast technology to improve mobile network performance.

The aim of the project was to verify the benefits of using high towers in LTE Broadcast to reduce the load on the mobile network during high usage of data-intensive services, such as live video, and to simulate a real-world mobile network scenario with the ability to serve users via three different network layers.

5.1.5.1 Technology and scenario

The demonstration utilised a mobile network simulation based on a real-world scenario in Hanover, where each user could be served by one of three network layers:

- **Standard LTE unicast layer:** Traditional mobile connectivity for individual data transfers.
- **Classic LTE Broadcast layer:** Broadcasting via standard LTE-A base stations using Rel-9 eMBMS technology.
- **Tower Overlay layer:** Use of the High Tower extension of LTE Broadcast (referred to as LTE-A+), where the signal can be transmitted from a high-altitude transmitter with much greater coverage and still be received on standard LTE devices.

5.1.5.2 Demonstration procedure

As part of a high-network-load simulation, intensive use of live video streaming was modelled, placing pressure on network capacity. As the number of users watching the live stream increased, the eMBMS layer was activated in the relevant cells, leading to a partial reduction in network load. As the load increased further, the Tower Overlay layer was activated, significantly reducing the load on the mobile network, as most LTE terminals switched the video service to this layer.

5.1.5.3 Results

The demonstration showed that the use of eMBMS, and in particular the Tower Overlay layer, can significantly reduce the load on the mobile network when there is high demand for the same content. Devices such as tablets automatically switched between the individual network layers in real time, without the user noticing any interruption or reduction in service quality. This multi-layer approach enables the optimisation of content distribution and improves overall network efficiency through the effective utilisation of network resources.

5.2 Austria

5.2.1 Vienna Field Trials in Austria

The Vienna Field Trials project in Austria focused on testing the performance of LTE-based 5G Broadcast technology (Release 14 and Release 16) in comparison with DVB-T2 and DAB+. The aim was to assess the maturity of infrastructure and receiver products, study use cases and applications, and support the development of the 5G broadcast ecosystem.

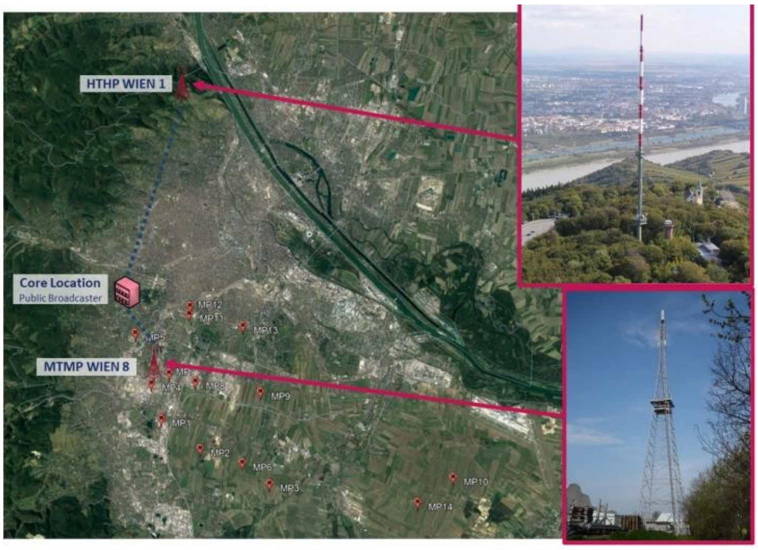

Figure 24: Test area, including transmission stations, key locations and the positioning of measurement points for stationary measurements Source:

https://www.ors.at/fileadmin/user_upload/ors/5G_Broadcast/PTD_21_012_Technical_implementation_status_of_5G_Broadcast_-_Vienna_Field_Trial_.pdf

The figure shows the test area in Vienna, which includes the locations of the Wien Kahlenberg and Wien Liesing transmission stations, the main sites of the core systems and the locations of measurement points for stationary measurements. The map provides an overview of the geographical distribution of the infrastructure used during the 5G Broadcast field trials, which aided the analysis of signal coverage and reception quality in various parts of the city.

Figure 25: Vehicles used for stationary measurements and measurements at high and low speeds for 5G Broadcast.

Source: https://www.ors.at/fileadmin/user_upload/ors/5G_Broadcast/PTD_21_012_Technical_implementation_status_of_5G_Broadcast_-_Vienna_Field_Trial_.pdf

The figure shows the vehicles used for 5G Broadcast measurements in Vienna. The vehicles were equipped with measurement equipment and antennas to carry out stationary measurements, as well as measurements at various speeds. Thanks to these vehicles, engineers were able to carry out signal reception tests both whilst stationary and whilst moving in urban traffic, at both low and high speeds, which enabled them to obtain comprehensive data on the performance of the 5G Broadcast network under real-world urban conditions.

The main objectives of the project were to assess the performance of LTE-based 5G Broadcast (Releases 14 and 16) compared with DVB-T2 and DAB+, to study the maturity of infrastructure and receiver products in collaboration with manufacturers, to evaluate use cases and applications, and to support the development of the 5G Broadcast ecosystem, as well as to foster the evolution of this ecosystem through the development and provision of open-source receivers for testing and application development.

5.2.1.1 Technology and infrastructure

- **Technology:** FeMBMS (Release 14) and LTE-based 5G Terrestrial Broadcast (Release 16).
- **Infrastructure:**
  - 2 HPHT (High Power High Tower) transmitters at the Wien Kahlenberg and Wien Liesing sites.
  - 2 core systems.
  - Receivers:
    - Open-source OBECA (Open Broadcast Edge Cache Appliance) receiver and 5G-MAG Reference Tools.
- **Spectrum/frequency:**
  - 739 MHz, 10 MHz bandwidth until 1 July 2020.
  - 667 MHz, bandwidth 8 MHz (Kahlenberg) and 10 MHz (Liesing) from 1 July 2020.
  - 640.5 MHz, 5 MHz bandwidth (Liesing) from 1 February 2022.

5.2.1.2 Project results

Between 2020 and 2021, the project focused on comparing simulations and measurements of FeMBMS Release 14/16 with DVB-T2 and DAB+, and on the technical evaluation of the use of 5G Broadcast for various services and applications. The results of this phase were summarised in a document submitted to CEPT.

In the second phase of the project (2021–2023), the project is concentrating on investigating hybrid use cases of 5G Broadcast and broadband connectivity, and on the further development of the 5G Broadcast ecosystem. In 2021, the smallest open-source 5G Broadcast receiver, OBECA, was developed and is now part of the 5G-MAG Reference Tools. In February and March 2022, the first reception tests were carried out using 5G Broadcast-enabled smartphone-style devices in an HPHT test environment.

The Vienna Field Trials project demonstrated that 5G Broadcast-enabled devices can be used for portable outdoor reception and significantly extend the reach of terrestrial broadcasting. 5G Broadcast technology has achieved performance comparable to DVB-T2 and enables innovation and new business models in terrestrial broadcasting thanks to its IP nature and ability to transmit standard OTT streams.

Although 5G Broadcast is at an early stage of development and requires further refinement for full operational deployment, the results support the continued use of spectrum below 700 MHz for broadcasting services until 2030 and beyond. This provides broadcasters with new opportunities for innovation and for extending services to mobile devices, thereby significantly increasing the number of potential users.

5.3 Italy

5.3.1 5G TOURS LTE-based 5G Broadcast Trial in Turin

The 5G TOURS LTE-based 5G Broadcast Trial project in Turin, Italy, focused on delivering 5G broadcast services to a wide audience via High-Power High-Tower (HPHT) infrastructure. The main objective was to study the performance of the 5G broadcast signal in a mobile environment (in-car scenario) and in urban outdoor conditions, to improve the video user experience, and to distribute audiovisual content and services to a potentially unlimited number of users.

The project's objectives were to provide 5G broadcast services to a mass audience using HPHT infrastructure, to study the performance of the 5G broadcast signal in a mobile environment (in-car scenario) and in urban outdoor conditions (coverage analysis), to enhance the video user experience through advanced technologies, and to distribute audiovisual content and services to a potentially unlimited number of users.

5.3.1.1 Technology and infrastructure

- **Technology:** FeMBMS (Release 14) and LTE-based 5G Broadcast (Release 16).
- **Infrastructure:**
  - One HPHT transmitter.
  - EnTV/EPC core from Rohde & Schwarz.
  - Hardware and software-defined receiver (SDR) from Rohde & Schwarz and iFN.
- **Frequency spectrum:** VHF channel 11 (216–223 MHz, centre frequency 219.5 MHz)

5.3.1.2 Description of use cases

The 5G-TOURS project has implemented several use cases aimed at enhancing the tourist experience through 5G technologies:

- **Enhanced tourist experience:** Development of an XR (Extended Reality) platform that provides tourists with an enhanced and interactive experience using AR/VR applications both inside and outside the Palazzo Madama museum, and an interactive wall at the GAM museum for children and students.
- **Robotic museum guides and telepresence:** Deployment of robots in museums that can act as guides or facilitate remote tours for users who cannot be physically present. The robots also provide tele-surveillance of the museum both day and night.
- **Distribution of high-quality video services:** Providing high-quality educational and informative content to tourists via smartphones, tablets or VR devices. Utilising multicast and broadcast technologies for the efficient distribution of content to a large number of users.
- **Remote and distributed video production:** Testing the production of live events, such as a multi-location music concert, where musicians perform at different venues and their performances are combined via a 5G network in real time.

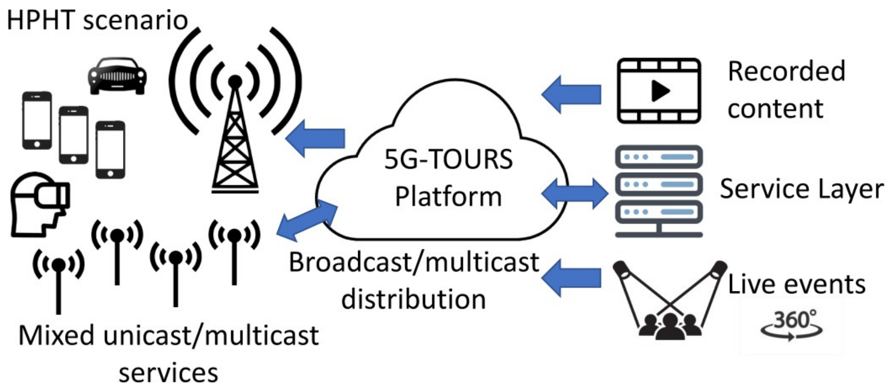

Figure 26: Distribution of video services via broadcasting

Source: https://5gtours.eu/documents/publications/Globecom2020_Touristic_City%20(1).pdf

The figure illustrates an approach focused on the broadcast of large-scale multimedia services using High-Power High-Tower (HPHT) infrastructure, as shown in the figure. This scenario utilises LTE-based 5G Terrestrial Broadcast technology, which enables one-way video broadcasting (downlink-only) to all devices simultaneously, regardless of the number of connected users.

5.3.1.3 Project results

The 5G TOURS LTE-based 5G Broadcast Trial project in Turin focused on studying the performance of the 5G broadcast signal in a mobile environment and in urban outdoor conditions. Reception tests were carried out in a car and an analysis of coverage within the city was conducted, demonstrating the ability of 5G Broadcast technology to deliver high-quality audiovisual services to a large number of users via HPHT infrastructure.

The roll-out of 5G networks has enabled the implementation of new services requiring high transmission capacity, low latency and high reliability, which has significantly improved the user experience of video and interactive applications. Tests showed that the 5G broadcast signal can effectively cover urban areas even during mobile reception, thereby improving the quality of service for users.

The project also demonstrated how 5G technologies can drive innovation in the tourism sector and open up new business models in the field of terrestrial broadcasting. This significantly increases the potential for extending services to mobile devices and reaching a wider audience.

5.3.2 Tower Overlay testing in the Aosta Valley

In April 2015, Rai CRIT launched an experimental trial in the Aosta Valley, aimed at evaluating the performance of the TOoL+ system, a solution based on the evolution of LTE-A+ (4G) technology, which enables data transmission to mobile devices using cost-effective High-Tower High-Power (HTHP) infrastructure.

The project aimed to verify the performance of the TOoL+ system in a real-world environment and to measure the impact of various LTE-A+ transmission parameters for effective TOoL+ network planning. It also involved investigating data transmission via DVB-T2 and LTE-A+ signals and ensuring mobile and high-capacity services using Unicast, eMBMS and TOoL+ technologies.

5.3.2.1 Technology

- **LTE-A+ (Advanced)** – an evolutionary LTE technology for efficient data distribution.
- **High-Tower High-Power (HTHP)** – a cost-effective infrastructure for wide-area broadcasting.
- **Software Defined Radio (SDR)** – software-defined radio technology used to generate and receive TOoL+ signals.

5.3.2.2 Equipment and infrastructure

- TOoL+ utilises SDR to transmit DVB-T2 and LTE-A+ signal data streams, which are implemented in Future Extension Frames (FEFs).
- Signal transmission using the first version of the live TOoL+ demonstrator.
- Measurements were carried out in urban, suburban and rural areas, as well as on motorways.

- **Frequencies/spectra:** Channel 53 (730 MHz) with the option to use up to five transmitters simultaneously on the same channel within the network.

5.4 United Kingdom

5.4.1 Project: 5G RuralFirst

The 5G RuralFirst project is one of the main projects funded by the UK government as part of the 5G Trials and Testbeds programme, which aims to enhance rural connectivity and harness the benefits of 5G technology for various industrial sectors, including agriculture, broadcasting and public services. The project is led by Cisco, with the University of Strathclyde as the lead partner. The project aims to test new ways of deploying 5G in challenging geographical conditions, such as rural areas of the United Kingdom, and to develop business models for the sustainable roll-out of 5G technology in these locations.

The primary test areas include the Orkney Islands, Shropshire and Somerset. The project combines spectrum sharing for 5G, brings connectivity to rural communities and enables ‘smart farming’ in collaboration with the Agri-EPI Centre. Other innovations include the use of drones, autonomous agricultural machinery and remote veterinary inspections. The project also involves collaboration with the BBC on innovative ways of broadcasting radio via the 5G network. In addition, 5G RuralFirst offers Internet of Things connectivity for public services and other sectors in these rural areas.

One of the main use cases is the delivery of radio broadcasts via 5G, in collaboration with the BBC, which is exploring how 5G technology can replace traditional broadcasting methods. The BBC believes that delivering radio content via the internet will become increasingly important in the future. As part of this trial in the Orkney Islands, the BBC is testing 5G’s capabilities for broadcasting both traditional radio and new forms of audio content.

5.4.1.1 Services and technologies

The 5G RuralFirst project offers a range of services and implements advanced technologies to achieve its objectives, including:

Service provision:

- Broadcasting 13 live BBC Radio stations directly to end users.
- BBC Radio on-demand services.
- General internet access for rural communities.

Technology:

- **3GPP Rel-12 eMBMS and LTE unicast:** These technologies are used to broadcast radio services and other content services. Rel-12 eMBMS is an efficient solution for delivering multimedia content to multiple users via mobile networks.
- **3GPP Rel-14/15 FeMBMS:** A more advanced version of the eMBMS specification, enabling content distribution via LTE and 5G networks. These technologies enable the use of 5G Terrestrial Broadcast for rural areas.
- **Software-Defined Radio (SDR):** A base station that utilises the flexibility of SDR to optimise signal transmission and distribution in rural areas.
- **eMBMS-compatible mobile devices:** Members of the public in the test locations were provided with mobile phones and smart devices supporting 5G and eMBMS so that they could receive radio broadcasts.
- **Custom-designed FPGA-based 5G Broadcast modem:** Modems designed specifically for this project implement the latest mobile broadcasting features that are not available in standard commercial devices.

Frequency and spectrum

- The project utilised the 700 MHz frequency (3GPP Band 28), which was used for signal propagation and the transmission of multimedia content.

Figure 27: OWC link to a solar cell Source: https://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=8696679

This figure shows the test environment at the King's Buildings Campus, University of Edinburgh, where an optical wireless link (OWC) with a solar cell was tested. A 20 cm × 20 cm solar panel receives data at a rate of 20 Mbps over a distance of 80 metres.

Figure 28: Deployment of OWC technology as part of the RuralFirst project

Source: https://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=8696679

The image shows the deployment of OWC technology at Hoy High Lighthouse on the island of Graemsay, which connects the optical network on the Orkney mainland to nearby homes using solar-powered OWC transceivers. This technology enables wireless data transmission in areas where traditional infrastructure is lacking.

5.4.1.2 Results

The 5G RuralFirst project has demonstrated the viability and reliability of 5G technology for rural areas that have traditionally been neglected in terms of communications infrastructure. Tests have unequivocally shown that 5G transmission can effectively cover vast and hard-to-reach areas where there is otherwise insufficient mobile network connectivity. The SDR base stations ensured stable and reliable coverage, delivering a high quality of service to the public. This technology was well received by users and has raised hopes for the long-term roll-out of advanced communications technologies in rural areas.

The project also demonstrated that 5G technology can bring about fundamental changes in access to essential services, such as radio broadcasting and high-speed internet. As 5G enables the direct delivery of multimedia content to mobile devices, it significantly improves the quality of life for rural residents who have previously had to rely on less reliable forms of connectivity.

In addition to the benefits for communications, the project highlighted the potential of 5G technology for new industrial applications, such as smart farming. Through the integration of technologies such as drones and autonomous agricultural vehicles, 5G offers opportunities to increase efficiency in agriculture and improve its sustainability. The project also enabled research into remote veterinary inspections and IoT solutions for public services, thereby opening up new avenues for technological innovation in these areas.

5.5 Finland

5.5.1 Wireless for Verticals – WIVE

The WIVE (Wireless for Verticals) project focuses on the development of 5G technologies and their application in various industrial sectors, known as ‘verticals’. Its main objective is to enhance competitiveness in areas such as automated transport, smart energy grids, massive machine connectivity and media distribution. The project, funded by the Finnish government through the Tekes agency, involves a wide range of partners from industry and academia, including Nokia Bell Labs, Telia, ABB, Digita and several leading Finnish universities.

The project focuses on 5G technologies, which offer significant benefits to various sectors, whilst also emphasising the development of business models for their effective application. WIVE’s aim is to support sectors where reliable and scalable connectivity is a fundamental element.

5.5.1.1 Main objectives of the project

- **Support for vertical sectors:** The project aims to increase commercial value and technological progress in sectors such as automated transport, smart grids and massive machine connectivity. It analyses and tests new technological possibilities that can be effectively utilised via 5G networks.
- **Commercial aspects:** As part of the work package dedicated to commercial aspects, the project analyses opportunities, new models and scenarios that may arise from the deployment of 5G technologies. The aim is to create profitable and widely applicable business models.
- **Media and entertainment:** The project also focuses on the media and entertainment sector. Test cases include the broadcasting of television and radio content via mobile networks, which represents an innovative method of media distribution. Particular emphasis is placed on the broadcasting of national official announcements and emergency alerts, which can be widely distributed via multicast.

5.5.1.2 Technological Approach

The WIVE project studies and tests new approaches to wireless connectivity, focusing on the challenges posed by the deployment of 5G networks in vertical sectors. The main technological elements include:

- Single Frequency Network (SFN) – The project is investigating the use of mobile networks for the distribution of TV and radio content, which is currently broadcast via dedicated broadcasting networks. The emphasis is on the Single Frequency Network (SFN), which transmits simultaneously via several transmitters on the same frequency, thereby optimising coverage at a national level.
- Signal robustness and throughput – Another aspect is finding a balance between signal robustness and throughput using various modulation schemes (MCS). This is particularly important for ensuring high signal quality and low latency under various conditions, such as high data transmission rates or user mobility.
- Mobility management – The project also addresses challenges associated with user mobility, such as seamless handover between different mobile network cells. This is essential for ensuring uninterrupted connectivity when switching between base stations.

5.5.2 5GTN+ Project

The 5GTN+ (5G Test Network Plus) project was launched with the aim of testing and developing advanced 5G technologies that will enable innovation across various sectors, known as verticals. Led by the University of Oulu and VTT Technical Research Centre of Finland, the project involved collaboration with more than 20 industrial partners. The main objective of the project was to create a scalable platform for testing new 5G technologies, exploring business models and delivering services in a real-world environment. One of the cornerstones of the project was the testing and validation of eMBMS technology for the distribution of content, such as TV and radio, directly to end users.

The vertical use cases included in the project were:

- Healthcare, wellbeing and fitness
- eHealth in hospitals and via mobile apps
- 5G-enabled digital factory
- Media production and distribution

The project brings together various 5G initiatives under the umbrella of 5G Test Network Finland (5GTNF) and provides a unique, innovative platform for testing technologies, services and applications in industrial sectors such as media, industrial applications, smart grids and transport.

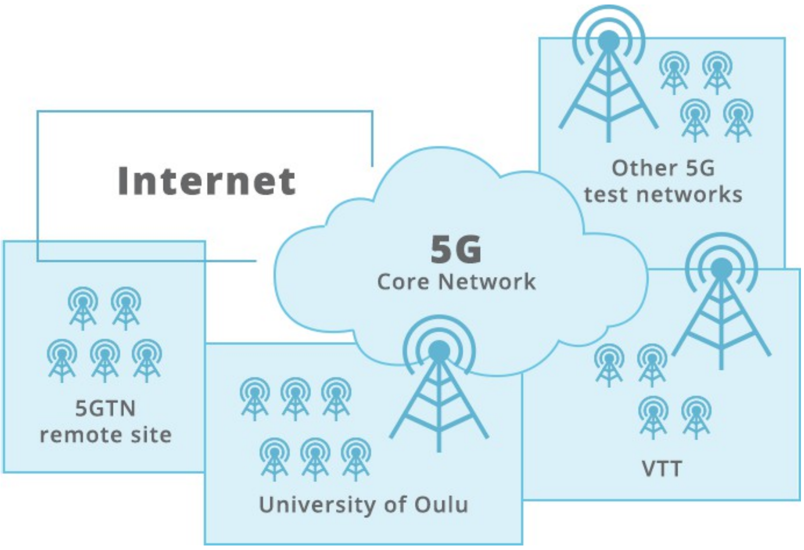

Figure 29: Structure of the 5G test network in the 5GTN+ project

Source: https://5gtn.fi/overview/

This figure illustrates the structure of the 5G test network within the 5GTN+ project, which connects various test networks and research organisations via a 5G backbone network. The main nodes are the University of Oulu, VTT and the 5GTN remote site, which are connected to the 5G core network and linked to the internet and other 5G test networks.

5.5.2.1 Technology:

As part of the 5GTN+ project, various 5G technologies focused on media distribution and supporting new industrial applications were tested:

- **eMBMS (Evolved Multimedia Broadcast Multicast Service):** This technology is designed for the efficient distribution of large volumes of data, particularly media content, over mobile networks. In the 5GTN+ project, it was implemented in the test network in Oulu and demonstrated high reliability and low latency when transmitting media content.
- **Unicast uplink and content distribution:** 4K streams (H.264) were also tested via a unicast uplink, enabling the transmission of media data from Oulu to Espoo via a fibre-optic link with a throughput of up to 130 Mbit/s. This technology ensures high-quality media transmission not only for consumers but also for industrial applications such as smart factories and healthcare.
- **Low latency and high transmission capacity:** 5G technology enables data transmission with very low latency, which is crucial for industrial applications and the transmission of live content. In Oulu, these technologies were tested for real-time broadcasting.

- **Light Path Backbone Network:** The project has developed a backbone network based on light paths, which connects all 5GTNF projects. This network ensures fast and efficient data distribution between remote locations with high throughput.

5.5.2.2 Results and Conclusion

The 5GTN+ project yielded several significant results that demonstrated the potential of 5G technologies for media distribution and industrial applications. Testing of eMBMS technology has shown that it can efficiently distribute media content to a large number of users with minimal bandwidth requirements. This enables media service providers to ensure high-quality transmission without overloading the network.

During unicast uplink tests between Oulu and Espoo, throughput of up to 130 Mbit/s was achieved. At the same time, 5G technology offers low latency, which is essential for real-time broadcasting and applications requiring rapid response times. The 5GTN+ project demonstrated that 5G technology can effectively support industrial applications, particularly in the fields of smart grids and the IoT, with minimal costs and high reliability. Testing involved the real-time transmission of data from industrial sensors and devices.

A significant achievement of the project was the creation of an innovative platform that enabled the interconnection of various projects via optical links. This platform was crucial for extensive testing of 5G technologies in real-world environments and offers new opportunities for research, development and deployment across industrial sectors and services.

Overall, the 5GTN+ project served as a validation platform for theoretical 5G research, with an emphasis on practical applications across various vertical sectors. The research and testing led to the commercialisation of solutions in the fields of care, wellbeing, eHealth, digital factories and media distribution, demonstrating the broad potential of 5G technologies for both industry and consumers.

5.5.3 5G eMBMS Demo

The project took place in 2018 at Nokia's headquarters in Karaportti, Finland. The main objective of the project was to demonstrate the capabilities of 5G networks to provide broadcast-like services and to promote their use for the distribution of multimedia content. The event was attended by representatives from the media and telecommunications industries, government ministries, the press, and organisations such as the EBU (European Broadcasting Union). The key demonstration involved the transmission of high-quality DASH (Dynamic Adaptive Streaming over HTTP) streams to mobile devices via a 5G network operating in the 2.9 GHz band. Project participants included major technology partners such as Nokia, Qualcomm and Enensys, as well as media companies Yle and MTV, and the telecoms operator Elisa.

5.5.3.1 Technology

The following technologies were tested as part of the 5G eMBMS Demo project:

- **LTE enTV (enhanced TV):** A technology that enables the broadcasting of digital television over mobile networks. Standardised as part of 3GPP Release 14, this technology delivers improvements in terms of broadcast capacity, coverage and deployment flexibility. LTE enTV supports both mobile and fixed devices and enables broadcasting without the need for SIM cards or service subscriptions, facilitating convergence between traditional television broadcasting and mobile networks.
- **eMBMS (Evolved Multimedia Broadcast Multicast Service):** eMBMS is a technology developed for the efficient distribution of multimedia content over mobile networks. It enables operators to distribute content to a large number of users via a single frequency without placing an excessive load on the network. eMBMS has proven to be essential for the provision of broadcasting services over mobile networks.
- **The 2.9 GHz band:** The band in which the technology was tested is important for the deployment of broadcasting services within 5G networks. Transmissions took place via the low-frequency spectrum, which ensures stable and high-quality broadcasting of media content.
- **Multiple devices receiving DASH streams:** The testing involved the real-time distribution of DASH streams to multiple mobile devices, with these devices capable of receiving broadcasts with high-quality picture and sound. The demonstration confirmed that 5G networks are capable of distributing content to a mass audience.
- **Support for SIM-free devices:** As part of the LTE enTV technology, the possibility of streaming to devices that do not require a SIM card or subscription was tested, opening up new possibilities for the digital distribution of television broadcasts directly to mobile devices.

5.5.3.2 Results

The 5G eMBMS Demo project yielded several results that demonstrated the capabilities of 5G networks and their technology for broadcasting and distributing multimedia content. Testing showed that eMBMS technology effectively distributes media content to a large number of devices without placing a significant load on the network, enabling service providers to achieve high-quality broadcasting without the need for additional bandwidth. The demonstration involved the distribution of high-quality DASH streams with high video and audio quality via a 5G network to various mobile devices, confirming the technology's ability to deliver broadcasts on a mass scale with minimal latency and high transmission stability.

Another significant advantage of this technology is its ability to simultaneously distribute content to large screens and mobile devices via a single network, opening up new possibilities for content providers. Testing also revealed that it is possible to stream digital content to devices without a SIM card or subscription, thereby expanding the possibilities for distributing content to a wider audience. Furthermore, the project demonstrated that LTE enTV and eMBMS technologies could, in the future, replace traditional digital terrestrial television (DTT) broadcasting, paving the way for the use of 5G networks as a new platform for the mass-scale delivery of media services.

In conclusion, the 5G eMBMS Demo project clearly demonstrated that 5G and eMBMS technologies have great potential for the distribution of multimedia content and can replace traditional digital television broadcasting systems. It has been proven that 5G networks are ready to provide high-capacity, high-quality broadcasting services not only to mobile devices but also to large screens. This technological advance opens up new opportunities for media companies, content providers and mobile network operators, whilst offering users greater quality and flexibility when viewing content.

5.6 Norway

5.6.1 Trial of LTE-B in rural Norway

The LTE-B project in Norway focused on testing LTE Broadcast (LTE-B) technology for the distribution of linear television to large television screens via 4G or 5G networks. The main objective of the project was to determine whether LTE-B technology could be used effectively in remote rural areas not covered by satellite or DTT signals. This project took place in Norway, where approximately 0.26 per cent of households live in so-called ‘shadow’ areas without coverage from standard television signals. The project also focused on the possibilities for commercial implementation and the potential benefits for the provision of broadband access and the expansion of emergency network coverage.

5.6.1.1 Technology

The following technologies and methods were used as part of the project:

- **LTE-Broadcast (LTE-B):** A technology for distributing linear television via 4G or 5G mobile networks. In this project, it was used to distribute television channels in remote areas without traditional DTT coverage.
- **Frequencies:** The 758–778 MHz frequency band was used for the downlink and the 708–718 MHz band for the uplink.
- **Transmitters:** 40 W transmitters were used, which enabled effective coverage of the test areas.
- **Signal distribution:** The main method of signal distribution was the DVB-T system, although the possibility of distribution via the internet was also tested.
- **Transmission rates:** Each of the NRK channels was broadcast in HD quality at a bitrate of 4–5 Mbit/s.

5.6.1.2 Results

The LTE-B project in Norway yielded several results. Above all, it confirmed that LTE-B technology is capable of effectively distributing television content to remote areas where traditional satellite or DTT coverage cannot be provided. The tests showed that it is possible to deliver up to four NRK channels in HD quality without placing a significant load on the network. LTE-B technology has also made it possible to reduce the costs of signal distribution in these ‘shadow’ areas, which could lead to significant savings in the future.

The project also verified the commercial feasibility of transitioning from traditional DTT broadcasting to LTE-B in collaboration with mobile operators, government bodies and other partners. In addition to television signal distribution, the project investigated whether LTE-B could also be used to expand broadband access and improve emergency communications in these remote areas.

Overall, the project demonstrated that LTE-B can be a viable alternative to traditional broadcasting systems and can open up new possibilities for service provision in hard-to-reach areas.

5.7 France

5.7.1 Tower Overlay

In 2015, TDF and RAI launched the first field trials of LTE-Advanced+ (LTE-A+) Broadcast technology from a high-power television transmitter in Paris. This project, based on the 'Tower Overlay' concept developed by the Technical University of Braunschweig in 2013, aimed to explore the possibilities for convergence between the LTE ecosystem and traditional broadcasting infrastructure. The basic principle of the project was to transmit digital media and television broadcasts using LTE technology, which would enable content to be shared with both mobile devices and domestic television sets without the need for dedicated receivers in mobile phones.

5.7.1.1 Technology

- **LTE-Advanced+ (LTE-A+) Broadcast:** The test utilised an experimental version of LTE-A+ technology, which was designed to improve media and video transmission over mobile networks. This technology, implemented prior to standardisation as part of 3GPP Release 14 EnTV, included features such as a larger Cyclic Prefix (CP), which enables high-power transmitters (High Tower/High Power) to transmit the eMBMS signal efficiently.
- **Transmission from the Eiffel Tower:** For the tests in Paris, a transmitter on the Eiffel Tower was used, broadcasting on an experimental frequency in the 700 MHz band (channel 54). The aim was to demonstrate the technology's ability to aggregate a wide range of digital content, such as live television broadcasts, video on demand, live radio, podcasts, news and software updates. All content was broadcast to mobile devices and stored for later access by the user. This approach significantly reduced the load on the LTE unicast network.
- **Channel sharing between DVB-T2 and LTE-A+:** One of the key aspects of the Tower Overlay technology was enabling time-division multiplexing of the transmission channel between traditional HDTV signal broadcasting via DVB-T2 and mobile data transmission via LTE-A+. This method of transmission allows for the efficient use of a single transmission channel for different types of devices.

Table 2: Transmission parameters tested during field trials for DVB-T2 and LTE-A+

Parameter	DVB-T2	LTE-A+
Carrier frequency	738.166 MHz	738.166 MHz
Bandwidth	8 MHz	8 MHz
Transmission power	2.7 kW ERP	2.7 kW ERP (vertical polarisation)
TDM (time division) ratio	50% / 0%	50% / 100%
Subcarrier spacing	558 Hz	2.5, 7.5 or 15 kHz
Guard interval / Cycle prefix	266 µs	100 µs, 3.3 µs or 16.67 µs
FFT size	16K	6144, 2048 or 1024
Modulation	64 QAM	QPSK (PMCH 1 & 2), 16-QAM (PMCH 3), 64-QAM (PMCH 4)
Coding ratio	0.5	0.28 (PMCH 1), 0.49 (PMCH 2), 0.51 (PMCH 3), 0.43 (PMCH 4)

Source: https://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=7521952

The table summarises the transmission parameters tested during field trials, for both the DVB-T2 and LTE-A+ components of the hybrid signal. LTE-A+ comprises a multiplex of four so-called physical multicast channels (PMCHs) which, similar to the physical layers in DVB-T2, allow for different levels of robustness for individual services on the same LTE-A+ carrier. This is achieved by using different modulation and coding schemes (MCS). This concept allows for the simultaneous evaluation of different modulation and FEC (Forward Error Correction) settings under given channel conditions.

For measurement purposes, a combined transmission configuration of DVB-T2 and LTE-A+ signals was selected, which enables spectrum sharing whilst using DVB-T2 as the reference signal. Three different subcarrier frequencies (f_Δ) for LTE-A+ were tested in the scenarios: 15 kHz (K = 1), 7.5 kHz (K = 2) and 2.5 kHz (K = 6). A scenario with LTE-A+ (without DVB-T2) was also selected for hybrid transmission, which included a subcarrier frequency of f_Δ = 2.5 kHz. The parameters for DVB-T2 were derived from previous tests carried out in northern Germany, where they were recommended as a suitable mode for the roll-out of DVB-T2.

5.7.1.2 Results

The tests in Paris yielded a number of significant results, highlighting the potential of LTE-A+ Broadcast technology for convergence between mobile and traditional broadcasting networks. During the trials, it was demonstrated that a single transmitter can simultaneously serve both mobile devices and traditional televisions without the need for a specific receiver on the part of mobile users. Mobile users were able to receive and download various types of multimedia content, including live television broadcasts.

The testing also demonstrated that this technology has the potential to reduce the energy consumption and operating costs of both broadcast and mobile networks, thanks to the ability to share broadcast infrastructure and spectrum. The results of the field trials included extensive measurements of waveform performance, which were used to further refine the LTE-A+ technology and the Tower Overlay system, and contributed to the development of an efficient mobile broadcasting system.

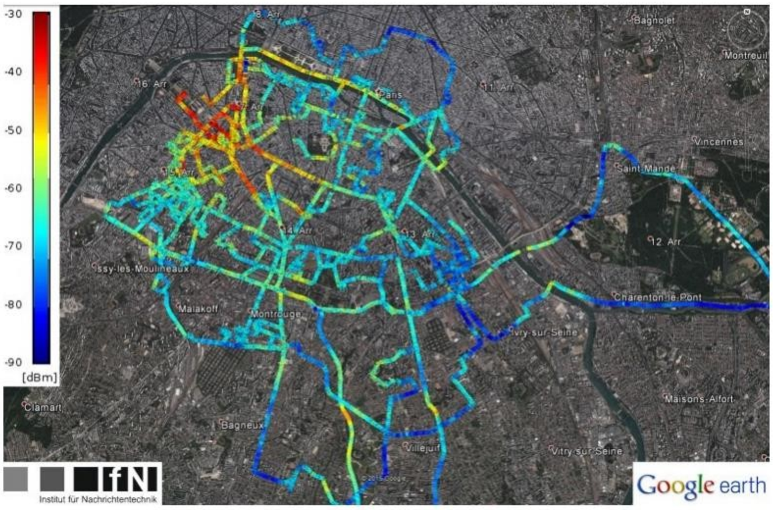

Figure 30: Overview of receiver input power levels measured during a field trial in central and south-eastern Paris Source:

https://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=7521952

The figure shows the input power levels of the LTE-A+ signal received during a field trial in central and south-eastern Paris. The data was collected using GPS information and timestamps to synchronise the results from different parts of the receiver. The results are displayed on a map using KML files for Google Earth, enabling the visualisation of signal performance characteristics depending on the receiver's location and mobility within the area. The figure demonstrates how signal strength varies across different parts of Paris based on distance from the transmitter and local conditions.

5.8 European projects

5.8.1 5G Broadcast of the Eurovision Song Contest

During the 2022 Eurovision Song Contest, the signal was broadcast live using 5G Broadcast technology from several major European cities – Paris, Stuttgart, Turin and Vienna. This event provided an ideal opportunity to showcase 5G Broadcast technology, which enables live broadcasting to mobile devices without the need for a SIM card or subscription. During the trial broadcast, the signal was available only to a limited number of users with 5G Broadcast-compatible phones. The main aim of the project was to demonstrate the potential of 5G Broadcast technology for distributing media content to a mass audience and its benefits for media companies and their infrastructure.

5G Broadcast technology enables the efficient delivery of live broadcasts to a large number of users whilst reducing the load on existing mobile networks. The traditional method of distributing live broadcasts via mobile networks can cause congestion during major events, such as the Eurovision Song Contest, when millions of viewers are watching simultaneously. 5G Broadcast offers a solution to this problem through 'one-to-many' technology, which allows content to be transmitted to many devices at once without the need for individual data transfers. Furthermore, it allows users to receive live content without the need for a SIM card or registration with mobile service providers. This free and openly accessible model opens up new possibilities for consuming media content whilst providing a more efficient and less resource-intensive distribution infrastructure.

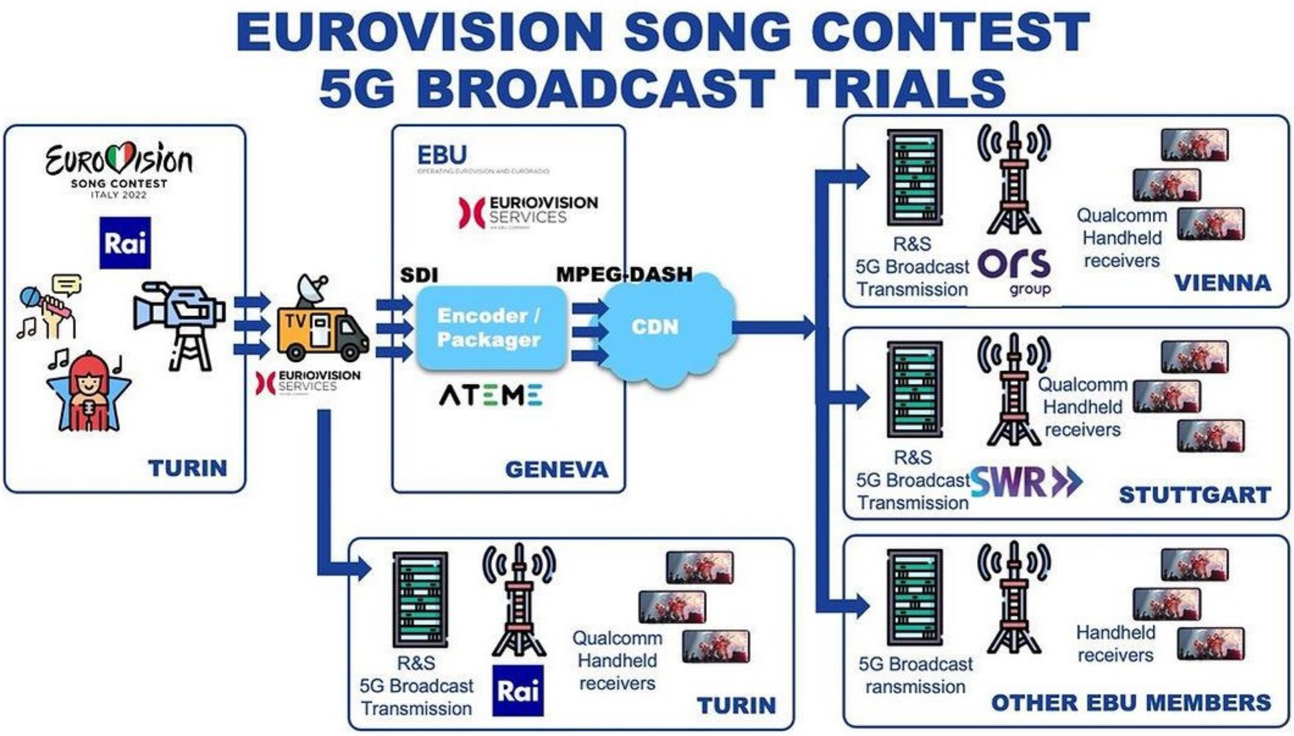

Figure 31: Diagram of the 2022 Eurovision Song Contest broadcast using 5G Broadcast technology

Source: https://www.5g-mag.com/post/multi-site-5g-broadcast-trials-during-eurovision-song-contest-in-italy-austria-france-and-germany

The figure illustrates the process of transmitting the live broadcast of the 2022 Eurovision Song Contest via 5G Broadcast technology in four European cities: Turin, Vienna, Stuttgart and Paris. The signal was generated by the Italian broadcaster RAI in Turin and then delivered to the Eurovision Services headquarters in Geneva, where an Ateme encoder converted it into MPEG-DASH format for distribution. The signal was then sent via a CDN to broadcast facilities in each city, where it was retransmitted using Rohde & Schwarz broadcast systems. Users with prototype Qualcomm phones in these locations were able to watch the live broadcast without the need for a SIM card or registration. This diagram summarises the collaboration between European broadcasters and technology partners in demonstrating the capabilities of 5G Broadcast technology for content distribution to mobile devices.

5.8.1.1 Technology

- Based on the features of the 3GPP Release 16 standard.
- Operates in 'Receive-Only Mode' (ROM) – for reception only, without the need for a return channel.
- Users do not need a SIM card or access to a mobile network to receive the signal.
- It enables freely accessible media content without the need for registration.
- It utilises the existing digital terrestrial television broadcasting infrastructure.
- It extends the reach of traditional broadcasting to mobile devices.
- Suitable for media transmission, emergency warning systems and applications in the automotive industry.
- It distributes content without overloading mobile networks, whilst ensuring high-quality services at sustainable costs.

5.8.2 5G-Xcast

The 5G-Xcast project, which forms part of the second phase of the 5G-PPP (Public-Private Partnership) initiative, focused on developing point-to-multipoint (PTM) communication technology within 5G networks. The main objective of this project was to meet the technical requirements of the Media and Entertainment (M&E) sector and to design an innovative network architecture that would enable the delivery of multimedia content on a large scale. The project focused on implementing multicast and broadcast functionalities, which are essential for optimising capacity within 5G systems. These functions complement unicast services and, together, enable the efficient delivery of content to many users simultaneously.

In line with the original plans, the project tested nine demonstrations:

- Hybrid broadcast service – Linear TV with supplementary content.
- Low-latency mABR live broadcasting in collaboration with SaT5G.
- Spectrum management demonstration.
- Hybrid broadcast service 'with on-demand MBMS (MooD)'.
- Hybrid broadcast service 'with Multi-Link'.
- Converged, autonomous MooD in fixed/mobile networks.
- Object-based broadcasting in a 5G network using Dynamic Adaptive Streaming over IP Multicast.
- Multimedia public alerts.
- Reliable multicast delivery in 5G networks.

One aspect of the project was the use of modern test environments. These test environments were updated to test technologies based on hybrid broadcast services in Munich, object-based broadcasting in Surrey, UK, and public warning services in Turku. For example, the trials of object-based broadcasting in Surrey utilised Dynamic Adaptive Streaming over IP Multicast, which was integrated with the 5G core and 5G NR CPE and subsequently presented in a demonstration at the EuCNC conference in June 2019.

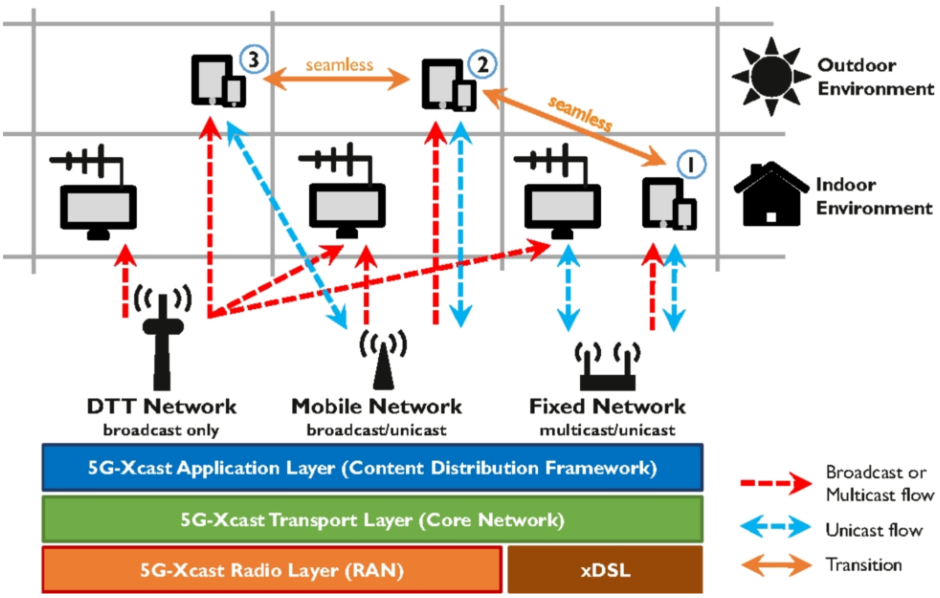

Figure 32: 5G-Xcast converged media delivery architecture

Source: http://5g-xcast.eu/about/

This figure illustrates the converged media delivery architecture within the 5G-Xcast project, which ensures seamless and uninterrupted access to content for users. The architecture interconnects fixed broadband, mobile broadband and terrestrial broadcast networks so that users can switch seamlessly between these different networks without any interruption to service.

5.8.2.1 Technology and innovation

- Advanced eMBMS technology
  - It is based on the enhanced Multimedia Broadcast Multicast Service (eMBMS).
  - First introduced in LTE and further enhanced in the 3GPP Release 14 standard.
- 5G Network Architecture
  - Optimisation of the Radio Access Network (RAN) and core network for media delivery.
  - Introduction of a dynamic network architecture that enables automatic switching between unicast, multicast and broadcast, or their parallel use.
- Use of caching technologies

  - A flexible solution has been designed for the efficient distribution of content via fixed, mobile and terrestrial broadcast networks.
- Test environments
  - Three test environments: Germany (Institut für Rundfunktechnik), the United Kingdom (University of Surrey), Finland (Turku University of Applied Sciences).
  - Testing of technologies in real-world environments, for example during broadcasts at the 2018 European Championship.
- Hybrid broadcast models
  - A combination of linear television and on-demand content to maximise the user experience.
  - Demonstration of hybrid broadcasting with the ability to link traditional television and new service formats.
- Object-based broadcasting
  - Transmission of media content (audio, video, subtitles) as separate objects.
  - Real-time content assembly on the user's device according to their preferences.

5.8.2.2 Results

The 5G-Xcast project has delivered significant results for the future of media content distribution via 5G networks, with an emphasis on multicast and broadcast capabilities. The technology has demonstrated significant potential for the convergence of mobile, fixed and broadcast networks, enabling the efficient delivery of high-quality and immersive media content to a wide range of users and devices. This approach has paved the way for new business models and applications not only in the media sector, but also in public safety, the automotive industry and the Internet of Things. The 5G-Xcast project has thus laid the foundations for the seamless migration of media services from traditional networks to the new 5G infrastructure.

The tests and demonstrations carried out proved the functionality of these innovations in a real-world environment. Test environments in Munich, Surrey and Turku proved essential for validating hybrid broadcasting, object-based broadcasting and public warning services. These trials confirmed the technological maturity of the solutions developed within the project and demonstrated how 5G can offer efficient and scalable means for the mass distribution of media services.

The 5G-Xcast project also made a significant contribution to the standardisation of 5G systems and provided a solid foundation for the further development of vertical industries such as the entertainment sector, public safety and the IoT, thereby laying the groundwork for future applications and new technologies.

5.9 Global projects

5.9.1 The Olympic Games

Over the years, the Olympic Games and their broadcasts have become one of the world's biggest media phenomena, thanks to gradual technological advances that have made the Games accessible to a wide global audience. The significance of television coverage of the Olympic Games is evident in the ever-growing number of viewers who watch the Games. The 2012 London Games are a case in point, having been watched by more than 4.8 billion viewers, representing 69 per cent of the world's population.

The history of broadcasting the Olympic Games dates back to the 1920s, when radio coverage made the Games accessible to a wider audience. Prior to that, people could only watch short film clips and news reports from the Games. A major turning point came in Berlin in 1936, when the Games were broadcast on television for the first time, albeit on a very limited scale. Viewers could only access these broadcasts in specially adapted rooms near the stadiums, but even so, this historic moment attracted over 162,000 viewers.

After the Second World War, television technology began to develop rapidly, and by the 1948 London Games, half a million viewers were able to watch the events from as far as 200 km away from the stadium. Subsequently, thanks to satellite broadcasting technology, the 1960 Rome Games marked the first time the Games became a truly global event, signifying a turning point in international broadcasting. The 1964 Tokyo Games were the first to be broadcast via satellite directly to the USA and Japan, thereby significantly expanding their reach. By 1968, broadcasts of the Olympic Games covered three continents and were watched by over 17 per cent of the world's population.

From the 1970s onwards, with the advent of colour television and other technological innovations, broadcasts became increasingly sophisticated. The 1972 Winter Games in Sapporo were the first Winter Games to be broadcast live and in full colour. In 1984, the Los Angeles Games introduced advances such as digital video and super-slow-motion footage, opening up new possibilities for the broadcasting of sporting events.

Olympic Broadcasting Services (OBS), established in 2001, has since become a key player in the broadcasting of the Olympic Games. OBS not only handles the technical aspects of the broadcasts but also ensures that viewers around the world can watch the Games in the highest possible quality, using state-of-the-art technology. In 2012, during the London Games, more than 1,000 cameras and 4,000 microphones were used for the broadcast, enabling every detail of the competitions to be captured from various angles and perspectives.

With the development of digital technologies and the internet, broadcasting possibilities have expanded significantly. The Olympic Games are no longer just about television broadcasts – it is now possible to watch the Games on various digital platforms, mobile devices and via interactive apps. OBS is constantly innovating and ensuring that viewers have access to live broadcasts, on-demand recordings and even analytical tools that allow them to follow the Games according to their preferences.

5.9.1.1 Technology

The technologies used by Olympic Broadcasting Services (OBS) have undergone significant development in recent years and are now among the most advanced in the world of sports broadcasting. OBS constantly strives to innovate in order to provide viewers with the highest-quality and most efficient viewing experience of the Olympic Games.

Technologies used by OBS:

- Artificial Intelligence (AI): AI plays a key role in the coverage of the Olympic Games, particularly in the analysis of sports data in real time. AI enables the automation of footage processing, recommends the most exciting moments and analyses competitions. This gives production teams the ability to react quickly to events on the pitch and deliver the best footage to viewers as efficiently as possible.
- Cinematic Approach: The Paris 2024 Olympic Games introduce a new approach to broadcasting that emphasises cinematic aesthetics. OBS uses multiple camera angles, dynamic shots and slow-motion sequences, creating an immersive experience for viewers and pushing the boundaries of traditional sports broadcasting.
- Innovation in content distribution: With the growing number of digital platforms, OBS is providing viewers with a wider range of options for watching the Olympic Games, not only live but also on-demand, with multi-channel content and multilingual versions. Viewers can now tailor their experience to their preferences and choose what they want to watch.
- 5G technology and its significance: 5G Broadcast technology is becoming a vital means of ensuring the reliability and speed of broadcasts at the Olympic Games. The Paris 2024 Games are relying on 5G as the main technology for broadcasts, which brings many benefits:
  - Faster data transfers: 5G enables more efficient data transfer, capable of handling the enormous volume of data generated by the Olympic Games. This is crucial at mass events where millions of viewers around the world watch the Games, both live and via mobile devices.
  - Network slicing: This technology allows the capacity of the 5G network to be divided up for specific tasks. This enables organisers to allocate part of the network's capacity solely to broadcasts of the Games, reducing the risk of network congestion and ensuring that broadcasts remain smooth even at times of peak demand.
  - Mobile cameras and new camera angles: 5G enables the use of mobile cameras mounted directly on athletes, offering viewers a completely new perspective on the action on the pitch. This approach was first tested at the 2018 Winter Olympics in PyeongChang and has been further developed since then.
  - Private 5G networks: At the Paris 2024 Games, a private 5G network was deployed and used during the opening ceremony, including the boat parade on the River Seine. Private networks are also used at venues such as the Stade de France and the Arena Bercy. This dedicated infrastructure ensures high-quality transmission, full control over broadcasts and, above all, stability even when public networks are under maximum load.

According to Frank Copsidas, president of the 5G Broadcast Collective, 5G Broadcast has enormous potential that is not limited to traditional linear broadcasting. 5G Broadcast enables the transmission of both video and audio streams directly to mobile devices, as well as critical emergency signals that can be delivered in less than half a second. The 2024 Paris Olympic Games are the perfect opportunity to fully harness this potential and take sports broadcasting to a whole new level.

6 Compatibility and interoperability of FeMBMS technology

6.1 Compatibility with 5G network architecture and infrastructure (SA/NSA)

FeMBMS has been designed with full compatibility in mind with various 5G network architectures, including both Standalone (SA) and Non-Standalone (NSA) modes. In NSA mode, FeMBMS utilises existing LTE infrastructure, enabling operators to adopt a hybrid approach in which LTE provides the basic anchor network, whilst 5G technology expands the possibilities for multicast and broadcast services. This hybrid model enables service providers to utilise existing network elements whilst implementing new functionalities without the need for major investment in upgrading the entire infrastructure. NSA mode therefore represents a cost-effective path to transitioning to 5G, allowing operators to make the most of available network resources whilst ensuring a seamless transition between technologies.

On the other hand, the Standalone (SA) mode takes full advantage of the virtualised and autonomous 5G architecture. This architecture ensures low latency, higher capacity and efficient management of network resources, which is essential for applications demanding high reliability and transmission capacity, such as high-definition live broadcasting, industrial applications or healthcare services requiring low latency. The SA architecture also enables effective support for applications with high bandwidth requirements, thereby ensuring optimal transmission quality for a variety of multimedia applications.

6.1.1 Comparison of SA and NSA architectures

6.1.1.1 Non-Standalone (NSA) mode

FeMBMS in Non-Standalone (NSA) mode builds on existing LTE infrastructure, which is economically advantageous for many operators. NSA combines LTE as the underlying anchor network with 5G technology, which adds new capabilities for multicast and broadcast services. Here, LTE handles mobility management and control signals, whilst 5G provides high-speed data transmission, particularly for bandwidth-intensive applications such as high-definition video streaming, augmented reality (AR) or virtual reality (VR).

Thanks to this architecture, operators can make effective use of existing LTE components, significantly reducing the costs of infrastructure modernisation and accelerating the return on investment. LTE also extends coverage and increases network capacity, whilst facilitating the roll-out of 5G services. NSA provides a seamless transition between 4G and 5G and offers users with 5G devices the opportunity to access higher data speeds even in areas where 5G coverage is limited.

The hybrid approach improves spectrum management and allows new 5G features to be added gradually without the need for major changes to the overall infrastructure. This model is particularly beneficial for operators seeking to deploy 5G technology quickly and at minimal cost.

6.1.1.2 Standalone (SA) mode

Standalone mode (SA) represents a fully independent 5G architecture, where both the radio access network (RAN) and the 5G core network are virtualised and separated from LTE. This approach provides networks with full autonomy and fully harnesses the potential of 5G technology, particularly in areas where low latency, high capacity and reliability are essential. SA is crucial for applications requiring ultra-low latency, such as autonomous vehicles, remotely controlled operations or industrial automation systems.

Furthermore, the SA architecture supports advanced features such as network slicing, i.e. the creation of virtual networks tailored to the specific requirements of applications. This approach is utilised for Internet of Things (IoT) applications, where different types of devices may have very different demands in terms of bandwidth, latency or reliability.

Furthermore, SA mode better supports bandwidth-intensive applications, such as high-definition live streaming, industrial deployments or healthcare services, where reliability and low latency are essential. In the long term, SA offers greater flexibility and better opportunities for the further development of 5G networks. Although implementing SA involves higher costs and takes longer, it is a strategic choice for operators who wish to fully realise the potential of 5G technology and who want to focus on innovations such as industrial IoT systems or smart cities, and who require a reliable and scalable network.

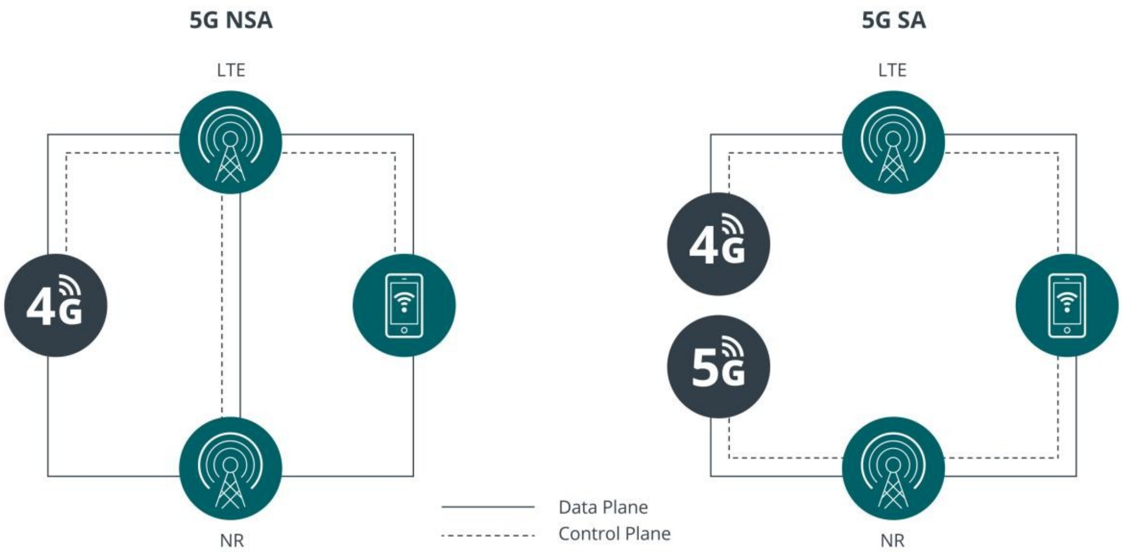

Figure 33: Comparison of 5G NSA and 5G SA

architectures Source: https://www.netscout.com/what-is/5g-sa-vs-nsa

*This figure compares two different architectures for 5G networks: **5G NSA (Non-Standalone)** and **5G SA (Standalone)**.*

***5G NSA**, shown on the left, utilises existing LTE (4G) infrastructure in conjunction with the new 5G NR (New Radio). The control plane, which manages signalling and mobility, is still controlled via LTE, whilst the data plane, which handles high-speed data transmission, is managed via 5G NR. This architecture represents a hybrid approach, where some functions still rely on 4G, but the data transmissions themselves now take place over the 5G network.*

*In contrast, **5G SA**, shown on the right, is fully independent of LTE. In this architecture, both the control and data planes are managed exclusively via 5G NR, giving the network full autonomy. All network functions, including data transmission, are provided via 5G technology, delivering lower latency, higher capacity and greater reliability.*

This difference illustrates how NSA still relies on LTE to manage certain functions, whilst SA operates entirely independently within the new 5G technology.

6.1.2 The benefits of combining SA and NSA with FeMBMS

FeMBMS is designed to be fully compatible with both 5G network modes, namely NSA and SA, which gives operators considerable flexibility when deploying the technology. In the case of NSA, operators can benefit from the economic advantages of transitioning to 5G whilst utilising existing LTE infrastructure. This approach allows for the maximum utilisation of available resources and a seamless transition between LTE and 5G networks, without the need for extensive investment in upgrading the entire network. As a result, NSA is often the first choice for operators wishing to roll out 5G quickly and efficiently.

On the other hand, SA represents the path to fully realising the potential of 5G technologies, particularly in the context of virtualised infrastructure, which enables the operation of advanced applications of the future. This mode offers better performance, lower latency and greater reliability, which is essential for applications demanding high transmission capacity and rapid response times. SA also supports features such as network slicing, which is essential for IoT applications and other technologies that will require a high level of flexibility and customisation to specific requirements in the near future.

The combination of FeMBMS with NSA offers operators an economic advantage through the use of existing resources, whilst SA paves the way for the development of new services and applications that fully utilise the capacity and capabilities of 5G networks. This flexibility in approach allows for the gradual expansion of 5G infrastructure and minimises the need for immediate large-scale investment, whilst also reducing the time required to recoup the investment.

FeMBMS's compatibility with both modes (SA and NSA) provides flexibility during implementation, allowing operators to tailor their deployment to the maturity of their existing infrastructure and to gradually upgrade their networks without being forced to make costly changes to the entire infrastructure. Furthermore, the hybrid model ensures better management of spectrum resources and increases capacity for the provision of multicast and broadcast services, which has a positive impact on the efficiency and quality of the services provided. The combination of different multiplexing approaches delivers higher spectral efficiency and service quality. This combination enables more efficient use of spectrum resources and provides greater capacity for multicast services in various environments.

6.1.3 Comparison of LDM-NOMA and FeMBMS-OMA

FeMBMS's compatibility with both modes (SA and NSA) offers flexibility in implementation, allowing operators to tailor their deployment to the maturity of their existing infrastructure and modernise their networks gradually, without the need for costly system-wide modifications. Furthermore, the hybrid model contributes to a more efficient use of spectrum resources and increases capacity for multicast and broadcast services, thereby improving the efficiency and quality of the services provided. Diverse multiplexing methods deliver higher spectral efficiency and better transmission quality. This approach ensures better management of spectrum resources and expands capacity for multicast applications under various conditions, which is essential for the development of 5G networks and their future applications.

FeMBMS-OMA (Orthogonal Multiple Access) and LDM-NOMA (Layered Division Multiplexing-Non-Orthogonal Multiple Access) are two distinct technologies designed for the efficient use of spectrum within 5G networks. Each of these methods has its own specific advantages and target applications, whilst both serve to increase network capacity and flexibility.

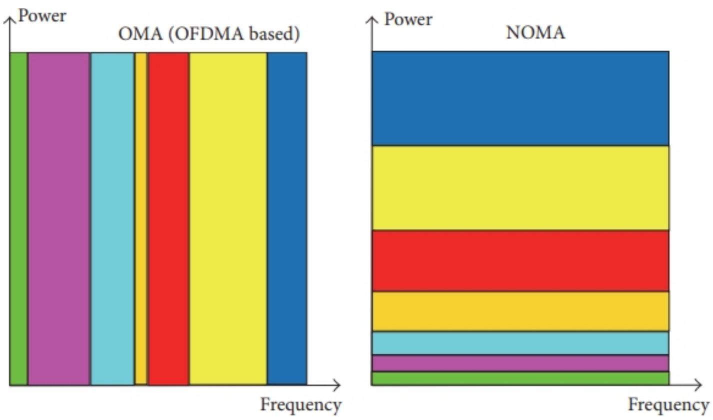

Figure 34: Comparison of spectral efficiency between OMA (OFDMA) and

NOMA Source: https://onlinelibrary.wiley.com/doi/10.1155/2018/9713450

*The figure visually compares spectral efficiency and throughput between two approaches to user multiplexing: **OMA (Orthogonal Multiple Access)**, based on **OFDMA** (Orthogonal Frequency Division Multiple Access), and **NOMA (Non-Orthogonal Multiple Access)**.*

***OMA (OFDMA-based)**: The left-hand side illustrates the principle of OMA, where each user is allocated a specific frequency resource regardless of their channel conditions. This means that a user with good or poor channel conditions receives the same portion of the frequency spectrum, leading to lower spectral efficiency. This approach limits the overall throughput of the system, as it does not utilise the full potential of the frequency resources, particularly when one of the users has poor conditions.*

***NOMA**: The diagram on the right illustrates the NOMA approach, where the same frequency resource is shared by multiple mobile users simultaneously, even if they have different channel conditions. A user with poorer conditions (a weaker user) and a user with better conditions (a stronger user) use the same frequency band. Interference between them is mitigated using SIC (Successive Interference Cancellation) techniques at the receivers. This approach increases spectral efficiency and significantly improves the overall throughput of the system.*

6.1.3.1 LDM-NOMA

LDM-NOMA utilises a non-orthogonal approach to spectrum allocation, which allows multiple users to share a single channel simultaneously. The technology allocates power amongst users based on their signal reception conditions, thereby increasing the efficiency of resource utilisation. This leads to an increase in network capacity and ensures greater flexibility in managing varying bandwidth requirements. LDM-NOMA is therefore well-suited to situations where resources need to be allocated to users with varying connection qualities.

Thanks to its ability to assign multiple users to a single channel, the technology achieves higher spectral efficiency. Furthermore, the combination with FeMBMS improves the capabilities for broadcasting multicast services and is particularly advantageous for applications requiring the distribution of identical data to a large number of receivers, such as television broadcasting or real-time video streaming. This approach thus delivers better results for mass data distribution.

6.1.3.2 FeMBMS-OMA

FeMBMS-OMA, by contrast, is based on an orthogonal approach, whereby each user is allocated their own channel. This method is particularly suitable where a high degree of stability is essential, for example in public service broadcasting or where interference between individual transmissions needs to be minimised. This approach achieves consistent and predictable performance, which is important in critical applications where outages or loss of transmission quality cannot be risked.

FeMBMS-OMA therefore ensures more robust transmissions and remains faithful to the traditional multiplexing method, whereby each user or service is allocated its own channel. This model is particularly effective in environments where maintaining a high quality of service without fluctuations is a priority.

6.1.3.3 Combination of technologies

The combination of LDM-NOMA and FeMBMS-OMA technologies offers a comprehensive solution for spectrum resource management. Whilst LDM-NOMA increases efficiency by allowing multiple users to share the same channel, FeMBMS-OMA provides transmission stability and robustness. This combination improves capacity for multicast and broadcast services in various environments and offers a high degree of customisation to meet the needs of individual applications. Efficient spectrum management is thus achieved through the combination of both approaches, resulting in a significant increase in network performance for both high-capacity transmissions and critical applications with high stability requirements.

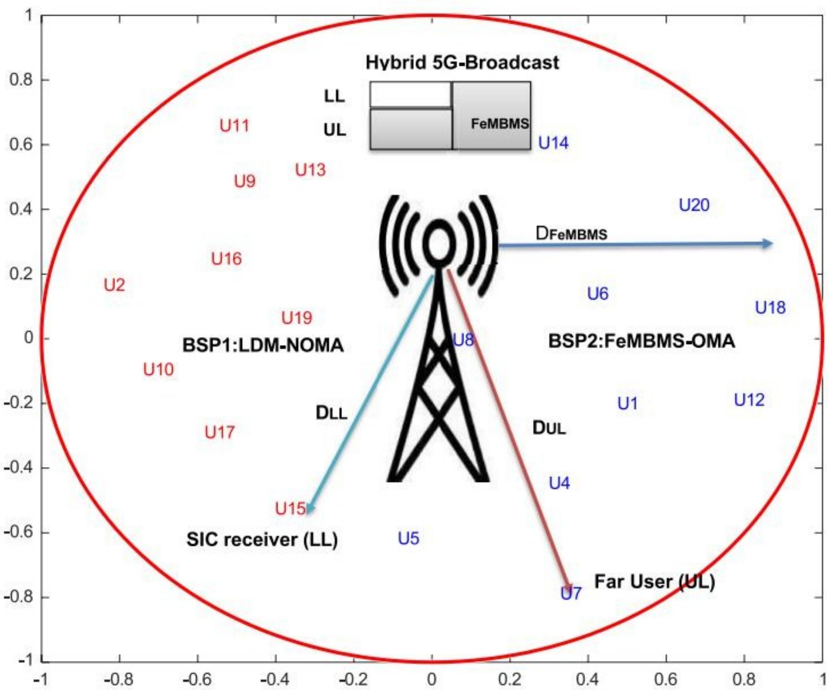

Figure 35: General overview of the BSP (Base Station Power) system with user multiplexing

Source: https://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=10214288

The figure shows three users within a single base station (BS) cell. Two of these users share the same sub-carrier, whilst the third user is assigned a different sub-carrier. This model corresponds to BSP (Base Station Power) technology. All three users are co-located within the frequency band.

*The **lower-layer (LL)** user, who is closer to the base station, has better channel conditions than the **upper-layer (UL)** user, who is further away and therefore has poorer channel conditions. The FeMBMS user is situated between these two users. The base station optimises the allocation of transmission resources for each user on each sub-carrier. Instead of allocating all transmission power to a single user, the LL user with better channel conditions receives less transmission power, whilst the UL user with poorer conditions receives more transmission power.*

*Compared with the conventional orthogonal access (OMA) scheme, the FeMBMS user is classified as **a medium-power user**, whilst the UL user benefits from being allocated a higher channel power. This approach results in a fairer allocation of resources. Allocating lower power to the LL user will slightly reduce its capacity, but has a significant impact on the performance of the UL user, to whom it provides better transmission capacity.*

The transmitted signal is defined by the number of RBS (Resource Blocks) and sub-carriers, and the number of users K is shown below as part of the proposed BSP system.

This figure thus illustrates an overview of the proposed system, in which the base station manages the allocation of power to different users depending on their signal conditions, thereby ensuring a fairer and more efficient utilisation of spectrum and transmission resources.

6.2 Integration with existing television broadcasting networks

The integration of FeMBMS technology with existing television broadcasting networks is a key element in expanding multimedia broadcasting capabilities and achieving wider coverage. FeMBMS enables the functionality of traditional digital broadcasting, such as DVB-T2, to be extended, and allows linear television services to be delivered via 5G mobile networks. This model provides end-users with access to television content on mobile devices.

6.2.1 FeMBMS and current television standards

FeMBMS represents a step forward in television broadcasting via 5G networks. Its main advantage is the expansion of traditional broadcasting capabilities to include new methods of content distribution, whilst remaining compatible with existing television technologies such as DVB-T2. This facilitates the transition to modern multimedia broadcasting without the need for major changes to the existing infrastructure.

6.2.1.1 Coexistence of DVB-T2 and FeMBMS

DVB-T2 has long been used for terrestrial digital broadcasting and represents a tried-and-tested method of distributing television signals. However, FeMBMS provides a new approach to content distribution via 5G networks, enabling users to watch television broadcasts on mobile devices as well. This significantly expands the reach of television broadcasting, making it available not only via televisions and set-top boxes, but also on phones and tablets.

Furthermore, FeMBMS complements the existing DVB-T2 infrastructure without interfering with its core functions. It enables the transmission of television content over mobile networks, thereby opening up new possibilities for content providers and offering viewers greater flexibility in accessing broadcasts. DVB-T2 continues to fulfil its role in the home, whilst FeMBMS enables viewers to consume content whilst on the move, which makes this technology highly attractive.

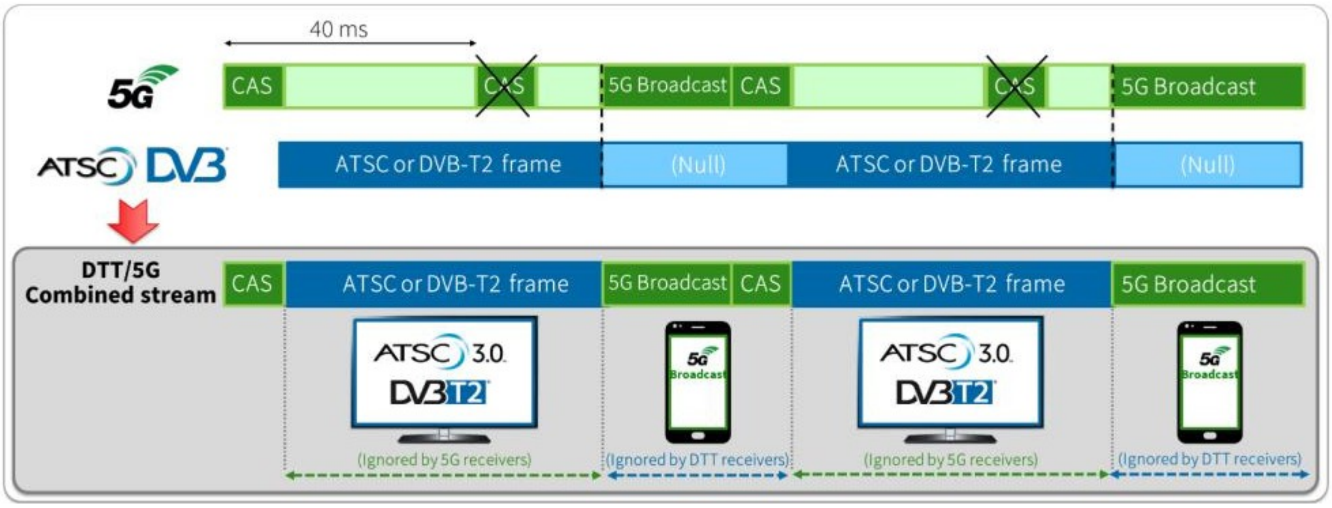

Figure 36: Principle and example of time multiplexing

Source: https://dvb.org/wp-content/uploads/2024/04/202404_DVB_IP-based-Broadcast-meets-5G_E-Dubs_FINAL.pdf

*This diagram illustrates the principle **of time division multiplexing (TDM)**, whereby the **DVB-T2** (or ATSC 3.0) and **5G Broadcast** transmission standards are used simultaneously within the same radio channel. This approach ensures the coexistence of both technologies on a single frequency by dividing the transmission time frame between the two standards.*

*At the top of the diagram is the 5G Broadcast frame, which includes **the** so-called **CAS (Cell Acquisition Subframe)** – a synchronisation signal transmitted every 40 ms. This signal enables receivers to detect and synchronise with the 5G broadcast. This is followed by the time slot for the 5G Broadcast*

*broadcast. Similarly, the figure shows the frame for **ATSC or DVB-T2**, which has fixed time slots for the transmission of the television signal. **The null windows** between them serve to align the different standards.*

*The lower part of the figure illustrates the principle of a combined broadcast stream (**DTT/5G Combined stream**), where both **DVB-T2** and **5G Broadcast** are transmitted within the same time frame. Each receiver (e.g. a DVB-T2-enabled television or a 5G-compatible mobile device) recognises and receives only the signal that is relevant to it. For example, **DVB-T2 receivers** ignore the 5G broadcast, and vice versa. This ensures the coexistence of both technologies on the same radio channel without mutual interference.*

This time-division multiplexing method enables the efficient use of the radio spectrum and simultaneous support for different types of devices, without the need to allocate a separate frequency band for each technology. This approach is particularly suitable in situations where it is necessary to ensure the coexistence of older receivers (DVB-T2 or ATSC 3.0) with new 5G devices without disrupting their operation.

6.2.1.2 Technical requirements for integration

The integration of FeMBMS into the existing television infrastructure requires several technical adjustments. One of the prerequisites is support for Single Frequency Networks (SFN), which enable signal transmission across large geographical areas using a single frequency, leading to more efficient spectrum utilisation, lower operating costs and wider broadcast coverage.

Support for High-Power High-Tower (HPHT) networks presents a further technical challenge. Utilising existing broadcast infrastructure to cover large areas minimises the need to build new infrastructure. Deploying HPHT networks with FeMBMS delivers further cost savings and extends coverage without the need for substantial investment.

Furthermore, FeMBMS supports so-called standalone downlink-only networks focused exclusively on content broadcasting, without the need to allocate resources for unicast services. This enables the provision of linear television broadcasting without relying on a connection to a mobile operator.

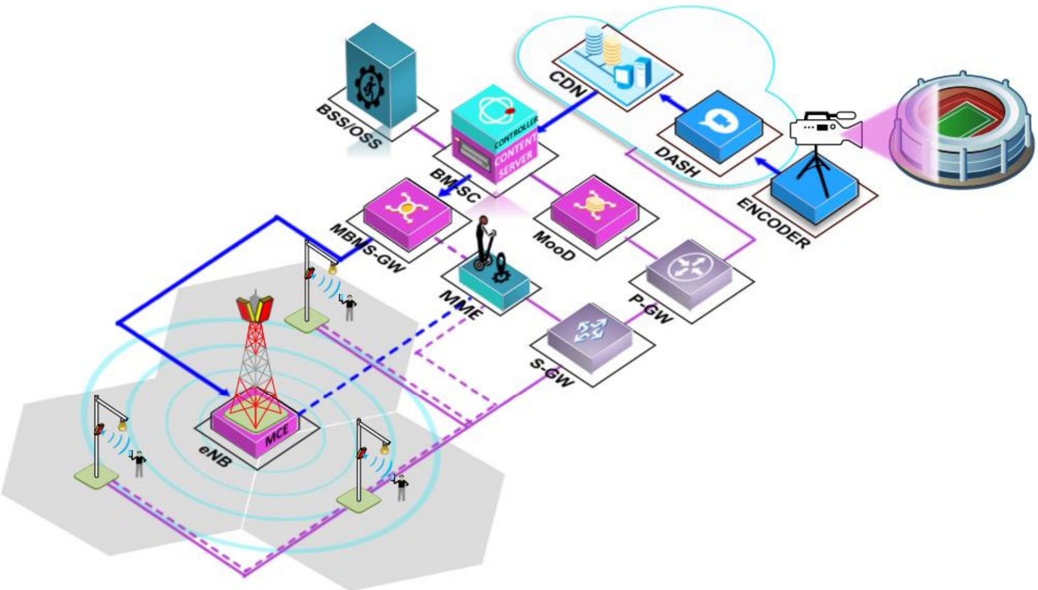

Figure 37: FeMBMS architecture in LTE/EPC networks with HPHT topology

Source: https://ieeexplore.ieee.org/document/10360845

The figure illustrates the architecture of FeMBMS (Further evolved Multimedia Broadcast Multicast Service) technology in an LTE/EPC network using HPHT (High-Power High-Tower) topology. This architecture ensures the distribution of media content via 5G Broadcast technology to various devices, such as mobile phones, tablets and televisions.

The BSS/OSS (Business Support System / Operational Support System) handle network and service management at the highest level, whilst the Content Server and BM-SC (Broadcast Multicast Service Centre) manage the distribution of multicast and broadcast services and administer content authorisation. The CDN (Content Delivery Network) ensures the fast and efficient delivery of content to users.

DASH (Dynamic Adaptive Streaming over HTTP) and the ENCODER are responsible for optimising media streams, with DASH dynamically adapting streaming to maintain transmission quality and efficiency. The MBMS-GW (Multimedia Broadcast Multicast Service Gateway) handles the transmission of multicast and broadcast services within the LTE core network, whilst the MME (Mobility Management Entity) manages user mobility and network signalling.

Furthermore, the P-GW (Packet Gateway) and S-GW (Serving Gateway) ensure the transmission of data to end-users and their devices, including routing and service provision. eNBs (evolved Node Bs), i.e. base stations, broadcast signals over large geographical areas and ensure coverage of extensive territories. The MCE (Multicast Coordination Entity) oversees the efficient allocation of transmission resources for multicast services.

The comprehensive FeMBMS architecture within the LTE network enables the efficient distribution of media content across a wide range of devices and ensures high-quality, stable broadcasting within the 5G Broadcast framework.

6.2.1.3 Benefits of integrating FeMBMS with DVB-T2

The integration of FeMBMS with DVB-T2 offers a number of benefits. One of these is **extended coverage**, making television content available on mobile devices, which gives users access to broadcasts even outside traditional viewing environments. This is particularly beneficial for live event broadcasts, such as sports matches or news programmes, where wide coverage and high reliability are required. Another advantage is the efficient use of spectrum, which FeMBMS ensures through a combination of SFN and HPHT networks. In this way, the need for duplicate coverage can be significantly reduced and interference between transmission stations minimised.

The introduction of FeMBMS into existing television broadcasting networks is therefore a logical step, enabling content providers to offer flexible and modern solutions for television broadcasting via 5G networks. In this way, they can extend the reach of their services to mobile devices whilst retaining their existing infrastructure, which enhances both the economic and technical benefits of this approach.

6.2.2 Use of HPHT (High-Power High-Tower) networks

FeMBMS technology makes effective use of **HPHT (High-Power High-Tower)** networks to extend coverage and optimise spectrum utilisation, particularly across large geographical areas. This broadcasting model relies on powerful transmitters located on tall towers, which are capable of covering vast areas using a single frequency, thereby reducing the need for additional transmitters and the costs associated with their operation. HPHT networks are therefore particularly well-suited to the broadcasting of news and sporting events, where stability and high-quality transmission are required.

6.2.2.1 Advantages of HPHT networks

Wide geographical coverage is one of the main advantages of HPHT networks. High-power transmitters, often reaching tens of kilowatts of EIRP (Effective Isotropic Radiated Power), enable the signal to be transmitted over long distances. Their placement on elevated sites, such as towers or hills, ensures stable coverage even in challenging terrain. The characteristics of HPHT networks reduce the need for extensive transmission infrastructure, as a smaller number of stations can cover large areas. The effectiveness of this approach is reflected in lower installation and maintenance costs and better signal availability in remote regions where traditional transmission methods are less effective.

Another advantage is Single Frequency Network (SFN) transmission, where all transmitters in a given area operate on the same frequency, eliminating the need to switch between channels and ensuring seamless coverage of large areas without interference. SFN technology synchronises transmitters so that the signal from all stations reaches the receiver simultaneously, thereby preventing mutual interference.

HPHT networks can handle the transmission of large volumes of data without any loss of quality, which is particularly valuable during events such as sports broadcasts or cultural events that require high image quality and low latency. They also offer high performance even in challenging conditions, such as densely populated urban areas or regions with complex terrain.

6.2.2.2 Single Frequency Network (SFN)

A Single Frequency Network (SFN) represents the optimal solution for spectral efficiency when combined with HPHT networks. All transmitters in a given area use the same frequency, which brings benefits such as spectrum optimisation and higher signal quality. This method works by synchronising the signals from individual transmitters in the network so that they reach every receiver in the area at the same time. This process eliminates interference between the signals from individual transmitters, which improves the overall quality of coverage and ensures seamless transmission without dropouts.

Another advantage of SFN is its increased network capacity, which allows broadcasting across a wide geographical area using a single frequency. This approach not only maximises the efficiency of spectrum utilisation but also provides greater flexibility in content transmission. SFN enables the transmission of various types of broadcasts, including live broadcasts, news, cultural events and other multimedia content, whilst maintaining high quality and low latency.

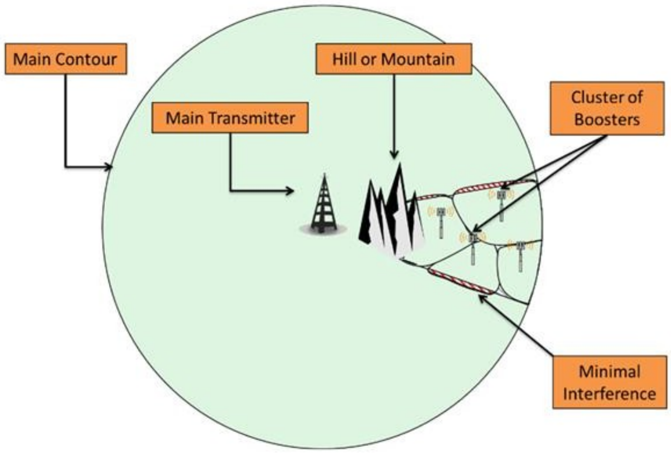

Figure 38: Diagram of a Single-Frequency Network

Source: https://www.gatesair.com/solutions/single-frequency-networks-sfn

The figure illustrates the principle of a Single-Frequency Network (SFN), which uses a single transmission channel to cover a large area. The main transmitter generates a high-power primary signal covering most of the area, known as the Main Contour. Signal boosters are used to improve coverage in hard-to-reach locations, such as areas behind hills or mountains. These boosters are strategically placed in locations where the main transmitter's signal cannot penetrate due to terrain obstacles.

Synchronisation between the main transmitter and the boosters ensures that no interference occurs, and the signal transmitted from the boosters seamlessly supplements coverage in hard-to-reach areas, thereby minimising interference. This system is particularly effective for large areas with challenging terrain, as it enables uniform coverage without the need for additional frequencies or a significant increase in the main transmitter's power. The SFN model thus ensures high-quality and consistent broadcasting that reaches even more remote locations.

FeMBMS, combined with HPHT and SFN, offers broadcasters the opportunity to make efficient use of the available spectrum whilst ensuring a high level of service quality for users across vast geographical areas.

6.2.3 Standalone downlink-only networks

FeMBMS in the standalone downlink-only network model provides a solution for the efficient distribution of content, particularly where the priority is the delivery of broadcast services without the need for unicast transmissions. The model allows the entire available network capacity to be reserved exclusively for broadcasting.

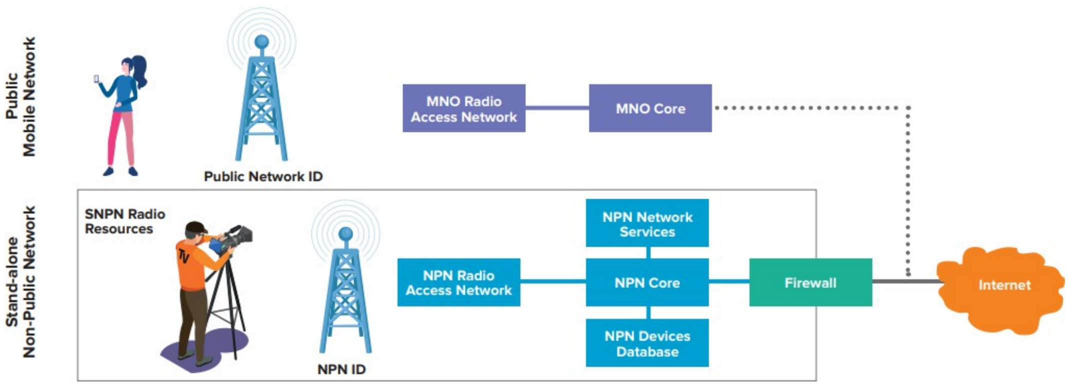

Figure 39: Diagram of a stand-alone Non-Public Network (SNPN) and a public mobile network

This figure illustrates the fundamental difference between a stand-alone Non-Public Network (SNPN) and a public mobile network. A public mobile network is intended for widespread public use, whilst an SNPN is an isolated network designed for specific purposes, such as for media organisations. This network can be fully managed by the entity operating it, and its operation is entirely independent of public mobile networks.

A public mobile network comprises the MNO Radio Access Network, which provides access to services via the radio part of the network, managed by mobile network operators. The core part of the public mobile network, the MNO Core, provides network functions and connectivity to the internet, enabling users to access public services. This public network is identified by a Public Network ID, which makes it accessible to the general public.

In contrast, the SNPN (Stand-alone Non-Public Network) utilises its own radio resources (SNPN Radio Resources), which are isolated from public networks. The NPN Radio Access Network serves specific purposes, such as media production, and has its own NPN ID. The core of this network, the NPN Core, provides complete control and management of network functions, whilst all data and services are separated from public mobile networks. In addition, NPN Network Services offer specific features such as low latency, high throughput and real-time monitoring, with all connected devices managed via the NPN Devices Database.

Security is ensured by a firewall, which protects access between the isolated NPN network and public networks. The firewall can also enable connectivity to the internet or facilitate roaming agreements with public mobile networks, where required. This model of isolated networks offers a higher degree of control and security compared to public networks and ensures reliability for specific applications and requirements.

6.2.3.1 Advantages of the downlink-only model

- **Maximising coverage and capacity:** The standalone downlink-only model allows the spectrum to be fully utilised for broadcasting, leading to extended coverage and higher capacity. This enables media providers to effectively reach a wide audience regardless of geographical barriers. The signal remains stable and reliable even in densely populated areas. Efficient use of the spectrum and the absence of unicast transmissions also contribute to increased service availability and allow a greater number of users to receive content simultaneously without any degradation in transmission quality.
- **Elimination of the need for unicast:** In the downlink-only model, unicast transmissions are not required. As the network does not need to handle the individual delivery of data to individual users, the management of transmission capacity is significantly simplified. All resources are dedicated to broadcasting a single stream, which can reach a large number of viewers simultaneously. This model thus enables the transmission of events with high bandwidth and capacity requirements, such as live sports matches, concerts or cultural events.

6.2.3.2 Provision of free-to-air services

In standalone downlink-only FeMBMS networks, operators can provide television broadcasts as free-to-air services without the need to connect to mobile operators. This approach allows users to watch content without incurring additional costs for mobile data or special services provided by operators. Linear television broadcasts can be easily delivered to a wide audience across various devices, including mobile phones, tablets and smart TVs.

This free-to-air model is advantageous not only from an economic perspective, but also in terms of accessibility and reliability. In the event of crises, such as natural disasters or emergencies, this technology enables broadcasting to continue uninterrupted and allows the public to be informed quickly, even in areas where standard communication networks are overloaded or out of service. Thanks to this capability, a standalone downlink-only network is a critical element of the modern broadcasting ecosystem, ensuring uninterrupted access to information for broad sections of the population.

6.2.4 Using the xMB interface for integration

The xMB interface enables the easy integration of FeMBMS technology into existing broadcasting and mobile networks. This standardised protocol simplifies the transition to 5G broadcasting and enables flexible management of audiovisual services via mobile and broadcasting networks.

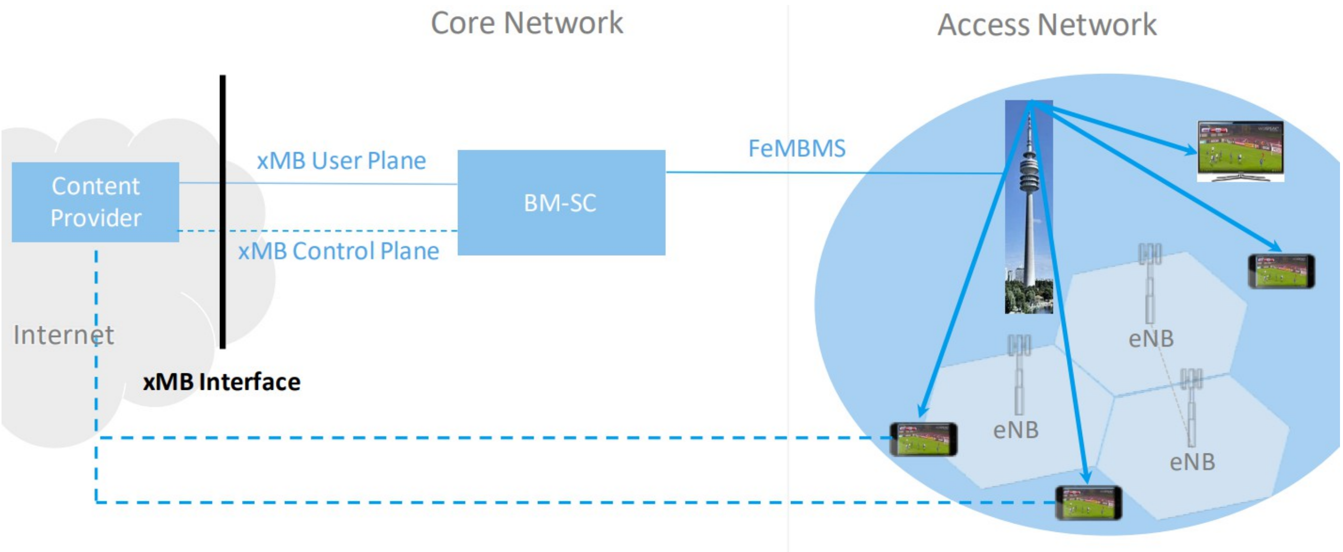

Figure 40: FeMBMS architecture utilising the xMB interface for content distribution

Source: https://tech.ebu.ch/docs/events/asbu_wot2019/presentations/Day3-slot6-EBU-ASBU-WoT-5G_today-Aneta%20Baier-IRT-2019.pdf

*The diagram illustrates the flow of content from the content provider to end users via FeMBMS technology in 5G networks. Content providers, such as media companies or television broadcasters, distribute content (e.g. live sports broadcasts) over the internet. Data is transmitted via **the xMB interface**, which is divided into two parts: **the xMB User Plane**, which handles the actual transmission of content, and **the xMB Control Plane**, which manages communication and synchronisation.*

*The content then passes through the central **BM-SC (Broadcast Multicast Service Centre)**, which manages and distributes the content to the base stations (**eNBs**). These base stations broadcast the content to end users on various devices, such as mobile phones, tablets and televisions.*

The entire process is optimised for broadcasting to a large number of users simultaneously, thereby minimising network load and ensuring high-quality, real-time transmission.

6.2.4.1 Easy integration with broadcast networks

The xMB interface provides a tool for broadcast service providers wishing to expand their services to include new broadcast platforms, such as 5G Broadcast or FeMBMS. This interface enables operators to easily manage audiovisual services, such as streaming or live broadcasts, via mobile and broadcast networks without the need for complex modifications. According to the specifications introduced in the 3GPP Release 14 standard and further expanded in Release 16, xMB separates the service control and transport layers. This separation facilitates the management and operation of both unicast and multicast services. Using this interface, media providers can transition to FeMBMS, whilst being able to efficiently deliver audiovisual data between broadcasters and end-users.

6.2.4.2 Flexibility and extensibility

One of the advantages of the xMB interface is its ability to provide a high degree of flexibility and scalability across various types of broadcast networks. The xMB interface enables media providers to easily adapt services to different devices and technologies, including mobile networks and television broadcasting. This solution supports a wide range of audiovisual formats, from standard definition (SD) to ultra-high definition (UHD). It also enables the use of dynamic features, such as the automatic adaptation of services based on demand (e.g. eMBMS Operation on Demand – MooD). xMB also supports shared broadcast networks, which allows multiple networks to be aggregated into a single platform and increases the efficiency of spectrum utilisation and available broadcast resources.

This approach makes xMB not only compatible with existing broadcasting systems, but also ready for future technologies and extensions, such as integration with new applications and features that 5G Broadcast will bring.

6.2.5 FeMBMS and future multimedia applications

FeMBMS offers the potential to deliver content in exceptionally high picture quality via 5G networks. This feature is particularly crucial for applications that require detailed imagery, such as sports broadcasts or cultural events. Support for high resolutions, such as HD and UHD, enhances the viewing experience by offering sharper and more faithful images, including advanced technologies such as HDR (High Dynamic Range). As a result, FeMBMS can play a significant role in shaping future television standards and provide new opportunities for the media industry in the field of high-quality broadcasting.

FeMBMS technology is designed to significantly reduce latency, which improves the delivery of multimedia services that rely on rapid response times. This is particularly important for live sports broadcasts or interactive broadcasting, where minimal delay between an event and its transmission to the viewer is essential. Low latency also opens up new possibilities for modern interactive applications, such as e-sports or live events, where immediate response is absolutely crucial for a seamless experience. The ability to provide stable and fast transmissions is becoming a fundamental requirement for future multimedia services, where the speed and quality of broadcasting will be key factors.

6.2.6 The transition to hybrid broadcasting models

Hybrid broadcasting offers new possibilities for integration with digital video broadcasting (DVB) and enables more efficient use of the spectrum.

- **Hybrid broadcasting with FeMBMS and DVB:** This model combines the capabilities of 5G broadcasting with traditional DVB technologies, thereby unifying the two systems. In this way, broadcasters can optimise their coverage and deliver content both linearly and on-demand.
- **FeMBMS and traditional broadcasting networks:** The use of hybrid models allows for continued compatibility with existing traditional networks, providing flexibility in the transition to modern technologies without the need to completely overhaul the existing infrastructure.
- **Hybrid TV models with 5G:** The combination of FeMBMS and DVB enables the creation of new hybrid television broadcasting models that support both linear and interactive broadcasting. This model is advantageous for a wide range of multimedia services, from live broadcasts to on-demand applications.
- **FeMBMS for linear and on-demand broadcasting:** The flexibility of FeMBMS allows content to be transmitted in various formats, for both linear broadcasting and on-demand content. This opens up new possibilities for delivering content to users with different preferences.
- **Integration of 5G with existing broadcasting infrastructure:** Deploying FeMBMS as part of hybrid models enables easier integration with existing broadcasting infrastructure, facilitating the transition to advanced technologies without disrupting current services.

Hybrid broadcasting models offer greater flexibility, efficiency and scalability of services, enabling better adaptation to the needs of the modern market whilst maintaining support for traditional broadcasting technologies.

6.3 Compatibility with various devices

FeMBMS technology has been designed to ensure broad compatibility with a wide range of end devices, including smartphones, tablets, smart TVs and other multimedia devices. This is achieved through the use of standardised protocols and technologies that are commonly supported in modern devices. FeMBMS technology utilises the LTE Broadcast concept, which enables devices equipped with an LTE modem to receive broadcast transmissions without the need for significant hardware modifications. This approach expands the potential applications of FeMBMS, particularly in mobile environments, where users expect seamless access to multimedia content regardless of the type of device.

FeMBMS supports various reception modes – ranging from unicast to full broadcast mode. This flexibility enables providers to optimise the use of network resources, improve the user experience and reduce network load during periods of high demand for content. The ability to switch between unicast and broadcast modes is key to efficient content distribution, enabling providers to respond flexibly to changes in demand, particularly during live broadcasts of popular events. Compatibility with a variety of devices is essential for the successful market adoption of FeMBMS technology. The ability to deploy the technology without the need for extensive modifications on the end-user's side facilitates its implementation and reduces barriers to market entry. This enables content providers and telecoms operators to respond quickly to dynamic market needs, making FeMBMS an attractive choice for a wide range of applications. The versatility and ease of integration of FeMBMS are key factors in maintaining competitiveness in the market and in the efficient distribution of multimedia content without the need for extensive investment in infrastructure or end-user devices.

6.3.1 Mobile devices and tablets

FeMBMS provides mobile devices and tablets with seamless access to linear television broadcasting, bringing about a fundamental shift in the way media is consumed on these devices. Mobile phones and tablets are now an integral part of everyday life, and thanks to technologies such as FeMBMS, mobile multimedia experiences are becoming increasingly accessible and of higher quality.

6.3.1.1 Benefits for mobile users

One of the main benefits of FeMBMS is that it ensures access to television content whilst on the move. Users can watch live television without interruption, wherever they are, regardless of signal quality or internet connection. FeMBMS significantly reduces reliance on traditional connections and offers stable content reception even in areas with weaker coverage.

Thanks to its support for both unicast and broadcast transmissions over 5G mobile networks, FeMBMS combines the best of both worlds – unicast for individual content and broadcast for mass transmission, such as sporting events or live concerts. This approach conserves network resources and provides stable transmission even for large numbers of users simultaneously.

6.3.1.2 Support for high definition (HD and UHD)

With the advent of 5G technology, the quality of multimedia content on mobile devices is improving dramatically. FeMBMS utilises high transmission speeds and low latency, enabling content to be streamed in HD or even UHD (4K) format without interruption or loss of picture quality. Users can expect smooth video playback, even in areas with high network traffic.

6.3.1.3 Compatibility with various operating systems

FeMBMS is designed to work on mobile devices running Android and iOS. Device manufacturers, together with technology partners such as Qualcomm, are already working on developing specific chipsets that support the reception of 5G broadcast signals. These chips incorporate advanced decoding capabilities and energy optimisation, enabling extended content viewing without excessive battery drain. Harmonised technical standards for FeMBMS across Europe ensure that devices will be mutually compatible, facilitating uniform access to broadcasts in all countries.

6.3.1.4 Technical hardware requirements

Systems supporting FeMBMS on mobile phones require 5G modems with multicast and broadcast capabilities, advanced antennas capable of receiving signals across various frequency bands, and specialised decoders optimised for high-definition (HD and UHD) reception.

6.3.2 Smart TVs and set-top boxes

FeMBMS technology represents an advanced approach to integrating television broadcasting directly into smart TVs and set-top boxes, thereby providing users with extensive opportunities for innovative use of multimedia content without the need for traditional reception systems. This technology is based on state-of-the-art transmission standards and represents a revolutionary step forward in the distribution of television content, meeting the requirements of digital transformation and delivering greater flexibility, accessibility and efficiency.

6.3.2.1 Modern smart TVs

Thanks to FeMBMS technology, smart TVs are able to receive television signals directly via 5G networks, eliminating the need for connection via traditional antennas or satellite equipment. This method of reception represents a significant simplification for end users, as it eliminates the need to install and configure complex reception systems. FeMBMS enables the distribution of high-quality linear television broadcasts, including picture and sound that meet the highest standards of contemporary audiovisual production. This technology ensures flexible content reception via 5G broadband infrastructure, thereby contributing to an overall increase in user satisfaction. FeMBMS not only simplifies the process of receiving broadcasts but also enhances the capabilities of multimedia services, including access to advanced interactive features and the integration of additional digital services directly within the smart TV environment.

FeMBMS also supports the implementation of Single Frequency Network (SFN) systems, which significantly optimise spectral efficiency and ensure consistent coverage across all geographical areas, including rural and hard-to-reach regions. This enables more efficient use of the available spectrum, which is essential for maintaining the quality and availability of services in areas with limited access to traditional broadcasting systems. According to SPINNER sources, FeMBMS technology has been successfully tested in several regions, including extensive trials in Bavaria and at remote locations in the UK. The results of these tests show that FeMBMS is capable of delivering reliable and stable transmission even under challenging conditions, thereby increasing its potential for widespread deployment.

6.3.2.2 Integration with home devices

FeMBMS also offers seamless integration with existing set-top boxes, enabling users to gradually upgrade their home reception equipment. However, to achieve full support for FeMBMS technology, it is often necessary to make technical modifications to certain set-top boxes, such as adding a compatible 5G modem or updating the software to support specific features. The integration of FeMBMS with home devices has been designed with a focus on minimising complications for end users, thereby ensuring simple and easy access to new television services without the need for major changes to existing home infrastructure. As a result, users can enjoy advanced multimedia features and access to high-quality television content without unnecessary technical barriers. The modernisation of set-top boxes via FeMBMS also enables the integration of additional digital services, such as on-demand applications, which significantly enhances the appeal of this technology for users.

According to a report by the European Broadcasting Union (EBU), FeMBMS technology offers the advantage of combining broadcasting infrastructure with multicast and unicast distribution. This combination enables universal coverage that delivers a high level of service quality even at high user densities, thereby ensuring the sustainability of the services provided even under high demands on network capacity. The combination of multicast and unicast also enables the efficient use of available network resources, which reduces content distribution costs and increases the efficiency of the entire system. FeMBMS thus represents a technology capable of effectively combining various transmission methods to achieve the widest possible coverage and the highest possible quality of service.

6.3.2.3 Free-to-air broadcasting

FeMBMS technology also enables the distribution of linear television broadcasts in a ‘free-to-air’ format, meaning that users can receive the television signal directly without needing access via a mobile operator or other connectivity provider. This method of distribution makes FeMBMS particularly attractive to users who own smart TVs or set-top boxes and wish to minimise the cost of accessing television services. FeMBMS enables fast and reliable transmission even in environments with high network traffic density, which significantly improves the availability and quality of services for users in various geographical locations, including rural areas. As a result, FeMBMS is an ideal solution for delivering television content where traditional systems are too costly or technologically inefficient.

The integration of FeMBMS technology into smart TVs and set-top boxes therefore brings a number of significant benefits, ranging from easy access to high-quality content without the need for complex installation processes to the optimisation of the benefits of 5G technology in the distribution of television broadcasts. This combination of efficiency, technological modernisation and a user-friendly solution creates a strong foundation for the widespread adoption of this technology as the standard method of distributing audiovisual content in the future. It is also important to note that FeMBMS can serve as a foundation for the further development of multimedia services, which include, for example, enhanced interactive capabilities, access to specialised thematic channels, or integration with other digital platforms. Such an expansion of the services provided could fundamentally change the way consumers access television content and contribute to the creation of an entirely new level of interactivity and user convenience.

6.3.3 Automotive devices and infotainment systems

Given that most modern cars are equipped with advanced infotainment systems connected to the internet, it is necessary to analyse how FeMBMS technology impacts this sector and expands the range of multimedia content available to passengers. FeMBMS technology brings fundamental innovations to the automotive environment, not only in terms of improving access to audiovisual services, but also in terms of effective communication and information services whilst driving.

- **In-car systems**: FeMBMS enables the efficient distribution of multimedia content directly to vehicles’ infotainment systems. This direct transmission of content eliminates the need to connect to traditional mobile networks, enabling passengers to watch TV programmes, films and other on-demand multimedia content, even whilst the vehicle is in motion in areas with limited or unreliable mobile coverage. In this way, FeMBMS ensures stable and seamless content reception regardless of the current load on the mobile network. In the future, this technology is likely to become a key feature of autonomous vehicles, where infotainment will be the primary means of entertainment and relaxation for passengers, as autonomous driving does not require their full attention.

- **High-speed coverage on motorways**: FeMBMS has been designed to ensure high signal quality even at high speeds, which is useful, for example, for passengers in cars and buses watching live broadcasts. The deployment of SFN technology enables consistent coverage even along long motorway routes, guaranteeing signal stability even in challenging geographical conditions. Results from pilot projects show that FeMBMS is capable of providing extensive coverage via high-power transmitters, which is essential for achieving the reliability and quality of multimedia services in an automotive environment. Furthermore, this technology is suitable for transmitting broadcasts with low latency, ensuring user comfort whilst travelling.

- **Emergency and traffic alerts**: FeMBMS has the potential to deliver critical emergency and traffic alerts. This feature enables travellers to be informed in real time about incidents such as road accidents, road closures or sudden changes in weather conditions that may affect their journey. Thanks to its high reliability and transmission speed, FeMBMS ensures that this vital information reaches users without delay or disruption. The ability to provide timely information has a direct impact on improving safety and the flow of traffic.

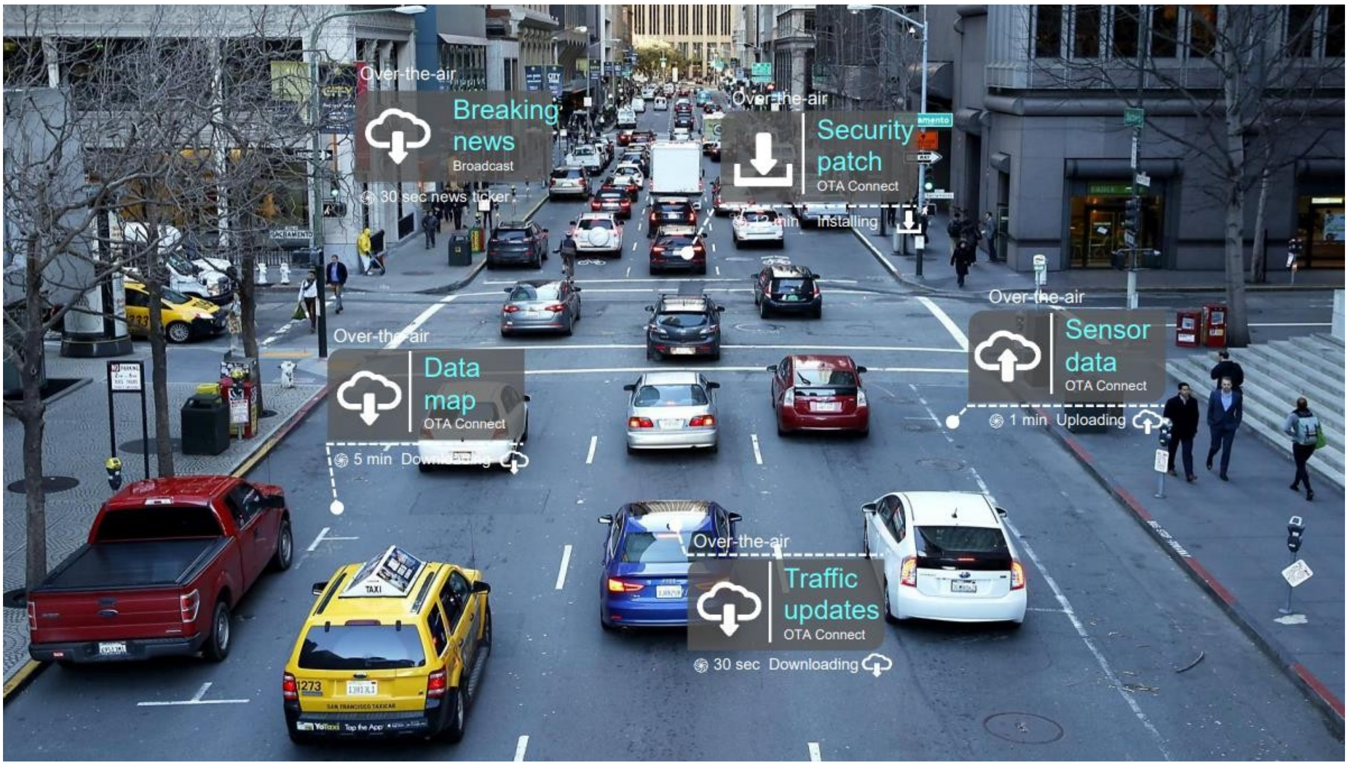

Figure 41: Transmission of updates and data in an automotive environment using

FeMBMS Source: https://f.hubspotusercontent00.net/hubfs/5253154/16%20-%20Mobile%20%26%20Automotive%20Applications%20and%20FeMBMS%20(5G-Broadcast)%20-%20Janner-1.pdf

The figure illustrates how FeMBMS technology enables the transmission of important information, such as the latest news, security patches and traffic updates. It also demonstrates how data from vehicle sensors can be utilised for early diagnostics and better decision-making whilst driving.

FeMBMS technology represents a step forward in the field of in-car entertainment and communications infrastructure. The integration of FeMBMS not only simplifies access to audiovisual content for passengers, but also provides essential information services that can significantly contribute to the overall comfort and safety of travel. FeMBMS thus offers not only enhanced multimedia capabilities but also brings new business opportunities through the efficient use of the spectrum, which benefits both multimedia service providers and car manufacturers seeking to offer their customers innovative and modern travel experiences.

7 Strategy for optimising data transmission

Optimising the transmission of audiovisual content in a 5G environment focuses on ensuring the best possible picture and sound quality whilst minimising bandwidth usage. FeMBMS technology offers a sophisticated way of utilising the available spectrum for the mass distribution of content with varying transmission capacity requirements. A successful transmission solution requires the deployment of advanced compression methods that enable the transmission quality to be dynamically adjusted according to current network conditions and the characteristics of the transmitted material.

Efficient bandwidth management is crucial not only for the quality of the services provided, but also for ensuring sufficient transmission capacity for a wide range of users. The current transmission of multiple programmes on a single channel, for example in the DVB-T format, allows up to 8 television programmes in standard definition (SD) to be broadcast over a single transmission network and places high demands on the efficiency of compression methods in order to maintain the required quality within limited capacity. The DVB-T2 standard allows for the transmission of up to 18 channels in standard definition, or up to 7 channels in high definition (HD). Using DVB-T2, terrestrial broadcasting can also transmit programmes in Ultra HD (4K) resolution. Applications demanding high data rates, where uninterrupted transmission must be ensured, include live studio reports requiring a minimum data rate of 70 Mbit/s.

The introduction of FeMBMS into 4G and 5G networks brings benefits in the form of more flexible control over transmission parameters, including more efficient use of the spectrum and the ability to transmit large volumes of data without compromising service quality. A codec is a general term for systems that encode (and decode) a signal during both transmission and reception. Modern codecs, such as H.265 (HEVC) and AV1, offer high compression efficiency, which allows high image quality to be maintained whilst reducing bandwidth requirements. Furthermore, thanks to its open licensing terms, AV1 supports easy deployment across various platforms.

Minimising latency is particularly crucial for live broadcasts and interactive events, where an immediate response is required. Adaptive streaming technologies, such as MPEG-DASH, ensure a smooth streaming experience by dynamically adjusting video and audio quality to current network conditions and available bandwidth. The deployment of single-frequency networks (SFNs) contributes to uniform coverage and improved signal stability in areas with a higher concentration of users.

Successful transmission optimisation involves not only effective compression methods and efficient use of the available spectrum, but also the correct choice of transmission protocols. The RTP/RTCP protocols are crucial for ensuring synchronisation and reliability; their adaptation for the 5G environment enables better quality of service management even under high network load. At the same time, security measures such as protecting data from unauthorised access and ensuring its integrity must be observed to safeguard sensitive and protected content.

7.1 Optimisation of television and audiovisual data transmission

Efficient use of the spectrum is one of the fundamental prerequisites for the successful roll-out of mass distribution services in 5G networks. Spectral efficiency focuses on maximising the volume of data transmitted via the available frequency band. FeMBMS enables the optimisation of transmission capacity not only by expanding the use of new frequency bands, but also by combining existing infrastructure with advanced technologies such as Single Frequency Networks (SFN). The implementation of SFN enables the simultaneous transmission of identical content from multiple transmitters on the same frequency. This approach also enhances the overall stability of the transmission network, as redundant coverage ensures transmission continues even in the event of individual transmitter failures. Effective coverage is particularly important in densely populated areas, where it is essential to ensure high-quality reception for a large number of users.

Minimising latency is another aspect of stream optimisation, particularly for live broadcasting and interactive audiovisual content. Low latency can be achieved by deploying advanced techniques such as adaptive streaming and advanced encoding methods, which dynamically adapt to network conditions. Adaptive streaming allows the transmission quality to be adjusted based on current network capacity, ensuring a consistent user experience. This technology, combined with advanced encoding methods such as H.265 and AV1, enables more efficient use of bandwidth thanks to higher compression ratios, leading to reduced transmission capacity requirements whilst minimising any loss of quality. The significance of adaptive streaming lies in its ability to respond to changing network conditions, maintaining the quality of audiovisual content without interruption or a reduction in transmission quality.

At the same time, 5G technology enables the integration of broadcasting and unicast streaming, increases the flexibility of transmission options and ensures the delivery of personalised content to individual users. The hybrid approach, which combines FeMBMS with OTT (Over-the-Top) services, represents a robust model for the distribution of television content, combining the advantages of broadcasting technologies with unicast personalisation. This hybrid model not only enables the widespread availability of traditional television broadcasting but also supports the interactivity and user customisation offered by OTT services. The combination of FeMBMS and OTT is therefore an ideal solution for providers seeking to meet the needs of a broad spectrum of viewers whilst offering personalisation options.

The next stage in transmission optimisation is the implementation of modern video codecs, such as H.265 and AV1, which utilise advanced compression algorithms for efficient data transmission with minimal loss of picture quality. These codecs, combined with adaptive streaming, enable high transmission quality to be maintained even with limited network capacity. Optimisation also includes advanced control methods, such as dynamic bitrate adjustment and adaptive transmission power control, which support the efficient use of network resources and improve transmission quality. Dynamic bitrate control adapts the transmission capacity to current network conditions.

Interoperability between different platforms and standards also plays a significant role in the transmission of television and audiovisual data over 5G networks. The integration of FeMBMS technology into existing broadcasting infrastructure represents an innovative approach that harnesses the potential of 5G for both traditional television broadcasting and modern OTT services. For providers seeking to achieve maximum coverage and service availability for a wide range of users, interoperability between different broadcasting platforms is essential. This approach also enhances the utilisation of synergies between traditional broadcasting technologies and modern content distribution methods, contributing to increased competitiveness and innovation in the services offered.

7.2 Compression techniques

7.2.1 Selection of suitable compression techniques

Effective compression is essential for optimising bandwidth when transmitting audiovisual content over 5G networks using FeMBMS technology, which supports the simultaneous broadcasting of television and multimedia content to a large number of users. Given the bandwidth demands of high-definition transmissions (e.g. 4K or 8K), effective compression is vital for reducing data volume, operational costs and network load. A balance must be struck between compression quality, bandwidth and computational requirements.

Codecs such as H.264 (AVC) and H.265 (HEVC) play an important role in this regard. H.264 offers improvements over older standards such as MPEG-2, but for very high resolutions (e.g. 4K), the bitrate can still be demanding. H.265 is popular due to its twice the efficiency, which allows the same image quality to be achieved with half the data volume.

7.2.2 MPEG-2 (Moving Picture Experts Group - 2)

MPEG-2 is one of the oldest and most widely used compression formats for digital video and television broadcasting. This technology was developed in the 1990s and quickly became the standard for digital television signal transmission (for example, for broadcasting in the DVB standard). Although MPEG-2 offers lower compression efficiency compared with newer standards, it is still widely used, particularly for applications where there are no high demands on bandwidth or image quality, such as in less data-intensive environments.

MPEG-2 is capable of transmitting video in SD (Standard Definition) and, to some extent, HD (High Definition) at relatively higher bitrates. Its compression algorithm works on the principle of predicting the image based on previous frames, which can be effective, but compared to newer standards such as H.264 or HEVC, it is less efficient at minimising the bitrate. MPEG-2 is suitable for transmissions in environments where bandwidth is relatively high and latency is not critical, such as in terrestrial broadcasting or older cable television systems. However, it is not the ideal choice for mobile networks, where bandwidth is limited and transmission capacity requirements are higher.

7.2.3 H.264 (Advanced Video Coding – AVC)

MPEG-2, developed in the 1990s, is one of the most widely used formats for digital video and television broadcasting, particularly within the DVB standard. Although it offers lower compression efficiency than newer codecs such as H.264 or HEVC, it is still used where there are no high demands on bandwidth or picture quality. MPEG-2 is capable of transmitting SD-resolution video and, to some extent, HD video at higher bitrates, making it suitable for terrestrial broadcasting or older cable systems, but less suitable for mobile networks with limited bandwidth.

7.2.4 HEVC (High Efficiency Video Coding – H.265)

H.264, also known as AVC, is a popular compression format introduced in 2003, which offers greater efficiency than MPEG-2. It enables the transmission of HD video at lower bitrates. It is suitable for television broadcasting, streaming, video conferencing and recording to various media. It utilises an advanced compression algorithm with prediction based on both preceding and subsequent frames, enabling efficient compression without loss of quality. Compared to MPEG-2, it achieves up to double the bandwidth savings. H.264 is attractive for FeMBMS due to its support for the transmission of high-quality content and its broad compatibility with various devices.

7.2.5 Comparison of MPEG-2, H.264 and HEVC

Table 3: Comparison of MPEG-2, H.264 and HEVC

Codec	MPEG-2	H.264	HEVC
Block size	16x16 (Macroblock)	16x16 (Macroblock)	8x8 to 64x64 (Encoding unit)
Partitioning	Inter 16x16, Intra 8x8	Sub-blocks up to 4x4	Intra: Down to 4x4 (symmetric), Inter 4x8 and 8x8 in bidirectional, asymmetric 4x4
Transform	Floating-point DCT	Integer DCT 8x8 4x4	Square IDCT from 32x32 to 4x4 + DST Luma Intra 4x4
Intra prediction	DC predictor	Up to 9 predictors	35 predictors
Motion prediction	Vector from one neighbour	Spatial median (5 blocks)	Advanced motion prediction with both spatial and temporal components
Motion compensation mode	Direct mode	Direct mode	Merge mode
Motion accuracy	½ pixel, linear	¼ pixel (6-tap system) + ½ pixel linear	½ pixel or ¼ pixel chroma with 1/8 pixel luma
Entropic encoding	VLC	CABAC or CAVLC	CABAC (with parallel operations)
Filters	Deblocking filter	Deblocking Filter	Deblocking filter and SAO adaptive offset
Multi-core tools	Slices	Slices	Wavefront parallel processing, tiles, slices
Scalability tools	Via extensions	Via extensions	Temporary scalability included (further options under discussion)

The table compares the tools used by the three main video compression standards: MPEG-2, H.264 and HEVC. Each of these standards offers different data compression techniques that affect image quality, compression efficiency, bandwidth and computational complexity. A detailed description of each aspect is provided below:

- Block size and partitioning: MPEG-2 and H.264 use fixed 16×16-pixel macroblocks, whilst HEVC introduces variable units ranging from 8×8 to 64×64 pixels, enabling more efficient compression of both large and complex areas of the image. HEVC also offers asymmetric block partitioning for better adaptation to image details.
- Transform: MPEG-2 relies on a floating-point DCT, H.264 uses an integer DCT for lower computational complexity, whilst HEVC introduces advanced techniques such as IDCT and DST with variable-size transforms for higher quality and lower bitrate.
- Intra prediction: MPEG-2 uses a simple predictor; H.264 offers 9 prediction directions; and HEVC increases this number to 35, which significantly improves compression for detailed images.
- Motion prediction and compensation: MPEG-2 has basic motion prediction; H.264 adds a median method; and HEVC combines spatial and temporal elements with higher precision (up to 1/8 of a pixel), which improves compression in fast-moving scenes.
- Entropy coding: MPEG-2 uses basic VLC; H.264 introduces advanced CABAC/CAVLC; and HEVC utilises parallel CABAC for higher compression efficiency.
- Filters and multi-core processing: MPEG-2 and H.264 rely on a ‘deblocking filter’; HEVC additionally introduces an SAO filter and utilises parallel processing (Wavefront) for improved efficiency.
- Scalability: MPEG-2 and H.264 offer basic scalability, whilst HEVC introduces temporal scalability to dynamically adjust quality according to network conditions, which is advantageous for 5G streaming.

8 Data transmission security

In 5G networks and FeMBMS technology, data backup and protection are essential for the reliability of the services provided. FeMBMS enables the broadcasting of multimedia content across a wide geographical area and places demands not only on transmission speed but also on data security and availability. Any loss or compromise may cause service interruptions, jeopardise providers' reputations or lead to legal consequences.

FeMBMS ensures the availability of television and audiovisual broadcasts to a wide audience and requires effective management of the risks associated with content protection. Encryption techniques protect data from unauthorised access and ensure that false reports or other falsified content, which could lead to the spread of disinformation, cannot be broadcast.

Emphasis is also placed on copyright protection to prevent the unauthorised copying and distribution of protected content, thereby averting financial losses and legal issues. Anti-piracy measures and safeguards against unauthorised access help to maintain service quality and protect authors' rights

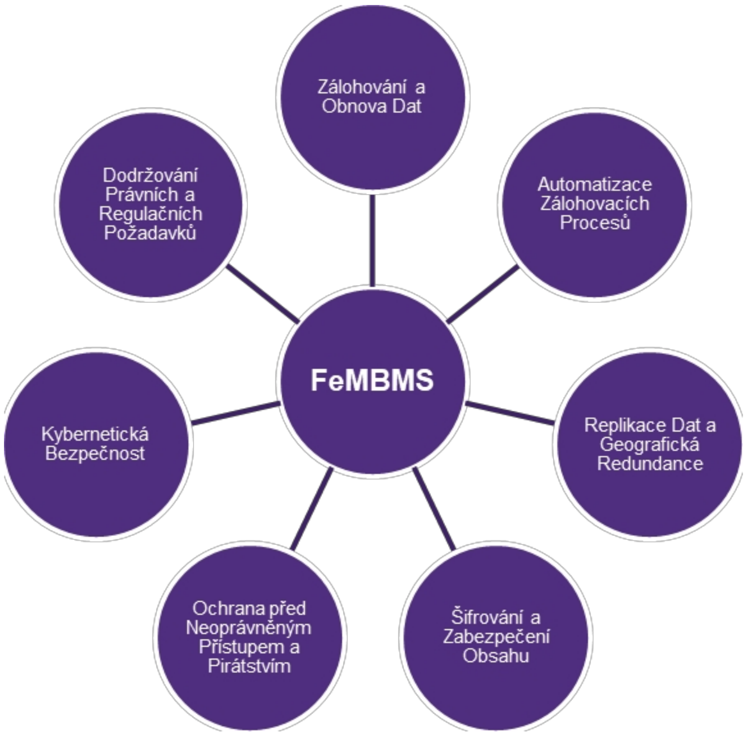

Figure 42: Factors Affecting FeMBMS

The diagram illustrates the areas that influence the functioning of FeMBMS technology. FeMBMS is positioned at the centre as the core element, whilst factors such as data backup and recovery, automation of backup processes, replication and geographical redundancy, encryption and content security, protection against unauthorised access and piracy, cyber security, and compliance with legal and regulatory requirements are listed around it. The diagram illustrates the interconnectivity and importance of each factor for the overall functionality and security of the FeMBMS service provided.

This chapter focuses on mechanisms for the backup and recovery of data transmitted via FeMBMS, as well as measures to secure content against unauthorised access, piracy and attacks on data integrity. A thorough analysis of these mechanisms and security measures is essential to ensure the continuity and security of services in 5G networks, particularly when deployed in critical applications such as television and audiovisual broadcasts.

8.1 Security aspects of FeMBMS

8.1.1 Verification and authentication

User and device authentication enables the efficient distribution of multimedia content over mobile networks. It ensures that only authorised entities can access the broadcast content, minimising the risk of unauthorised access and potential security threats.

One of the main pillars of authentication within FeMBMS is the Public Key Infrastructure (PKI). PKI enables the secure management, distribution and verification of public and private keys used for encrypting and decrypting communications on the network.

8.1.1.1 Public Key Infrastructure (PKI)

- PKI is a comprehensive system comprising:
  - Certification Authorities (CAs): Trusted entities that issue digital certificates confirming ownership of a specific entity's public key.
  - Key registration and management: Processes for generating, storing and renewing key pairs (public and private keys).
  - Certificate distribution: Mechanisms for the secure distribution of public keys and associated certificates amongst users and devices.
- PKI operates on the principle of asymmetric cryptography, where:
  - The public key is available to all entities on the network and is used to encrypt messages or verify a digital signature.
  - The private key is secret and held only by the owner; it is used to decrypt messages or create a digital signature.
- The PKI authentication process:
  - Key pair generation: The user or device generates a pair of keys (public and private).
  - Obtaining a certificate: The public key is sent to a certification authority, which verifies the applicant's identity and issues a digital certificate.
  - Certificate distribution: The certificate is distributed across the network, where other entities can use it to verify the identity of the public key holder.
  - Authentication: When a user or device wishes to connect to the network or access content, they prove their identity using their private key in combination with the public key contained in the certificate.

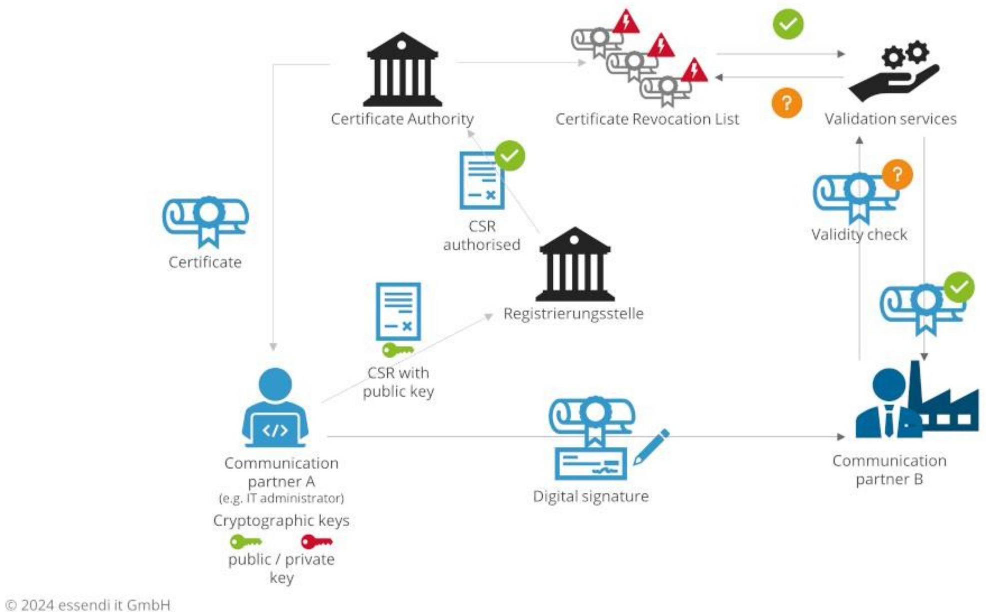

Figure 43: How a PKI works

Source: https://www.essendi.de/en/what_is_a_pki/

This diagram illustrates how a public key infrastructure (PKI) works, enabling the secure management and distribution of certificates within a network. The process begins with the creation of a certificate signing request (CSR) containing the public key of the user (communication partner A). The certification authority verifies this request and issues a digital certificate, which the user can then use for digital signing. The certificates are subsequently checked by validation services, which verify their validity against a certificate revocation list (CRL). Communication partner B then receives the certificate from partner A and can verify its validity and authenticity, ensuring secure and trustworthy communication.

The entire process is based on asymmetric cryptography, where the public key is used for encryption or verifying digital signatures, whilst the private key is used for decryption or creating signatures.

- Advantages of PKI:
  - Security: A high level of security thanks to the use of asymmetric cryptography.
  - Trustworthiness: Certificates issued by trusted authorities ensure the authenticity of entities.
  - Scalability: Suitable for networks with a large number of users and devices.

8.1.1.2 Authentication protocols

Various authentication protocols are used to integrate authentication mechanisms into the FeMBMS network architecture. These protocols ensure not only identity verification, but also authorisation management and activity monitoring.

- EAP (Extensible Authentication Protocol)

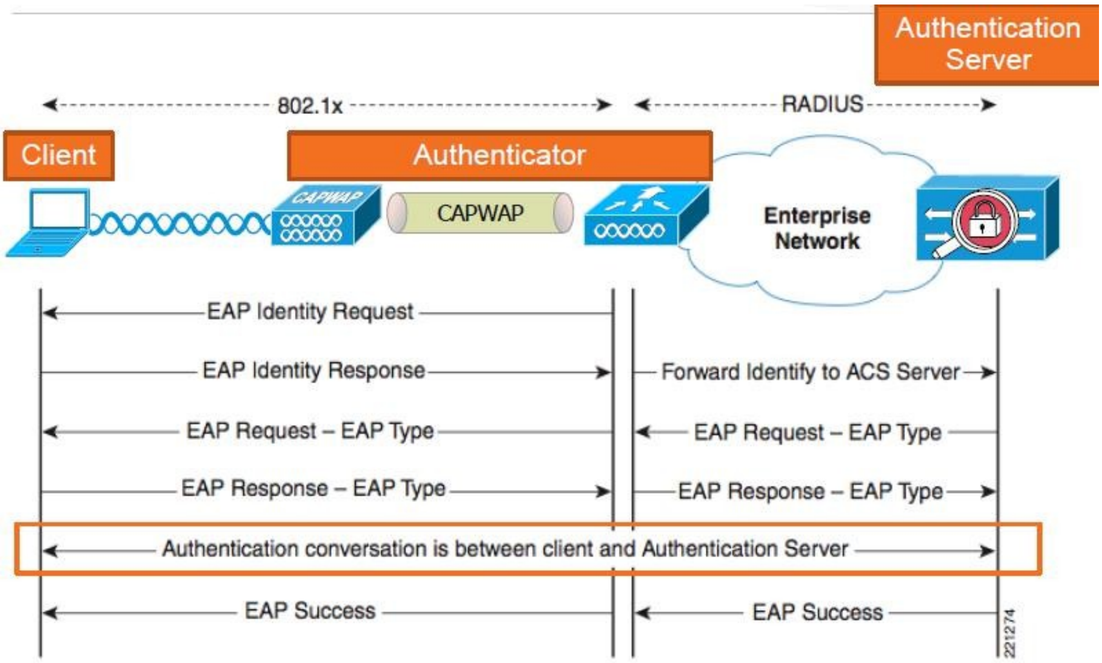

Figure 44: How EAP works

Source: https://mrncciew.com/2013/03/03/eap-overview/

This diagram illustrates the authentication process within the EAP (Extensible Authentication Protocol). EAP is used to securely verify the identity of the client, the authenticator and the authentication server over a network. The client sends its identity and receives an EAP request for further data required for authentication. Following an exchange of requests and responses between the client and the server, the authentication dialogue takes place directly between the client and the authentication server, with the process concluding with successful authentication (EAP Success).

This diagram illustrates the message flow between the client, the authenticator and the authentication server, using the RADIUS protocol within an enterprise network. EAP enables a flexible and modular approach to authentication using various methods, such as EAP-TLS, EAP-TTLS or EAP-PEAP, ensuring a high level of security and compatibility across different types of networks.

- EAP is a flexible authentication framework that allows the use of various authentication methods:
  - EAP-TLS (Transport Layer Security): Uses digital certificates for mutual authentication between the client and the server. It is considered one of the most secure protocols.
  - EAP-TTLS (Tunneled TLS): Enables one-way server authentication using a certificate, followed by client authentication via a secure tunnel.
  - EAP-PEAP (Protected EAP): Creates a secure tunnel between the client and the server, within which authentication takes place using other methods, such as passwords or tokens.

- Advantages of EAP:
  - Modularity: Easy integration of new authentication methods according to network requirements.
  - Security: Support for strong encryption algorithms and secure authentication methods.
  - Compatibility: Wide support across various network types, including Wi-Fi, Ethernet and mobile networks.
- AAA protocols (Authentication, Authorisation, Accounting) – AAA protocols are essential for comprehensive management of user access and activities on the network.

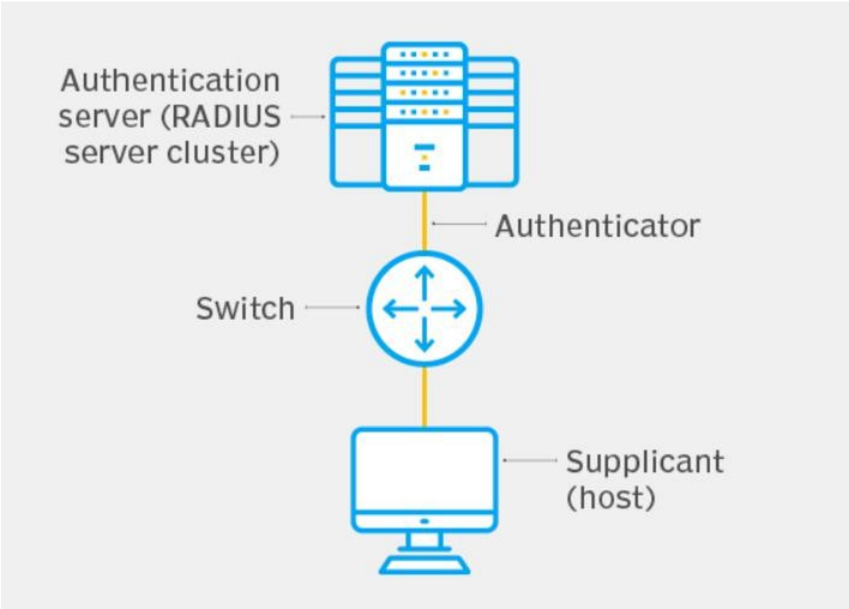

Figure 45: AAA protocol

Source: https://medium.com/@sabinajafar533/authentication-authorization-and-accounting-aaa-75592e37642b

This diagram illustrates the basic components of an AAA (Authentication, Authorisation, Accounting) system. The figure shows the interaction between the three main elements:

Supplicant (host): A client or device requesting access to the network.

Switch (Authenticator): A device that mediates communication between the supplicant and the authentication server.

Authentication server (RADIUS server cluster): A server that manages the authentication, authorisation and accounting processes within the network. The server verifies user information and determines access rights.

- RADIUS (Remote Authentication Dial-In User Service):
  - Authentication: Verifies the user when they log in to the network.
  - Authorisation: Determines which services the user has access to.
  - Accounting: Tracks user activities for monitoring and billing purposes.
- Diameter:
  - Developed as the successor to RADIUS to meet the needs of modern networks.
  - It supports more advanced authentication mechanisms and improved security.
  - Suitable for networks with high demands on performance and scalability, such as LTE and 5G.
- AAA protocol functions in FeMBMS:
  - Access security: Ensures that only authorised users and devices can access the network and content.
  - Access control: These allow rules to be defined and applied for access to different types of content.
  - Monitoring and auditing: These provide tools for tracking user activities, which is important for security analysis and regulatory compliance.
  - Other authentication methods and technologies

In addition to PKI and the protocols mentioned above, other authentication methods can also be implemented within FeMBMS:

- Biometric authentication:
  - Fingerprint, facial recognition or iris scanning to verify a user's identity.
  - This enhances security by utilising unique physical characteristics.
- One-time passwords (OTP):
  - Passwords that are valid for only a single login or transaction.
  - Sent via text message, email or generated by specialised apps.
- Two-factor authentication (2FA):
  - A combination of two independent authentication factors, such as a password and an OTP.
  - Significantly reduces the risk of unauthorised access should one of the factors be compromised.
- Hardware-based certificates:
  - Storing private keys on secure hardware devices, such as TPMs (Trusted Platform Modules) or smart cards.
  - This enhances security as the keys never leave the secure hardware environment.
- Implementation and challenges – Implementing effective authentication mechanisms in FeMBMS presents certain challenges:
  - Management complexity: Managing a large number of keys, certificates and users requires robust systems and processes.
  - Performance and latency: Authentication processes can introduce delays, which is critical in real-time applications.
  - Compatibility and standardisation: Ensuring that different devices and systems can interoperate seamlessly requires adherence to standards and protocols.
  - Security threats: Ever-evolving threats, such as phishing, malware or man-in-the-middle attacks, require regular updates to security measures.

User and device authentication is essential for securing the content and services provided via FeMBMS. The use of advanced methods, such as PKI, combined with flexible authentication protocols such as EAP and AAA, provides a robust framework for protection against unauthorised access.

Implementing these technologies requires careful planning and management, but brings significant benefits in the form of enhanced security, trust and user satisfaction. In the dynamic environment of modern mobile networks, it is important to constantly monitor developments in the field of security and adapt authentication mechanisms to new threats and requirements.

8.1.2 Resilience to attacks

In today's digital age, resilience to attacks is a crucial aspect of security in telecommunications networks. With the growing number of threats, it is essential to implement robust protection mechanisms that ensure service continuity and protection against various types of attacks, including cyber and physical attacks.

8.1.2.1 Denial-of-Service (DoS) attacks

Denial-of-Service (DoS) attacks are attempts by an attacker to disrupt the availability of a network or service by flooding it with an excessive amount of data or requests. This can lead to system overload, service slowdowns or complete outages, which have a negative impact on both users and service providers.

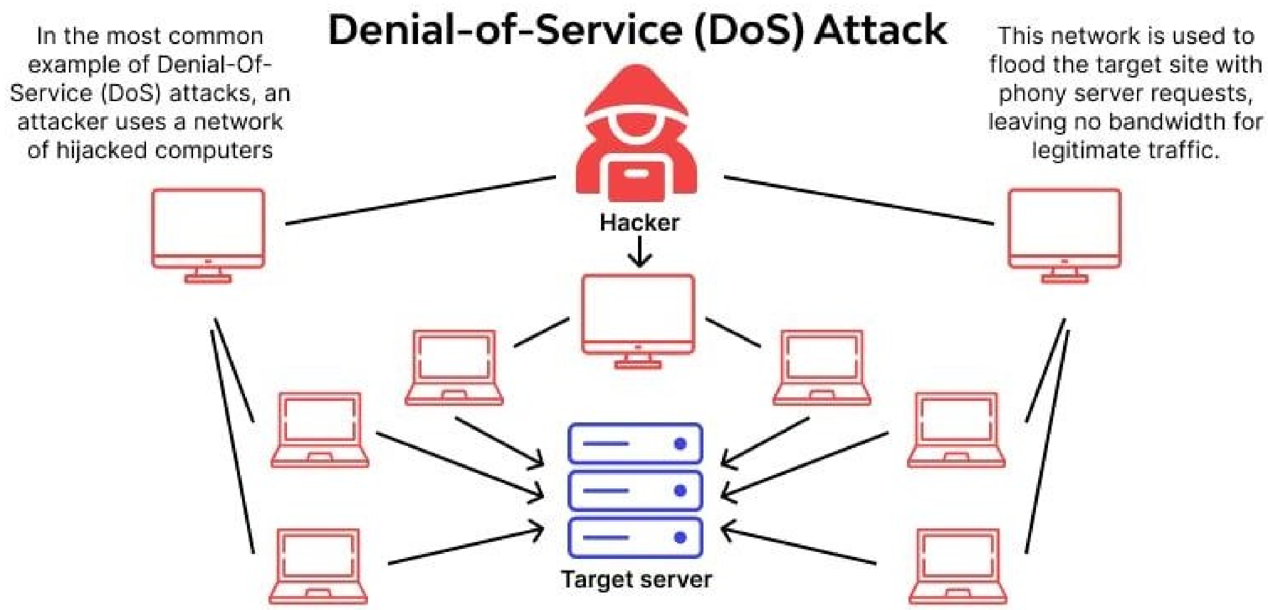

Figure 46: Denial-of-Service (DoS) attack

Source: https://www.wallarm.com/what/dos-denial-of-service-attack

This diagram illustrates the process of a Denial-of-Service (DoS) attack, in which an attacker uses a network of compromised computers (a botnet) to flood the target server with fake requests. This prevents the server from handling legitimate traffic, leading to an outage or slowdown in the services provided. The attacker uses various computers to overwhelm the target server, thereby preventing it from functioning normally. This type of attack is a common method of disrupting the availability of online services and causing damage to both service providers and users.

Mechanisms for protection against DoS attacks:

- Detection systems (IDS/IPS):
  - Intrusion Detection Systems (IDS) monitor network traffic and look for suspicious activity or patterns that indicate an ongoing attack.
  - Intrusion Prevention Systems (IPS) not only detect but also actively block malicious traffic, thereby preventing attacks in real time.
- Signal encryption:
  - Encrypting communication between devices ensures that only authorised entities can access the network and exchange data.
  - Authenticating users and devices using certificates or cryptographic keys prevents unauthorised access and misuse of the network.
- Rate limiting:
  - Implementing policies that limit the number of requests from a single IP address or device can prevent network congestion.
  - Throttling ensures that the network remains available to other users even during periods of increased traffic.
- Redundant infrastructure:
  - Load balancers and distributed servers spread the load across multiple devices, increasing resilience against attacks targeting a single point.
  - Geographically distributed networks (CDNs) can absorb attacks by dispersing traffic across the globe.
- Network traffic analysis:
  - The use of machine learning and artificial intelligence to detect anomalies in network traffic enables rapid identification of and response to suspicious activity.
  - Proactive monitoring helps prevent attacks before they cause any damage.
- Firewall and packet filtering:
  - Advanced firewalls can block malicious traffic based on predefined rules and dynamic analyses.

– Packet filtering enables the control and management of access at the level of individual data packets.

8.1.2.2 Protection against physical attacks

Physical attacks, such as jamming or signal interference, aim to disrupt wireless communications by having an attacker transmit signals on the same frequency, thereby causing interference. These attacks can lead to a degradation in service quality or a complete loss of communication.

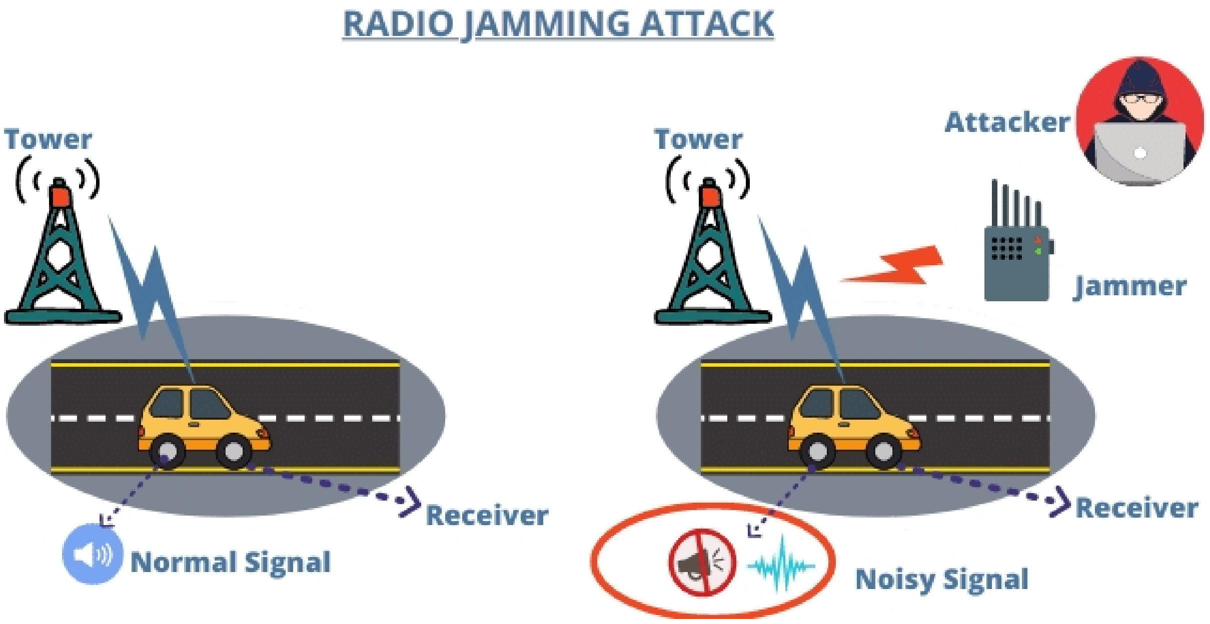

Figure 47: Radio Jamming Attack

Source: https://networksimulationtools.com/radio-jamming-attack-network-projects/

Figure description: This diagram illustrates a radio jamming attack, in which an attacker (labelled 'Jammer') transmits malicious signals on the same frequency used by legitimate wireless communication equipment. The left-hand side of the figure shows a typical situation where the receiver receives a normal signal from the transmitter (tower). On the right-hand side, we see an attack in which the attacker disrupts communication between the transmitter and the receiver by generating noise signals, leading to a degradation in signal quality or a complete loss of communication.

In the context of protection against physical attacks such as jamming, various techniques need to be implemented, for example, frequency-hopping spread spectrum (FHSS, DSSS) techniques, robust modulation techniques (OFDM), directional antennas, jamming detection and other protective measures described in the text. These technologies ensure greater resilience to such attacks and enhance the security of wireless communications.

Protective measures against physical attacks:

- Spectrum-spreading techniques:
  - Frequency Hopping Spread Spectrum (FHSS): Rapid switching between frequencies in a predetermined pattern, making it difficult for an attacker to track and jam the signal.
  - Direct Sequence Spread Spectrum (DSSS): Spreading the signal across a wide frequency band using a special code, which the receiver must know in order to decode it correctly.
- Robust modulation techniques:
  - Orthogonal Frequency Division Multiplexing (OFDM): Dividing the signal into multiple orthogonal frequencies increases resistance to interference on individual frequencies.
  - Adaptive modulation schemes allow for real-time adaptation to changing conditions.
- Directional antennas and beamforming:
  - Directional antennas concentrate transmission energy in a specific direction, reducing the likelihood of interference from other directions.
  - Beamforming uses multiple antennas to create a strong signal in the desired direction and suppress interference from other directions.

- Interference detection and localisation:
  - Spectral sensors monitor the radio spectrum and detect unusual signals or interference.
  - Geolocation technology can determine the location of the source of interference, facilitating its removal or legal action.
- Regulation and cooperation with authorities:
  - Legal frameworks and regulations set out penalties for the illegal jamming of radio signals.
  - Cooperation with government and security agencies can help to resolve interference incidents quickly.
- Backup communication channels:
  - Redundant systems using different frequencies or technologies can ensure service continuity in the event of interference with the primary channel.
  - Automatic switching to less congested frequencies increases network resilience.
- Encryption and authentication at the physical layer:
  - Physical Layer Security (PLS) utilises the characteristics of the physical channel to secure communications, making it more difficult for an attacker to successfully jam or eavesdrop.
  - Authentication protocols ensure that only authorised devices can communicate on the network.

8.1.2.3 Implementation and challenges

Implementing effective protective measures against attacks presents several challenges:

- Technical complexity:
  - Advanced technologies, such as beamforming or adaptive modulation schemes, require sophisticated hardware and software solutions.
  - Integrating various security mechanisms can be challenging in terms of compatibility and performance.
- Costs:
  - Investment in advanced security systems and infrastructure can be financially demanding.
  - Striking a balance between costs and security levels is key to effective implementation.
- Updates and maintenance:
  - Regular updates are essential to maintain protection against new types of attacks.
  - Managing security policies and configurations requires specialist knowledge and resources.
- The human factor:
  - Staff training in security is essential for an effective response to incidents.
  - User awareness of security threats can reduce the risk of successful attacks utilising social engineering.
- Legal and ethical aspects:
  - Protective measures must comply with legal regulations and ethical standards.
  - Ensuring user privacy whilst monitoring and analysing network traffic is essential.

Resilience against attacks is essential for maintaining the security and reliability of modern communication networks. A combination of technical solutions, such as detection systems, encryption and advanced antenna technologies, together with organisational measures, such as training and cooperation with regulatory authorities, forms a comprehensive defence strategy.

A proactive approach to security, involving constant monitoring of threats and updating of protective mechanisms, is essential for successful defence against DoS attacks and physical threats such as jamming. This ensures the continuous availability of services and user confidence in the security of the communication systems provided.

8.2 Content security

Broadcasting via FeMBMS (Further Evolved Multimedia Broadcast Multicast Service) technology involves not only the distribution of multimedia content but also critical data security issues. When transmitting audiovisual services and other content in real time, it is essential to protect this data from unauthorised access, piracy and cyber-attacks. These measures are important both for the protection of intellectual property rights and for ensuring the integrity and security of data for end users.

8.2.1 Protection against unauthorised access and piracy

In the FeMBMS environment, it is essential to ensure that content is accessible only to authorised users. This includes protection against piracy and the unauthorised distribution of content, which could jeopardise the financial interests of content providers and infringe intellectual property rights.

- Digital Rights Management (DRM): DRM systems are implemented as part of FeMBMS to protect content from unauthorised copying or playback. DRM systems control which users are authorised to access a given piece of content and how they may use it (e.g. by limiting the number of plays or sharing).
- Conditional Access Systems (CAS): FeMBMS can utilise CAS technologies, which enable the control of access to broadcast content based on a valid subscription or other authorisations. CAS prevents unauthorised users from receiving content without the appropriate rights. This system is crucial for the broadcasting of paid content, such as premium television channels.

8.2.2 User authentication and authorisation

User authentication is another important mechanism for ensuring content security. Authentication methods can be used to ensure that only authorised users can access broadcast content.

- Two-factor authentication (2FA): Two-factor authentication adds an extra layer of security by requiring two different forms of verification (for example, a password and a one-off code sent to the user's mobile phone). This minimises the risk of unauthorised access, even if login credentials are compromised.
- Certificate-based authentication: In the FeMBMS environment, users can also be authenticated using digital certificates. This process utilises asymmetric encryption, whereby the user's device is equipped with a certificate issued by a trusted certification authority. The certificate is verified every time a connection is made to the broadcast server, thereby ensuring secure communication between the server and the end device.

8.2.3 Data integrity protection

It is essential to ensure that data transmitted via FeMBMS is protected throughout the entire transmission process and that it is not subject to unauthorised alteration or modification.

- Checksums and hashing: FeMBMS implements techniques such as checksums and cryptographic hash functions (e.g. SHA-256) to verify the integrity of the transmitted data. These techniques ensure that the data has not been corrupted or altered during transmission and enable the immediate detection of any unauthorised interference.
- Detection of unauthorised changes: If data integrity is compromised during transmission, the broadcasting system can respond immediately and either resume the transmission or send new, undamaged data packets. This mechanism is particularly critical for live broadcasts, where any delay or signal loss can cause significant disruption to the service.

8.2.4 Protection against cyber attacks

The FeMBMS infrastructure is vulnerable to various types of cyber threats, ranging from direct DDoS (Distributed Denial of Service) attacks to attempts to compromise the network and steal data. It is therefore essential to implement advanced security mechanisms to protect both the transmission infrastructure and the data being transmitted.

- Attack detection and prevention (IDS/IPS): FeMBMS transmission networks are equipped with intrusion detection and prevention systems (IDS/IPS), which monitor traffic in real time and identify attempts at unauthorised access or attacks. These systems can automatically block suspicious activity or redirect traffic to secure servers, thereby minimising the impact of an attack.
- Protection against DDoS attacks: In 5G networks, it is essential to protect against distributed attacks that can overload the network and cause service outages. FeMBMS implements various methods to mitigate DDoS attacks, including load balancing, traffic filtering and the automatic redirection of unwanted traffic to a sandbox for analysis.

8.2.5 The importance of encryption in television and audiovisual services

Encryption has become one of the tools for protecting content in modern television and audiovisual services. With the development of digital broadcasting and streaming platforms, which make content available to the general public via the internet, cable networks or mobile devices, the risks associated with unauthorised access, piracy and copyright infringement are also on the rise. Without properly configured protection, any sensitive content – including pay-TV channels, films or private videos – could easily be stolen, distributed and used without the consent of the rights holders.

8.2.5.1 Security risks associated with the transmission of media data

The transmission of media data over public networks, such as the internet, is exposed to various security threats. One of the greatest risks is unauthorised access, whereby an attacker gains access to audiovisual content without authorisation, often with the intention of distributing or misusing it. Another problem is piracy, which involves the unauthorised distribution of protected content without the consent of the copyright holders. This problem is particularly serious in the entertainment industry, where illegal copies of films, television programmes or sports broadcasts can lead to losses running into billions.

Encryption ensures that data remains unreadable to unauthorised persons whilst in transit. When data is encrypted, it is converted into a format that can only be decrypted using a specific key. This process ensures that even if an attacker gains access to the data, they will not be able to decrypt it without knowledge of the encryption key.

8.2.5.2 Privacy and copyright protection

In television and audiovisual services, the protection of users' privacy and copyright is essential. Pay-TV programmes, streaming services and on-demand content must be protected to ensure that only authorised users have access. Without encryption, it would be easier for users to circumvent payment systems and consume content illegally.

Encryption technologies such as AES (Advanced Encryption Standard) or RSA (Rivest-Shamir-Adleman) are designed to ensure a high level of content protection. AES is a fast symmetric encryption algorithm that ensures transmitted content is protected even in real time. RSA, as an asymmetric encryption method, ensures secure transmissions between service providers and end users.

8.2.5.3 Encryption as part of legislative requirements

In the European Union, the protection of copyright and the transmission of audiovisual content is enshrined in legislation, specifically the Audiovisual Media Services Directive (AVMSD), which requires audiovisual service providers to ensure that their content is protected against unauthorised access. In addition to copyright protection, emphasis is placed on protecting vulnerable groups, such as children, from inappropriate content, which requires additional encryption and transmission security mechanisms.

Encryption technologies are therefore not only a technical but also a regulatory requirement for content providers wishing to comply with data protection and privacy regulations. In many cases, they are also combined with other technologies, such as digital rights management (DRM), which ensures control over who has access to what content and prevents its illegal distribution.

8.2.5.4 The role of encryption in the security of streaming services

Streaming services such as Netflix, Amazon Prime Video and Disney+ rely on robust encryption protocols to ensure that their content is transmitted securely from servers to users. These platforms use a combination of symmetric and asymmetric encryption techniques for content protection and access control. TLS/SSL protocols are often used to encrypt communication between the user and the server, whilst AES is used for the actual transmission of media content.

Encryption ensures that content can be distributed securely even on networks where there is a high risk of attacks, and that users can consume content without fear of their personal data being leaked or unauthorised access to their devices.

8.2.6 Analysis of encryption technologies

Encryption technologies form the basis of data and content security in modern communication networks, including 5G networks and multimedia services such as television broadcasting and streaming platforms. Different encryption algorithms vary in terms of their application, computational complexity, speed and security, and their selection depends on the specific purpose and requirements. In television and audiovisual services, encryption is used both to protect the transmission of content itself and to authenticate users and protect sensitive information.

8.2.6.1 Symmetric encryption technologies

Symmetric encryption is based on the use of a single key for both encrypting and decrypting data. This type of encryption is particularly popular due to its speed and efficiency, which make it an ideal choice for the transmission of large volumes of data, such as videos and multimedia files.

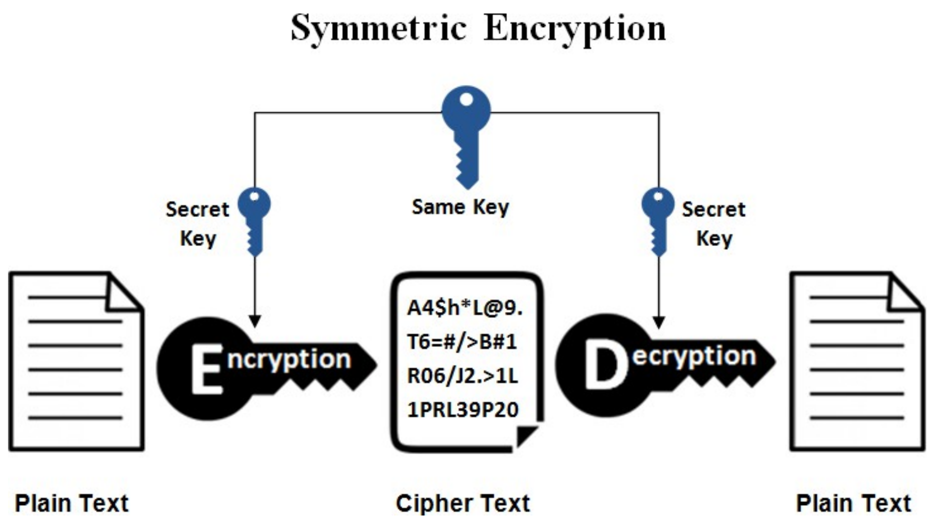

Figure 48: Symmetric encryption

Source: https://www.ssl2buy.com/wiki/symmetric-vs-asymmetric-encryption-what-are-differences

This figure illustrates the principle of symmetric encryption. On the left-hand side is plain text, which is encrypted using a secret key during the encryption process. The result is ciphertext, which can be decrypted using the same secret key on the right-hand side during the decryption process, thereby restoring the original plaintext. In symmetric encryption, the same key is used for both encryption and decryption, which requires a secure method of sharing the key between the sender and the recipient

AES (Advanced Encryption Standard)

AES (Advanced Encryption Standard) is one of the most widely used symmetric encryption algorithms in the world, having become the gold standard for data encryption in government, financial and healthcare systems. It was designed in 2001 as the successor to the older DES (Data Encryption Standard) algorithm, which had become vulnerable to modern attacks. AES has not only brought greater security, but also significantly improved performance and flexibility.

- How AES works: AES is a symmetric encryption algorithm, which means that the same key is used for both encrypting and decrypting data. AES uses block ciphering, meaning it processes fixed-size blocks of data, each 128 bits (16 bytes) in length. In addition, AES supports various encryption key lengths, which can be 128, 192 or 256 bits. Longer keys provide a higher level of security, but also place greater demands on computational power.
- AES operates on the basis of repeated operations known as encryption rounds. The number of these rounds varies according to the key length:
  - 10 rounds for 128-bit keys,
  - 12 rounds for 192-bit keys,
  - 14 rounds for 256-bit keys.

  Each round comprises several basic steps, such as byte substitution (SubBytes), row shifting (ShiftRows), column mixing (MixColumns) and key addition (AddRoundKey). These operations transform the original data into an encrypted message that is transmitted securely.
- The use of AES in audiovisual services: In the field of television and audiovisual services, AES is highly important due to its ability to quickly encrypt large volumes of data without significantly impacting device performance. Audiovisual content, such as films, television programmes or live sports broadcasts, requires efficient real-time data processing. Thanks to its optimised structure, AES enables the transmission of this data without any noticeable delay. AES encryption is commonly used in conjunction with TLS/SSL protocols, which ensure secure communication between servers and end devices. Here, AES serves as the primary mechanism for encrypting transmitted content, whilst asymmetric algorithms, such as RSA, are used for exchanging encryption keys and authenticating users.
- For audiovisual services that deliver content to millions of users worldwide, AES is the ideal solution, as it ensures:

- Fast encryption and decryption of data: Thanks to its high speed, AES can easily encrypt multimedia content in real time.
- Low computational impact: Although AES provides a high level of security, it has a minimal impact on device performance and can therefore be used even on less powerful devices, such as smartphones or tablets.
- Wide cross-platform support: AES is standardised and supported by most modern platforms, meaning it can be used effectively on various types of devices, including televisions, computers and mobile devices.

- AES security features: One of the main advantages of AES is its resistance to a wide range of attacks. Thanks to its structure, AES is considered highly secure even against modern attack techniques such as brute-force attacks or differential cryptanalysis. Its security is proportional to the key length. Keys of 128 bits in length provide more than sufficient security for most applications, whilst keys of 256 bits in length are considered practically unbreakable using current computing power.
- AES is also energy-efficient. Its use is advantageous in mobile and cloud environments, where energy consumption needs to be optimised.
- Advantages and disadvantages of AES
  - Advantages of AES:
    - Speed: AES is designed for fast data processing, making it an ideal algorithm for streaming and online broadcasting.
    - Security: It offers a high level of security even when using shorter keys (128 bits), whilst longer keys provide virtually unbreakable protection.
    - Efficiency: As AES requires relatively few computational resources, it can be deployed across a wide range of devices, from high-performance servers to mobile devices.
  - Disadvantages of AES:
    - Symmetric nature: As AES is a symmetric algorithm, it requires the sender and recipient to share the same key, which can be complicated when distributing keys in large-scale systems. This issue is addressed by combining AES with asymmetric algorithms, such as RSA, for secure key exchange.

AES remains one of the most important encryption algorithms today. Its combination of speed, security and efficiency makes it an ideal solution for encrypting large volumes of data, particularly in the field of television and audiovisual services. Thanks to its widespread support, robust security features and low impact on performance, AES is an indispensable component of modern encryption systems across many industries, including 5G networks and digital broadcasting.

DES (Data Encryption Standard)

DES (Data Encryption Standard) was one of the first widely used encryption algorithms for protecting digital data. DES was developed in the 1970s and was standardised as an encryption method for the US federal government in 1977. Although it was considered groundbreaking at the time, its gradual replacement by more modern and secure algorithms, such as AES, highlights its limitations in the context of current security requirements.

- How DES works: DES is a symmetric block cipher, which means it uses the same key for both encrypting and decrypting data. DES operates on 64-bit blocks of data and uses a 56-bit key (8 bits are reserved for parity checking, making the effective key length 56 bits). This relatively short key length became one of the main reasons why DES was considered vulnerable to modern attacks, such as brute-force attacks.
- DES operates on the basis of the Feistel structure, which comprises 16 rounds of encryption. Each round consists of the following operations:
  - Splitting the input block into two halves (left and right).
  - Permutation and substitution – Substitution boxes (S-boxes) are a key element of DES, where parts of the block are replaced with other values according to defined rules.
  - Bit shifts and XOR operations with keys generated for each round.

  Following these operations, ciphertext is produced, which can subsequently be decrypted provided the correct key is available.
- Historical significance of DES: At the time of its creation, DES was considered revolutionary. It became the basis for data encryption in many industries, including the banking sector and government systems. Given the relatively limited computing power of the 1970s and 1980s, a 56-bit key length was considered sufficiently secure against attempts to break the cipher. One of the main advantages of DES at the time was its simplicity of implementation. The algorithm was designed to be easy to use in both hardware and software, making it an accessible choice for a wide range of applications. Furthermore, its Feistel structure provided an acceptable level of security with relatively low computational complexity.
- Disadvantages of DES:

- However, with the increasing computational power of modern computers, DES has become vulnerable. Brute-force attacks, in which an attacker systematically tries all possible key combinations, have become the main threat to DES security. With a key length of 56 bits, the number of possible combinations is 2^56 (approximately 72 quadrillion), which was previously considered an insurmountable number. However, modern computing technology makes it possible to explore these combinations relatively quickly, meaning that DES can no longer be regarded as a secure algorithm.
- Another weakness of DES is its vulnerability to structural attacks. The S-boxes used in DES were designed to withstand certain types of attack, but over time new methods, such as differential cryptanalysis, have been discovered that have managed to break these security features.

- Triple DES (3DES): Triple DES (3DES) was developed to overcome the security limitations of DES. This algorithm applies DES three times in succession using different keys, thereby effectively extending the key length to 112 or 168 bits. Although 3DES offers significantly greater security than the original DES, it is also considerably slower, making it a less suitable choice for performance-critical applications, such as the real-time encryption of audiovisual data. 3DES was widely used in banking and financial transactions, where it was considered secure enough to protect sensitive information. However, with the advent of more modern and faster algorithms, such as AES, its use has gradually declined.
- Performance and use of DES: In the context of audiovisual data encryption, DES was historically used to provide basic security for transmissions. However, due to its relatively short key length and weak resistance to modern attacks, DES has gradually been replaced by more modern algorithms, such as AES, which provide a much higher level of security and better performance. When encrypting large volumes of data, such as streamed videos or multimedia transmissions, computational efficiency is a crucial factor. DES, which operates with relatively short keys and has 16 rounds of encryption, is slower than modern algorithms. Given that current services require the encryption of large volumes of data with minimal latency, DES is no longer considered a suitable choice for these environments.

At the time of its creation, DES was regarded as state-of-the-art encryption technology and served as the standard for data security for a long time. However, as a result of rapid advances in computing technology and new attack methods, its security profile has deteriorated significantly. Today, DES is considered obsolete and has been superseded by more modern and secure algorithms, such as AES.

DES remains useful for historical purposes and for understanding the evolution of encryption technologies, but for modern applications, such as securing audiovisual transmissions in 5G networks, it is recommended to use newer algorithms with longer keys and better resistance to attacks.

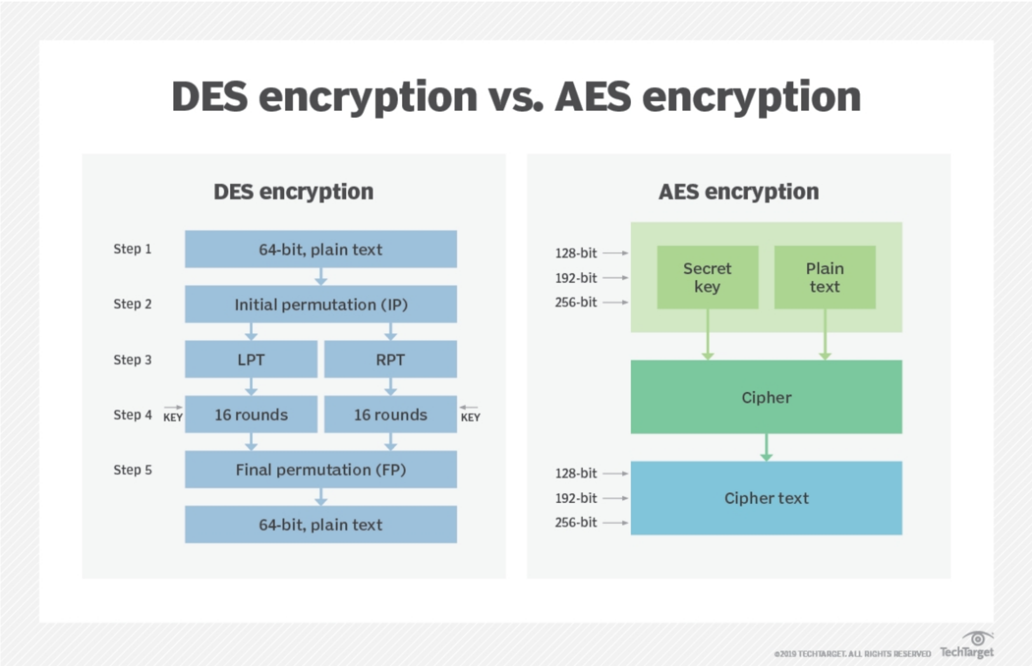

Figure 49: Comparison of DES and AES encryption

methods Source: https://www.techtarget.com/searchsecurity/definition/Advanced-Encryption-Standard

The DES (Data Encryption Standard) and AES (Advanced Encryption Standard) encryption processes differ significantly, although both are symmetric block ciphers. DES uses a 64-bit block for plaintext and a 56-bit key for encryption. During the encryption process, 16 rounds of encryption take place, in which the data is divided into left and right halves and transformed using key-controlled permutations.

AES, on the other hand, offers key lengths of 128, 192 or 256 bits and provides a significantly higher level of security than DES. The AES encryption process involves multiple rounds (10, 12 or 14 rounds depending on the key length), ensuring greater resistance to attacks. AES is also much more efficient, making it suitable for applications requiring high performance, such as modern encryption systems.

Blowfish and IDEA

Blowfish and IDEA (International Data Encryption Algorithm) are symmetric encryption algorithms that were developed as alternatives to the then-current DES standard, which had gradually become obsolete and vulnerable to brute-force attacks. Although both of these algorithms offered improvements in security and performance over DES at the time of their creation, they were eventually superseded by more modern algorithms, notably AES, which is now the standard for most encryption applications.

- Blowfish – Blowfish was designed by Bruce Schneier in 1993 as a fast and secure encryption algorithm that could replace DES. Its main features include:
  - Speed and efficiency: Blowfish is known for its high speed, making it suitable for applications requiring rapid data encryption, such as in network protocols and file encryption. The algorithm is particularly fast when encrypting data on 32-bit processors.
  - Flexibility: Blowfish allows for key lengths ranging from 32 bits to 448 bits, ensuring a flexible level of security tailored to the needs of a specific application. Unlike DES, which had a fixed key length of 56 bits, Blowfish offers much broader configuration options and, consequently, a higher level of security.
  - Security: Blowfish is still considered a secure algorithm provided it is implemented correctly and uses a sufficiently long key. There are no known effective attacks against a fully implemented Blowfish algorithm, although some vulnerabilities have been discovered when using truncated keys and in resource-constrained applications.

  Blowfish uses 64-bit blocks, which may, however, be considered a disadvantage compared to AES, which uses 128-bit blocks. Encryption with smaller blocks may be more vulnerable to certain types of attacks, particularly in the context of modern high-volume data streams.

  Blowfish was widely used in various encryption applications, such as OpenSSH and disk encryption tools. However, with the advent of AES, which offers greater security and efficiency with larger data blocks, Blowfish has gradually been replaced by more modern algorithms.

- IDEA (International Data Encryption Algorithm) – IDEA was developed in 1991 by James Massey and Xuejie Lai as a replacement for DES. This algorithm was designed to address some of DES's weaknesses, particularly its vulnerability to brute-force attacks. IDEA became particularly popular in Europe and was used in various cryptographic protocols. The main features of IDEA include:
  - Strong security: IDEA uses a 128-bit key, which provides a much higher level of security compared to DES. Thanks to its design, IDEA is considered highly resistant to cryptanalytic attacks, including differential and linear cryptanalysis.
  - Block cipher: Like DES, IDEA operates on 64-bit blocks. At each stage of the encryption process, a series of operations—including modular addition and multiplication—take place, ensuring a complex transformation of the input data.
  - Use in PGP (Pretty Good Privacy): One of IDEA's major achievements was its use in PGP, a popular piece of software for encrypting emails and files. PGP has become one of the most important tools for ensuring secure communication on the internet, and IDEA has consequently gained widespread attention.
  - Licensing and restrictions: IDEA was originally patented, which limited its wider deployment in certain applications where open-source encryption algorithms, such as Blowfish or, later, AES, were preferred. The patent on IDEA expired in 2012, removing licensing barriers, but by then the algorithm had been superseded in many areas.

  Like Blowfish, IDEA is considered a highly secure algorithm, but its use in modern systems has given way to AES, which offers more efficient performance and flexibility when encrypting large volumes of data.

- The replacement of the Blowfish and IDEA algorithms by AES – Although Blowfish and IDEA were developed as improvements on DES, both algorithms have gradually been replaced by AES. AES has become the dominant encryption algorithm in many applications, as it offers a better combination of security, speed and efficiency. AES encrypts data in 128-bit blocks, which ensures greater security when processing large volumes of data, particularly in the context of modern communication networks such as 5G or cloud services. Furthermore, AES supports various key lengths (128, 192, 256 bits), offering flexibility in security, whilst its speed enables efficient real-time encryption without significantly impacting device performance. Currently, both Blowfish and IDEA are considered secure algorithms; however, in terms of performance and versatility, AES is regarded as the standard solution for most encryption needs in the world of IT and communications technology.

8.2.6.2 Asymmetric encryption technologies

Asymmetric encryption, also known as public-key encryption, uses two different keys: a public key for encryption and a private key for decryption. This approach is less efficient for encrypting large volumes of data, but is essential for secure key exchange, authentication and securing real-time communications.

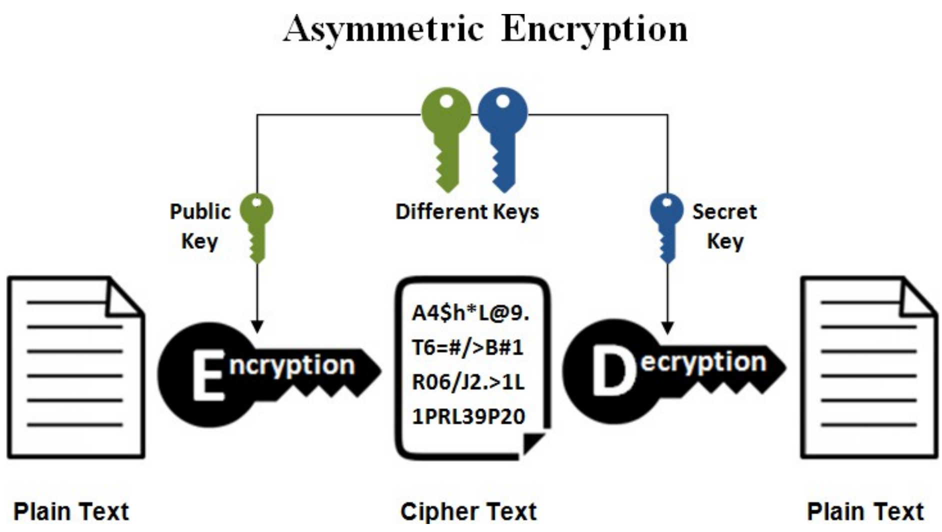

Figure 50: Asymmetric encryption

Source: https://www.ssl2buy.com/wiki/symmetric-vs-asymmetric-encryption-what-are-differences

This figure illustrates the principle of asymmetric encryption. On the left-hand side is plain text, which is encrypted using a public key during the encryption process. The result of encryption is ciphertext. This ciphertext is then decrypted on the right-hand side using the corresponding private key during the decryption process, thereby converting the text back to the original plaintext. A key aspect of asymmetric encryption is that different keys are used for encryption and decryption – the public key for encryption and the private key for decryption.

RSA (Rivest-Shamir-Adleman)

RSA (Rivest-Shamir-Adleman) is one of the best-known and most widely used asymmetric encryption algorithms. It was developed in 1977 by three mathematicians – Ron Rivest, Adi Shamir and Leonard Adleman – from MIT, hence the algorithm's name. RSA has become the foundation of modern cryptography and digital security and is widely used for secure communication on the internet, particularly in the fields of e-commerce, digital signatures and authentication.

- How RSA works:
  - Unlike symmetric encryption algorithms, such as AES or DES, which use the same key for both encryption and decryption, RSA uses a pair of keys – a public key and a private key. This principle is known as asymmetric cryptography. The public key is used to encrypt messages, whilst the private key is used to decrypt them.
  - RSA works on the basis of factoring large numbers. The security of the algorithm lies in the difficulty of breaking down very large numbers (products of two large prime numbers) into their prime factors. This problem is computationally intensive and cannot be solved within a reasonable time even with modern computing resources, which makes RSA secure, even though its theoretical basis is relatively simple.
- Steps of the RSA algorithm:
  - Key generation: In RSA, two large prime numbers (let us denote them p and q) are first generated; these are multiplied to form the so-called modulus n. The modulus n is the public part of the key. A public exponent (usually a small number, often 65537) and a private exponent are also derived from these prime numbers; together with n, they form the private key.
  - Encryption: The sender of the message uses the recipient's public key (comprising n and the public exponent) to encrypt the original message (referred to as plaintext). The result is ciphertext, which can be sent securely over an unsecured network, as only the recipient with the private key can decrypt it.
  - Decryption: The recipient of the message uses their private key (composed of n and the private exponent) to decrypt the message back to the original plaintext. This step is computationally complex and, without knowledge of the private key, practically impossible.
- Advantages of RSA:

- Security: RSA is a highly secure encryption algorithm, particularly when using long keys. RSA keys can range in length from 1024 bits to 4096 bits, with longer keys providing a higher level of security. The algorithm is extremely resistant to brute-force attacks, as factoring very large numbers is mathematically difficult.
- Authentication and digital signatures: RSA is widely used for digital signatures and user authentication. In addition to encryption, it allows the authenticity of the sender to be verified, as only the sender with the correct private key can sign a message, which can then be verified by anyone with the public key.
- Widespread use: RSA is a component of many security protocols, such as TLS/SSL (for securing websites), PGP (email encryption) and SSH (secure server login). It is also widely used in the security of digital certificates.

- Disadvantages of RSA:
  - Computational complexity: RSA is much slower than symmetric encryption algorithms such as AES. The process of encryption and decryption using RSA requires significant computational resources, particularly when using long keys, which can be a disadvantage when encrypting large volumes of data or in environments with limited processing power, such as on mobile devices.
  - Longer key lengths: Whilst longer key lengths provide greater security, they also place a greater load on the system and increase the time required for encryption and decryption. For this reason, RSA is often used only to encrypt small blocks of data or to encrypt symmetric keys, which are then used to encrypt the main data using faster algorithms such as AES.
- Using RSA in combination with AES – Due to the computational complexity of RSA, in practice it is often used in combination with symmetric algorithms such as AES. This approach works as follows:
  - First, a symmetric key (e.g. for AES) is generated, which is used to encrypt the data quickly.
  - This symmetric key is then encrypted using RSA and securely transmitted to the recipient.
  - The recipient decrypts the symmetric key using their RSA private key and then uses it to decrypt the main data encrypted with AES.

  This procedure combines the security of RSA with the performance of AES and is frequently used in modern cryptographic systems, for example in file encryption, connection security (TLS) and cloud systems.

ElGamal

ElGamal is an asymmetric encryption algorithm developed in 1985 by Tahar ElGamal. It is based on the computational difficulty of the discrete logarithm problem, a mathematical problem that is computationally complex and is therefore used as the basis for cryptographic operations. ElGamal is popular for its use in encryption and digital signatures.

- How ElGamal works: ElGamal uses a key pair – a public key and a private key. The public key is used to encrypt messages and the private key to decrypt them. The algorithm is based on mathematical operations involving groups, which provides strong security.
  - Key generation: ElGamal generates the public and private keys using large prime numbers and mathematical operations, ensuring a high level of security.
  - Encryption: The sender uses the recipient’s public key to encrypt the message. The encryption operation results in two ciphertexts, which are sent to the recipient.
  - Decryption: The recipient uses their private key to decrypt the received ciphertexts and retrieve the original message.
- Advantages:
  - ElGamal is considered to be very secure, as its security is based on the computational difficulty of the discrete logarithm problem, which cannot be solved efficiently even using modern computational methods.
- Disadvantages:
  - A disadvantage of ElGamal is the relatively large length of the ciphertext compared to other algorithms. This can result in higher demands on storage and bandwidth when transmitting encrypted data. Furthermore, ElGamal is slower than some more modern encryption algorithms, which limits its use in certain applications with high performance requirements.

ElGamal is frequently used in cryptographic systems where encryption and the generation of digital signatures are required, for example in applications for electronic voting, encrypted communication or blockchain technology.

DSA (Digital Signature Algorithm)

DSA is a digital signature algorithm designed by David Kravitz and adopted in 1991 as the US federal standard for digital signatures (FIPS 186). DSA is an asymmetric algorithm that uses a key pair to create and verify a digital signature.

- How DSA works: DSA operates on the principle of generating a public and a private key. The private key is used to create a digital signature, whilst the public key is used to verify that signature.
  - Key generation: Like ElGamal, DSA generates a key pair – a public and a private key – based on mathematical operations involving prime numbers.
  - Digital signature: When a user wishes to sign a document or message, they use their private key to create a digital signature. This signature is attached to the message and sent along with it.
  - Signature verification: The recipient uses the sender's public key to verify the signature. If the signature is valid, this means that the message has not been altered and originates from the declared sender.
- Advantages:
  - DSA is highly effective for generating and verifying digital signatures. The algorithm is standardised and widely used to ensure the integrity and authenticity of data. DSA is also relatively fast at generating signatures and less computationally intensive compared to other asymmetric algorithms.
- Disadvantages:
  - The main disadvantage of DSA is that it is used solely for digital signatures and cannot be used for data encryption. Furthermore, if not implemented correctly, it may be vulnerable to certain types of attacks, such as a nonce re-use attack.

Uses of ElGamal and DSA: ElGamal and DSA are popular in environments where there is an emphasis on security and the verification of digital signatures. ElGamal is often used in applications that require both encryption and digital signatures, whilst DSA is the standard for digital signatures in various security protocols, such as SSL/TLS, SSH and digital certificates.

For example, DSA was adopted by the US government as the standard for signing official documents, leading to its widespread adoption worldwide.

ElGamal and DSA are important asymmetric cryptographic algorithms used for various purposes. ElGamal has proven its worth in encryption applications and the generation of digital signatures, whilst DSA is a standardised algorithm for digital signatures used to verify the authenticity and integrity of messages. Although both algorithms have their specific advantages, modern cryptographic systems often combine different algorithms to achieve greater security and performance.

8.2.6.3 The combination of symmetric and asymmetric encryption techniques

The combination of symmetric and asymmetric encryption techniques has become a widespread method for ensuring a high level of security in modern television and audiovisual services. This approach combines the advantages of both types of encryption and provides comprehensive protection for data during transmission over public networks, such as the internet or mobile networks. This combination proves particularly essential in environments where large volumes of data need to be transmitted quickly and securely, such as in video streaming or live television broadcasts.

Symmetric and asymmetric encryption: Key differences

Symmetric encryption, such as AES, uses a single key for both encrypting and decrypting data. This key must be shared between the sender and the recipient, which makes symmetric encryption fast and efficient for processing large volumes of data, but increases the risk should the key be leaked or stolen.

Asymmetric encryption, such as RSA, uses a pair of keys – a public key for encryption and a private key for decryption. The advantage of this approach is that the public key can be freely shared, whilst the private key remains secret, ensuring that only the authorised recipient can decrypt the data. Asymmetric encryption is therefore very secure, but slower than symmetric encryption, which limits its use when encrypting large volumes of data.

Key exchange and authentication

In modern television and audiovisual services, where it is necessary to ensure both the rapid processing of large data streams and the secure exchange of encryption keys, a combination of both methods is often used. Asymmetric encryption plays an important role here, specifically in the exchange of encryption keys and the authentication of users and devices.

For example, in protocols such as TLS (Transport Layer Security) or SSL (Secure Sockets Layer), which are used to secure data transfers between servers and client devices, asymmetric encryption is used for the secure exchange of symmetric keys. Once this key has been securely exchanged, it is then used to encrypt and decrypt data during transmission using a faster symmetric encryption algorithm, such as AES.

This process can be summarised in the following steps:

- Asymmetric phase (RSA):
  - The sender and recipient first exchange public keys using asymmetric encryption. The recipient uses the sender's public key to encrypt the symmetric key (e.g. an AES key).
  - This encrypted key is then securely transmitted to the recipient, who decrypts it using their private key.
- Symmetric phase (AES):
  - Once the encryption keys have been exchanged, a symmetric key (such as AES) is used to encrypt the data itself, such as videos, files or television broadcasts. Symmetric encryption enables the efficient and rapid encryption of large volumes of data without significantly slowing down the process.

This combination utilises the advantages of both approaches: asymmetric encryption provides secure key exchange, whilst symmetric encryption provides high-performance data processing, which is particularly important for real-time transmissions where the slowdown caused by purely asymmetric encryption would be unacceptable.

Advantages of the combined approach

- Key security – Asymmetric encryption (e.g. RSA) ensures that keys for symmetric encryption do not need to be transmitted unprotected. This approach minimises the risk of key compromise, which is a common problem with purely symmetric encryption methods where the key must be shared between the sender and the recipient.
- Performance and speed – Once the symmetric key has been exchanged, the encryption and decryption of data takes place very quickly thanks to symmetric encryption. This is essential for multimedia services that require rapid encryption and decryption of large volumes of data, for example during the streaming of HD videos or live broadcasts.
- Authentication – Asymmetric encryption also enables the authentication of users and devices. Through the use of public and private keys, the identities of the sender and recipient of data can be securely verified.
- Flexibility – This approach can be easily scaled and adapted to different security requirements. For example, users can employ longer keys for both asymmetric and symmetric encryption to enhance security without significantly slowing down system performance.

Applications in television and audiovisual services

In the context of television and audiovisual services, this combination of encryption techniques is important. For example, when streaming video or distributing digital content via platforms such as Netflix, YouTube or other OTT (over-the-top) services, secure key exchange via asymmetric encryption and fast data encryption using symmetric algorithms are essential for protecting copyright and preventing piracy.

Furthermore, this combined approach is also used in other areas, such as digital television, where content needs to be protected against unauthorised access, and in on-demand video service applications, which ensure that only authorised users can view the content.

8.2.6.4 Performance and security of encryption algorithms

The choice of the correct encryption algorithm depends on performance and security requirements. AES is considered a highly efficient and secure algorithm, suitable for encrypting large volumes of data in real time, such as videos or streams. RSA, on the other hand, is more computationally intensive but offers a high level of security for authentication and key distribution.

When deploying encryption technologies in systems such as FeMBMS (Further evolved Multimedia Broadcast Multicast Service), it is important to take into account both data transfer speed and security requirements. The combination of AES and RSA provides an optimal solution for the transmission of television and audiovisual content with a high level of security and efficiency.

8.2.7 Integration of encryption techniques into FeMBMS

FeMBMS is a technology that enables the efficient broadcasting of multimedia content, such as television programmes and videos, via 5G networks. This system is designed to distribute data to a large number of devices simultaneously and optimises bandwidth, making it an ideal solution for mass transmissions, for example during sports broadcasts, emergency situations or software updates

. As this involves public broadcasting, security is one of the key aspects that must be ensured through robust encryption techniques.

8.2.7.1 The role of encryption in FeMBMS

Encryption is an essential technology for protecting content from unauthorised access and piracy, and for safeguarding sensitive data. In FeMBMS, encryption is implemented to secure data streams, even during transmission over public networks, to ensure that only authorised users have access to the transmitted content. At the same time, encryption techniques play an important role in protecting copyright and sensitive information contained within television broadcasts and audiovisual media.

In a FeMBMS environment, it is essential to ensure that encryption does not affect transmission quality; this means that the encryption techniques used must be sufficiently fast and efficient so as not to disrupt the multimedia services provided to end users.

8.2.7.2 Symmetric encryption in FeMBMS

Symmetric encryption algorithms, such as AES, are most commonly used to protect data in FeMBMS. AES is a symmetric block cipher that ensures a high level of security whilst providing sufficient performance for the rapid encryption of large volumes of data, such as high-definition videos or live television broadcasts.

AES is used with various key lengths (128, 192 or 256 bits), with longer keys providing greater security. Thanks to its efficiency and speed, AES is capable of encrypting multimedia content in real time without any noticeable delay, which is essential for applications such as live streaming and on-demand videos.

8.2.7.3 Asymmetric encryption and key distribution

Asymmetric encryption is frequently used for the distribution of encryption keys within FeMBMS, particularly algorithms such as RSA. Asymmetric algorithms utilise a key pair – a public key and a private key – which enables the secure sharing of keys between the content provider and end users

In practice, RSA works within FeMBMS by encrypting a generated symmetric key (for example, for AES) using the public key and securely transmitting it to the user, who holds the corresponding private key to decrypt it. This model ensures that, even when data is transmitted over public networks, unauthorised parties cannot gain access to the encryption keys and, consequently, to the content itself. After decrypting the symmetric key, the user employs AES to decrypt the multimedia content itself.

8.2.7.4 Compatibility and efficiency

When integrating encryption techniques into FeMBMS, it is essential to ensure compatibility with a wide range of devices. FeMBMS targets various types of devices – from mobile phones and tablets to smart TVs and other connected devices. Therefore, the encryption algorithms must be optimised for different hardware platforms to ensure the same level of security across all devices without compromising performance.

One of the challenges is to ensure that encryption algorithms are flexible enough to be used on less powerful devices, which may not have sufficient computing capacity to process complex encryption operations. At the same time, it is important that modern devices, which support advanced encryption techniques, provide a high level of both security and performance during data transmission.

8.2.7.5 Protection against unauthorised access

One of the main objectives of integrating encryption techniques into FeMBMS is to prevent unauthorised access to transmitted content. In the television services sector, piracy remains a major threat, particularly for live broadcasts or premium content. Encryption ensures that only authorised users who possess the appropriate encryption keys can decrypt and view the transmitted content.

Thanks to encryption, data is protected against tampering or theft during transmission. In addition, advanced techniques such as data integrity protection can be implemented to ensure that any unauthorised changes to the transmitted content are detected and the transmission is rejected.

8.3 Compliance with legal and regulatory requirements

Given the growing volume of data being transmitted and increasing regulatory requirements, compliance with legal and regulatory standards is a key factor in the implementation of technologies such as FeMBMS. To ensure the protection of user data, service providers must adhere to a wide range of rules and guidelines that safeguard not only multimedia content but also users' personal data. In a 5G network environment, where large volumes of data are transmitted, it is essential to ensure that all backup and security procedures comply with applicable laws and standards.

Compliance with legal and regulatory requirements in the field of television and audiovisual services is essential for ensuring the protection of copyright, user privacy and the security of transmitted data. European legislation, in particular the Audiovisual Media Services Directive (AVMSD), sets out the obligations of audiovisual content providers regarding protection against unauthorised access and the security of media data transmission. The implementation of encryption technologies, such as AES or RSA, not only ensures user security and privacy but also enables service providers to fulfil their legal obligations regarding data protection and digital rights management (DRM). These legislative measures are essential for protecting sensitive content from piracy and unauthorised distribution, whilst also helping to protect vulnerable groups from inappropriate content.

8.3.1 Protection of personal data

One of the most important aspects of regulatory compliance is the protection of personal data. FeMBMS technology can transmit not only multimedia content but also sensitive information, such as users' personal data, which is subject to specific legal protections, particularly under the GDPR (General Data Protection Regulation) and other regulations.

- The GDPR and data protection: The GDPR is a regulatory framework that sets out strict conditions for the processing and storage of personal data. When transmitting data via FeMBMS, it is essential to ensure that all personal data is protected using strong encryption and that only authorised parties have access to it. This means that service providers must implement encryption protocols to ensure that data is protected both during transmission and whilst in storage.
- Encryption of personal data: To protect personal data from unauthorised access, it is essential to use modern encryption techniques, such as the AES or RSA encryption algorithms. These methods ensure that data cannot be read or modified without the appropriate decryption key. When transmitting via FeMBMS, it is important that all personal data is transmitted in encrypted form, which minimises the risk of it being leaked or misused.

8.3.2 Auditing and monitoring of backup and security processes

To ensure compliance with regulatory standards, such as the GDPR, and other legal requirements, it is necessary to carry out regular audits of backup and security processes. These audits verify that all processes comply with legal and technical requirements and that all security standards protecting data from unauthorised access or cyber threats are met.

- Regular audits: Audits are a key tool for ensuring regulatory compliance. During an audit, backup processes, encryption protocols, authentication mechanisms and other elements of the FeMBMS infrastructure are checked. Regular audits help to identify any security weaknesses and enable timely measures to be taken to rectify them.
- Monitoring of security processes: Monitoring and documenting backup and security processes are essential to ensuring continuous data protection. Automated monitoring systems can detect suspicious activity, such as unauthorised attempts to access data or breaches of security policies, and intervene immediately. In this way, the risk of cyber-attacks can be minimised and data protected in real time.
- Process documentation: To ensure compliance with legal requirements, it is necessary to maintain detailed documentation of all backup and security processes. This documentation is essential not only for audit purposes but also for the rapid identification of problems in the event of a failure or security breach. The documentation includes detailed records of the encryption algorithms used, backup methods, data replication and other security measures.

8.3.3 Liability and compliance

Compliance with data security legislation is not only a technical but also a legal requirement. Service providers using technologies such as FeMBMS must be prepared to take responsibility for the management and protection of their users' data. Failure to comply with these requirements may lead to legal sanctions, a loss of user trust or reputational damage.

- GDPR compliance: Service providers must ensure that all processes relating to the processing of personal data comply with the GDPR, including users' rights to access, rectify or erase their data. This requires the deployment of systems that enable transparent management of personal data and ensure its security throughout the entire processing process.

- Service providers’ responsibility: Providers of broadcasting services via FeMBMS must bear full responsibility for data management and protection. This includes implementing technical measures for data protection, conducting regular audits of security processes, and complying with all relevant legislation and regulatory standards.

9 Data and technology backups

The data backup process plays a crucial role, as it ensures the continuous availability of content even in the event of temporary network outages or other operational issues on the part of the broadcast provider. If a multicast transmission is disrupted, as mentioned in Chapter 1, FeMBSM technology enables an automatic switch from broadcast to unicast mode, thereby transferring the end user from group transmission to individual transmission. The main parties involved in this process are:

- **Broadcast provider** (e.g. a telecoms operator): The broadcast provider is responsible for ensuring the reliable distribution of content via the broadcast mechanism. At the same time, it is obliged to allocate the adequate bandwidth necessary for the effective distribution of content and to ensure its uninterrupted availability.
- **End user**: End users who receive content on their devices, such as mobile phones or smart TVs, can connect via multicast or unicast, depending on the quality of their connection and the availability of the broadcast. One of the main advantages of 5G broadcast technology is the ability to switch dynamically between unicast and broadcast modes, which provides users with a high degree of flexibility when viewing content, even if the broadcast mode changes.
- **Licence Rights Provider**: This party is responsible for managing licence rights and ensuring that the broadcast content complies with all legal and licensing requirements. The licence rights provider must work closely with the broadcaster to ensure alignment between legal obligations and the technical specifications for distribution.

9.1 Data backup and recovery mechanisms

In the context of 5G networks, particularly when providing broadcast services via this technology, it is necessary to design data backup and recovery mechanisms that take into account data volume, transmission speed and low-latency requirements. These factors are critical for ensuring the reliable transmission of multimedia services, particularly in high-load situations such as live broadcasts. The speed at which content is distributed and consumed requires sophisticated and automated backup processes that minimise the risk of data loss in the event of any system failure or crash. FeMBMS-based broadcasting networks must be able to quickly restore transmission to prevent service interruptions, which are unacceptable to users of audiovisual media, particularly during live broadcasts or high-priority events.

To ensure this reliability, it is essential that backup mechanisms are capable of responding in real time and are robust enough to cope with unexpected failures. This involves not only the rapid recovery of data, but also the prevention of data loss and the safeguarding of the integrity of the transmitted information. In the case of live broadcasts, such as sports coverage or emergency reports, the ability to restore data immediately is crucial, as signal loss or delay can have significant negative impacts on both the user experience and overall trust in the services provided. It is therefore necessary to have backups and redundancy mechanisms implemented at the infrastructure level to minimise the risk of failure.

9.1.1 Types of backups

To ensure the continuity of broadcast services in the event of accidents, outages or cyber-attacks, it is important to implement suitable backup methods that maximise the speed of data recovery and minimise the risk of data loss. In a FeMBMS environment, three basic types of backups can be distinguished: full backups, incremental backups and differential backups. Each of these methods has its own specific characteristics and advantages, which enable the effective restoration of broadcast services.

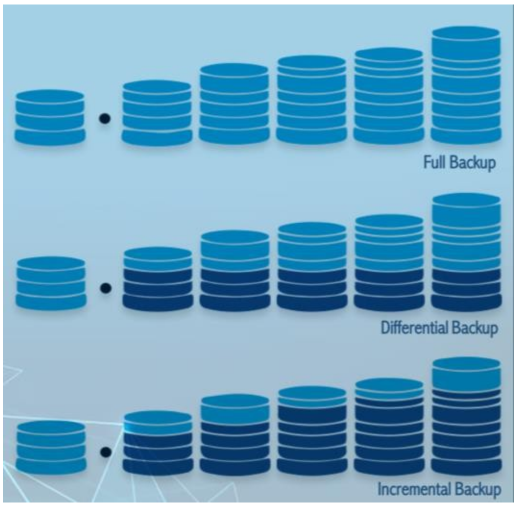

Figure 51: Comparison of backup methods

Source: https://www.mityung.com/blog/the-difference-between-incremental-differential-and-full-backup

This figure visually illustrates the differences between the three main types of backup: full, differential and incremental backups.

Full Backup: Each backup using this method contains a complete copy of all data. This means that every backup is identical, regardless of previous backups. This type of backup takes up the most space and takes the longest to perform, but allows for quick and easy system recovery.

Differential backup: A differential backup copies all changes made since the last full backup. As we can see in the diagram, the size of the backup increases with each subsequent level, as all changes since the last full backup are added. This approach saves time during recovery, as only the latest full backup and the latest differential backup need to be used.

Incremental Backup: This method records only the changes made since the last backup (whether full or incremental). The diagram illustrates how each new level contains only newly added or modified files, which saves storage space and reduces backup time, but increases the time required to restore the system, as it is necessary to load all backups in sequence starting from the last full backup.

9.1.1.1 Full backup

Full backups provide a complete copy of all data, which means rapid recovery in the event of a failure. This method is suitable for preserving content in critical situations or during longer broadcasts, where continuity is essential. Although full backups are demanding in terms of storage space and bandwidth, their main advantage is the ability to restore quickly without having to combine multiple backup copies. In a FeMBMS broadcast environment, full backups are ideal for ensuring continuity during critical events where no delay in recovery can be tolerated.

9.1.1.2 Incremental backups

Incremental backups record only the changes made since the last backup, thereby saving storage space and reducing backup time. This method is advantageous in situations where it is necessary to minimise the volume of data transferred, which reduces the strain on the network infrastructure. In a FeMBMS environment, incremental backups can reduce the load on the infrastructure, which is useful during normal operations. However, a potential disadvantage is a longer recovery time, as all previous incremental backups must be retrieved in order to restore the system. This method therefore requires careful planning and monitoring to ensure sufficient data availability for recovery.

9.1.1.3 Differential backups

Differential backups represent a compromise between full and incremental backups. They include all changes since the last full backup, which simplifies the recovery process compared to incremental backups, as it is not necessary to load all individual changes sequentially. Differential backups thus enable faster recovery whilst maintaining relatively low storage space requirements. This approach is optimal in environments where the emphasis is on rapid recovery, but also on the efficient use of available resources.

9.1.2 Automation of backup processes

The automation of backup processes is essential for maintaining the continuity of multimedia content broadcasting within FeMBMS. Automated backup systems perform regular backups without the need for manual intervention, thereby reducing the risk of human error and ensuring broadcast continuity. This is particularly important during live broadcasts or in emergency communications, where delays must be minimised.

Thanks to the regularity and flexibility of these systems, the backup frequency can be dynamically adjusted to suit the specific needs of the content. For example, important data can be backed up more frequently, which is beneficial for high-priority broadcasts such as sporting events or emergency alerts. Automating backups also optimises resource utilisation, leading to lower operating costs and reduced network load. These processes can be complemented by analytical tools that help anticipate potential problems and respond to them quickly.

Another benefit of automation is the ability to carry out regular data recovery tests. These tests confirm that backups are fully functional and that data can be restored when needed. Automated tests provide greater assurance that the infrastructure is prepared for emergencies, which is essential in an environment where uninterrupted broadcasting is critical. Rapid response to incidents and minimising the time required for recovery ensure that the negative impact on users is kept to a minimum.

9.1.3 Data replication and geographical redundancy

Data replication and geographical redundancy are key elements in achieving high availability and resilience for FeMBMS broadcast services. High availability is essential for maintaining broadcast quality, particularly for live broadcasts, where even a brief outage or delay can significantly affect the viewer experience.

Replicating data across different geographical regions ensures that data remains accessible even in the event of a failure at a single site. This approach helps to maintain broadcast continuity in situations where the broadcast infrastructure faces unexpected problems, such as natural disasters or technical faults. FeMBMS enables the replication not only of the data itself but also of the broadcasting services, allowing another server in a different geographical region to take over the broadcast immediately, thereby ensuring uninterrupted service for users.

Geographical redundancy also ensures an even distribution of the load across individual sites. Broadcasting can be optimised to prevent infrastructure overload, which is particularly important during periods of high demand for broadcasts, such as during sports events or emergency situations. Spreading the load across separate locations not only improves performance but also reduces the risk of failure in individual parts of the infrastructure.

Replication and geographical redundancy are therefore essential elements of an effective solution for broadcast services within 5G networks, ensuring the availability of multimedia content even in the event of local outages or overloads. This approach not only enhances reliability and security but also improves the user experience, which is crucial to the success of FeMBMS services. Thanks to these mechanisms, the capacity of the broadcast infrastructure can be flexibly adapted to current needs, helping to maintain competitiveness in the market.

Backup and replication mechanisms play a significant role in the FeMBMS broadcast environment in ensuring the reliability and quality of services. The right combination of backup strategies, automation and data replication enables providers to minimise the risk of outages and ensure maximum broadcast continuity. FeMBMS thus offers an innovative and robust solution for modern multimedia services that meet the high demands for quality, speed and availability of real-time content.

9.2 Copyright and licensing rights for recording

The process of granting recording licences requires the conclusion of appropriate contractual agreements that allow creators to decide how their content will be recorded, broadcast and distributed. A successful licensing process depends on coordination between content providers, broadcasters and end users, which ensures the protection of creators' rights and compliance with all legal obligations. This includes ensuring strict legal protection and guaranteeing the fair distribution of revenue associated with the recording and dissemination of content.

The legal framework for licensing rights relating to recording and broadcasting is based on principles that grant authors and broadcasters the right to specify the conditions under which content may be stored and subsequently reproduced. In the field of digital broadcasting, it is necessary to take into account not only traditional copyright law but also rights relating to broadcasting, including retransmission and cross-border distribution of content. It is essential that any retransmission or recording takes place only with the consent of the authorised rights holders, in accordance with the prescribed licence conditions.

The public broadcasting of radio and television programmes in commercial premises constitutes a specific case which requires specific licence rights not only for the broadcasting itself, but also for the recording and any subsequent reproduction of the content. These rights are often essential, particularly in situations where content is broadcast in public or semi-public settings. Transparent setting of licence conditions and compliance with these obligations are essential to ensure compliance with legal regulations and to protect the rights of all parties involved.

The process of granting a licence for the operation of digital broadcasting involves not only consent to the broadcasting of content, but also requirements for the technical security of the broadcast, which also enables recording. The licence then serves as legal proof of the content owners' consent to its distribution and recording, which is an important condition for the lawful operation of digital broadcasting services. Technical requirements include ensuring appropriate standards of broadcast quality and security, which further strengthens trust amongst all participants in this process.

10 Financial analysis and implementation costs of FeMBMS

10.1 Approximate costs of deploying FeMBMS technology

Deploying FeMBMS technology requires investment in several areas: hardware, infrastructure, spectrum licensing and compliance with specific regulatory requirements. The approximate costs can be broken down into the following categories:

10.1.1 Hardware (HW) requirements

Deploying FeMBMS technology requires both an upgrade of the existing infrastructure and investment in new hardware. Based on supporting documentation and studies, it is possible to identify areas where it will be necessary to deploy new technologies or optimise existing infrastructure components.

10.1.1.1 Upgrading existing infrastructure

One of the main approaches to reducing the costs of FeMBMS deployment is to utilise existing broadcast infrastructure, in particular T-DAB (Digital Audio Broadcasting) and DVB-T (Digital Video Broadcasting – Terrestrial) systems. Simulations show that existing T-DAB infrastructure can be adapted to support FeMBMS. This includes:

- **Increasing transmission power**: To transition to 5G broadcast, it is essential to increase the transmission power of existing transmitters in order to achieve greater coverage and network capacity. Simulations show that an increase in power of up to 6 dB is necessary to compensate for the poorer signal propagation conditions in the UHF band compared with the VHF band, where T-DAB operates.
- **Optimisation of antenna systems**: FeMBMS will require the optimisation of antenna systems, including the installation of new antennas or modifications to existing ones, to ensure the signal is distributed evenly across the target areas. The document notes that transmission stations with antenna heights ranging from 30 to 290 metres can be used for FeMBMS, thereby minimising the need to construct new antennas.

10.1.1.2 Requirements for new hardware

Although some of the existing infrastructure can be utilised, FeMBMS nevertheless requires the deployment of new technology to improve network efficiency and coverage.

- **New transmitters**: To cover large areas and ensure sufficient power for FeMBMS, new transmitters will need to be installed. These transmitters must be equipped with advanced energy-efficient technologies that enable long-range operation with low energy consumption. The construction of new transmitters focuses primarily on rural and remote areas where the existing infrastructure is inadequate.
- **Energy efficiency and longer range**: New transmitters must support high energy efficiency and a longer range, which involves the implementation of technologies such as **QPSK** and **256QAM** modulation, enabling more efficient data transmission even under higher network loads. These improvements are key to ensuring reliable, high-definition transmission with minimal latency.

10.1.1.3 Transmitter stations and servers

The implementation of FeMBMS technology involves significant costs for upgrading existing transmission stations, which must support 5G broadcast. In most areas, existing macrocell infrastructure is likely to be utilised. This strategy will allow the use of current macrocells, which are already equipped for high-frequency broadcasting, and their upgrade for 5G broadcast. This will significantly reduce the costs of building new transmitters, because:

- **Macrocells will be used as the core network elements**: These cells are already integrated into most 4G and 5G networks, and upgrading them to support FeMBMS will increase their transmission capacity.
- **Servers and data centres**: FeMBMS requires support in terms of storage and server infrastructure to ensure reliable content delivery across wide geographical areas. Server costs include both their acquisition and their operation and maintenance. This aspect will play a particularly important role in cases where data backup and dynamic switching between broadcast and unicast content are required.

Utilising existing infrastructure will significantly reduce the costs of deploying FeMBMS, but it requires some investment in new transmitters and technologies to ensure sufficient performance and coverage. A key aspect is the modernisation of existing macrocells and the addition of new antenna technology and energy-efficient transmitters capable of delivering high-capacity transmission within the 5G broadcast framework.

10.1.2 Spectrum licensing

Spectrum licensing represents one of the most significant cost areas in the deployment of FeMBMS technology. Given the high demand for the use of the UHF spectrum, which is traditionally used for television broadcasting, a significant increase in spectrum licence fees is expected. Access to spectrum in bands such as the 600 MHz band is essential for the effective deployment of FeMBMS, which entails considerable financial costs. Spectrum management is carried out both at international level through the International Telecommunication Union (ITU) and at national level by the Czech Spectrum Authority (ČTÚ).

10.1.2.1 Demand for radio spectrum

In the coming years, demand for spectrum for 5G broadcast is expected to grow. The UHF band, in particular, is ideal for transmitting signals over long distances and through obstacles, making it well-suited to FeMBMS. Traditionally, the UHF band has been used for television broadcasting (DVB-T and DVB-T2), which means that requirements for access to this spectrum will need to be coordinated with other broadcast service providers. Spectrum management must be carried out in accordance with ITU rules and ČTÚ decisions, which influence the possibilities for development and access to the spectrum.

10.1.2.2 Frequency bands and spectrum fees

Another aspect of deploying FeMBMS is obtaining licences to use specific frequency bands that are suitable for transmitting high-quality audiovisual content with minimal delay. For the effective operation of FeMBMS, the 600 MHz band is often utilised, as it provides sufficient bandwidth for the transmission of large amounts of data. Frequencies in this band allow for better penetration into buildings and greater range than higher frequencies.

- **Spectrum fees**: Fees for spectrum usage can vary considerably depending on the region, the specific band and the type of transmission. As spectrum is a limited resource, regulatory bodies, such as national telecommunications authorities (e.g. the ČTÚ in the Czech Republic), often allocate spectrum through auctions. With high demand for 5G broadcasting, the price of spectrum is expected to rise. In larger, more densely populated countries, the cost of a spectrum licence may be significantly higher than in smaller, less populated areas.
- **Regional differences**: The cost of spectrum licensing may also be influenced by differing regulatory requirements in individual countries. In some cases, local telecommunications authorities may impose additional fees for spectrum licences, intended to cover the costs of administering and monitoring spectrum usage.

10.1.2.3 Impact of regulatory requirements

Additional costs may arise from the need to comply with regulatory rules governing spectrum allocation. Regulatory authorities may set specific requirements regarding minimum utilisation of a frequency band or the implementation of technologies to ensure minimal interference with other broadcast service providers. This may include an obligation to make technical modifications to broadcasting equipment or to apply special technologies to reduce interference, which increases the costs of licensing and operating the spectrum.

10.1.2.4 Impact on financial planning

High spectrum licensing costs can have a significant impact on the financial sustainability of a FeMBMS project. It is important for broadcasters to include spectrum costs in their financial plans not only in the initial stages but also in the long term, as licence fees are usually paid on a regular basis (annually or over several years). Furthermore, costs may increase depending on changes in regulatory policies or when transitioning to newer versions of technology, as will be required for future 5G broadcasting services.

10.1.2.5 International and national spectrum management

Spectrum management is a key factor in ensuring the effective operation and availability of 5G broadcast technologies. The ITU, as a global organisation, sets international rules and standards for spectrum use. These rules are then implemented by national regulatory authorities, such as the Czech Telecommunications Office (ČTÚ), which ensures that the rules are adhered to and adapted to local conditions. Cooperation between the ITU and the Czech Telecommunications Office thus plays a vital role in balancing the needs of broadcasting services, optimising spectrum use and ensuring compatibility with European and international standards. This coordination enables the efficient use of spectrum and minimises interference.

10.2 Operating costs and maintenance

Operating costs represent the regular financial expenditure necessary to maintain and operate the broadcasting infrastructure. These costs include several items:

10.2.1 Energy consumption

The operation of broadcasting equipment requires a significant amount of electrical energy, particularly in the case of high-power transmitters covering extensive geographical areas. Energy consumption includes:

- **Transmission equipment**: Transmitters and antenna systems consume the energy required to transmit the signal at the desired frequency and power. For example, macrocells in mobile networks typically have a transmission power of around **100 W** with an efficiency of approximately **50 per cent**, which means an actual energy consumption **of 200 W** per transmitter.
- **Cooling systems**: Electronic equipment generates heat, which must be efficiently dissipated to prevent overheating and damage to the equipment. Cooling systems add to the overall energy consumption.
- **Data centres**: Servers and network infrastructure supporting the transmission and distribution of data for FeMBMS require a constant supply of power for both operation and cooling.

10.2.1.1 Example of energy cost calculation:

At an electricity price of **€0.15** per kWh and continuous operation (8,760 hours per year), the annual energy costs for a single macrocell transmitter are:

Annual energy costs = 0.2 kW × 8,760 h × 0.15 €/kWh = 262.8 €

If the network comprises, for example, **20**,**360** macrocell transmitters, the total annual energy costs are:

262.8 € × 20,360 = 5,350,608 €

10.2.2 Spectrum leasing

The use of the frequency spectrum for FeMBMS broadcasting is subject to licence fees set by regulatory authorities. The costs include:

- **Licence fees**: Regular payments for the use of allocated frequency bands. The amount of the fees varies depending on the geographical area, the type of spectrum and regulatory policies.
- **Administrative costs**: Costs associated with maintaining compliance with licence conditions, such as monitoring compliance with the rules and liaising with regulatory authorities.

10.2.3 Staff costs

The maintenance and operation of broadcasting infrastructure requires qualified staff. Costs include:

- **Salaries for technicians and engineers**: Staff responsible for maintaining transmitters, resolving technical issues and monitoring the network.
- **Training and development**: Investment in the continuous training of staff to keep their knowledge of the latest technologies and standards up to date.

- **Monitoring systems**: The costs of implementing and operating systems for monitoring network performance, fault detection and traffic management.

10.2.4 Modelling operating costs

Operating costs can be expressed using the following formula:

Equation 1: Formula for calculating operating costs

$$Opex = \sum_{i=1}^{\text{transmitter classes}} \sum_{k=1} (\text{Energy\_consumption}_{i,k} + \text{Heat\_dissipation}_{i,k}) + \sum_{j=1}^{\text{locations}} (\text{Rent}_j + \text{O\&M}_j)$$

Where:

- $\text{Energy\_consumption}_{i,k}$ – is the energy consumption of the k-th transmitter of class i.
- $\text{Heat\_dissipation}_{i,k}$ – is the energy required to dissipate heat from the k-th transmitter of class i.
- $Nájem_j$ – is the rent for site j.
- $\text{O\&M}_j$ – represents the operation and maintenance (O&M) costs for site j.

10.2.4.1 Example of operating cost calculation

Let us take as our basis the data presented in the EBU study[1] , which analyses the operating costs of mobile networks:

Unit Opex costs for a mobile network:

Table 4: Opex costs for a mobile network

Site category	Transmitter power	Efficiency	O&M costs	Rent
Macrocell	100 W	50%	€3,300	€5,000
Micro-cell	50 W	50%	€1,000	€2,500
Pico cell	10 W	50%	€900	€0

Total operating costs for macrocells:

- Number of macrocell transmitters: 20,360
- Annual energy costs per transmitter: €262.8

Total energy costs:

€262.8 × 20,360 = €5,350,608

Total costs for rent and O&M:

(€5,000 + €3,300) × 20,360 = €168,988,000

Total operating costs for macrocells:

€5,350,608 + €168,988,000 = €174,338,608

Total network operating costs:

If we add the costs for microcells and any picocells, the total operating costs of the network could amount to:

[1] https://tech.ebu.ch/docs/techreview/EBU_Tech_Review_2019_Lombardo_Cost_analysis_of_orchestrated_5G_networks_for_broadcasting.pdf

Estimated total Opex for a 5G network in 2030: **€214.3 million** per year for a single operator covering one-third of the population.

10.2.4.2 Optimisation of operating costs

The following measures may be considered to reduce the operating costs of FeMBMS infrastructure:

- **Energy-efficient technologies**: Investment in more energy-efficient transmitters and effective cooling systems can reduce energy consumption.
- **Infrastructure sharing**: Sharing transmission masts and other infrastructure elements between operators can reduce rental and maintenance costs.
- **Automation and remote monitoring**: Implementing advanced monitoring systems enables more efficient maintenance and faster troubleshooting, thereby reducing staff costs.
- Use of MIMO antennas: MIMO (Multiple Input, Multiple Output) technology enables dynamic control of transmission power based on the number of end-users within a cell's coverage area. This results in more efficient use of available bandwidth and a reduction in energy costs, as transmission adapts to current conditions. This approach is ideal for reducing operational costs and maximising transmission efficiency.

10.2.4.3 Revenues and economic benefits of FeMBMS

FeMBMS technology not only delivers advanced capabilities for the transmission of multimedia content, but also offers a range of opportunities for generating new revenue streams. The implementation of FeMBMS enables broadcasters to expand their services and introduce new business models that can significantly contribute to their financial stability.

Revenue-Generating Opportunities

- Targeted advertising: FeMBMS technology enables providers to utilise interactive features and targeted advertising, which offers the potential to achieve greater effectiveness in advertising campaigns. Targeted advertising is aimed at specific audience groups, which increases its effectiveness and generates higher revenues compared with traditional advertising models. For example, by utilising DAB (Digital Audio Broadcasting), broadcasters can reach listeners more effectively and provide advertising content tailored to their preferences.
- Expansion of programming: Thanks to the efficient use of the spectrum and the possibilities offered by StatMux (Statistical Multiplexing) technology, broadcasters can expand their programming.
- Frequency auctions: In the Czech Republic, for example, approximately 80 million CZK was raised through frequency auctions for digital radio (DAB+). This revenue was distributed amongst the frequency providers, with Czech Digital Group (CDG), a subsidiary of České Radiokomunikace, acquiring frequencies for 26.35 million CZK.
- Premium and supplementary services: Offering exclusive content, such as sports broadcasts, cultural events or specialised programmes, enables broadcasters to generate additional revenue from subscriptions or paid content.

FeMBMS has the potential to transform the ways in which media services are delivered and monetised. Combining linear broadcasting with modern interactive elements not only delivers higher-quality transmission but also opens up new revenue streams. Collaboration between broadcasters, operators and other industry players can thus pave the way for innovative business models and ensure the financial sustainability of broadcasting infrastructure in the future.

10.3 Financial sustainability of the investment

Investment in FeMBMS technology represents a financial commitment that requires planning and analysis to ensure long-term sustainability. The financial sustainability of this investment depends on several factors, including the optimisation of operating costs, efficient use of spectrum, technological innovation and the potential to generate revenue from new services.

10.3.1 Return on Investment (ROI)

One of the key indicators of financial sustainability is **return on investment (ROI)**. FeMBMS enables a reduction in operating costs through more efficient use of infrastructure and spectrum, whilst offering new business opportunities. For example, delivering linear broadcasting on mobile devices without the need to use mobile data can attract a wider audience and increase the value of advertising space.

The growth of targeted services, such as interactive TV applications and personalised advertising, can contribute to return on investment. Furthermore, FeMBMS can serve as a platform for new services, such as a mobile Content Delivery Network (CDN), which can open up additional sources of revenue.

10.3.2 Efficient use of spectrum

Efficient use of spectrum is key to the financial sustainability of investment in FeMBMS:

- **Optimisation of frequency bands**: FeMBMS can operate in lower frequency bands, such as **the 600 MHz and 700 MHz bands**, which provide better coverage and require fewer transmitters.
- **StatMux technology**: As mentioned, StatMux enables more efficient use of available spectrum, leading to savings on spectrum costs and increased capacity for transmitting more services.
- **Standardisation and harmonisation**: The publication of **the** new **5G Broadcast Receiver Profile** by the European working group facilitates the standardisation of technical requirements for equipment. This promotes compatibility across Europe and increases the attractiveness of investment for equipment manufacturers and service providers.

10.3.3 Infrastructure lifecycle planning

Long-term financial sustainability requires careful infrastructure **lifecycle planning**:

- **Regular modernisation**: Hardware and software updates ensure that the network remains compatible with the latest standards and technical requirements.
- **Scalability**: The infrastructure should be designed to allow for easy expansion and the integration of new technologies, such as **5G Broadcast**.
- **Maintenance and operation**: Effective maintenance strategies can reduce operating costs and extend the lifespan of equipment.

10.3.4 Potential revenue growth

FeMBMS opens up new opportunities for **generating revenue**:

- **Linear broadcasting on mobile devices**: It allows users to watch live TV broadcasts on mobile phones without using their data allowance, which can increase viewership and attractiveness to advertisers.
- **Targeted advertising**: Thanks to interactive features, providers can offer personalised advertising, which increases the effectiveness of advertising campaigns and potential revenue.
- **Premium services**: Offering paid content or exclusive services, such as sports broadcasts or cultural events, can generate additional revenue.
- **Partnerships with operators**: Collaboration with mobile operators can open up new business models, such as the use of FeMBMS for offloading data traffic, which reduces the load on their networks and creates additional sources of revenue.

10.3.5 Strategies for ensuring financial sustainability

To minimise risks and ensure the financial sustainability of the investment, it is important to:

- **Industry collaboration**: Partnerships between broadcasters, operators, equipment manufacturers and regulatory bodies can facilitate standardisation and cost-sharing.
- **Innovation in business models**: Developing new services and monetisation strategies that leverage the unique capabilities of FeMBMS.
- **Efficient use of technology**: Implementing advanced technologies, such as StatMux, to maximise efficiency and minimise costs.

11 Use of the 600 MHz band for broadcast transmission

11.1 Potential uses of the 600 MHz band for TV broadcasting

11.1.1 Characteristics of the 600 MHz band

The 600 MHz band falls within the lower part of the UHF (Ultra High Frequency) spectrum, which is advantageous from several technical perspectives. Lower frequencies generally have a greater ability to propagate over longer distances and penetrate physical obstacles such as buildings, trees or mountains more effectively. This characteristic enables coverage of large areas with fewer transmitters, leading to lower infrastructure construction and operating costs. The 600 MHz band is becoming an important tool for the effective coverage of rural and remote areas, where a stable television signal needs to be provided at minimal infrastructure cost.

In urban areas, the advantage of better signal penetration through obstacles is also evident, ensuring higher reception quality even in densely built-up cities. Many higher frequencies used for television broadcasting or mobile networks have a poorer ability to propagate in urban environments, particularly on the upper floors of buildings, where the signal is more difficult to reflect and penetrate into interiors. By contrast, thanks to its physical properties, the 600 MHz band offers more stable signal propagation and higher picture quality without the need for further investment in additional technologies or repeaters.

Another significant advantage of this band is the possibility of using it in environments with lower transmitter power. This means that television operators can reduce energy consumption whilst achieving a high level of coverage, which has a positive impact on operating costs and environmental sustainability.

11.1.2 The transition to digital broadcasting

During the digitisation of television broadcasting, certain frequency bands were released, particularly in the 700 MHz and 800 MHz bands, which were reallocated for mobile services (e.g. 4G/LTE and 5G). This process, known as the ‘digital dividend’, has enabled more efficient use of the spectrum for modern mobile communications. Although these frequencies were released, the 600 MHz band has remained reserved for terrestrial television broadcasting, which represents a strategic advantage for television service providers.

The 600 MHz band is currently one of the frequency ranges used for continued high-quality broadcasting via DVB-T2, the standard used for digital terrestrial television. As this standard allows for higher compression and better picture quality than the older DVB-T, television operators can provide viewers with more channels within the same spectrum without compromising on quality. This means that operators can maintain or even improve broadcast quality whilst paving the way for the integration of new technologies, such as FeMBMS.

From a practical perspective, it is advisable to retain the 600 MHz band for current DVB-T2 broadcasting, which is intended for stationary reception. If 5G Broadcast proves to have economic potential for the distribution of multimedia content to mobile devices, it will be possible to consider using this band for this purpose as well. However, this band should not be allocated to 5G mobile networks with unicast traffic, so as to preserve the advantages of high-power, high-tower (HPHT) transmitters for the effective coverage of large areas.

11.1.3 Interoperability with DVB-T2

The use of the 600 MHz band is fully compatible with existing terrestrial television broadcasting technologies, such as DVB-T2. This means that the existing broadcasting infrastructure, including transmitters, receiving antennas and other network components, can continue to used, which significantly reduces the costs of necessary technological upgrades. Rather than building entirely new infrastructure, operators can utilise existing networks and gradually transition to more modern systems, such as FeMBMS.

Interoperability between DVB-T2 and FeMBMS offers the advantage of combining traditional linear television broadcasting with new multimedia services. FeMBMS enables multicast broadcasting not only to conventional television sets but also to mobile devices such as smartphones and tablets. This opens up new possibilities for broadcasters, who can offer hybrid broadcasting models where viewers watch television on both their television sets and their mobile devices.

Such interoperability would allow for the gradual modernisation of infrastructure, where traditional broadcasting would coexist with more advanced technologies, such as mobile streaming, without the need for a costly and rapid transition to new technology. This approach is cost-effective and allows for adaptation to gradual changes in bandwidth requirements and media consumption patterns.

11.2 Optimising spectrum utilisation within FeMBMS

11.2.1 FeMBMS and efficient spectrum utilisation

FeMBMS (Further evolved Multimedia Broadcast Multicast Service) represents a major innovation in the field of efficient spectrum utilisation, primarily due to its ability to simultaneously broadcast various types of content, such as linear television broadcasting, multimedia services and interactive applications. This technology enables the use of multicast mode, whereby a single signal is broadcast to multiple devices simultaneously. Thanks to this feature, bandwidth requirements do not increase even as the number of users grows, thereby improving spectral efficiency.

FeMBMS thus enables providers to broadcast several channels or services within a single frequency band, thereby not only increasing spectral efficiency but also reducing operating costs. This technology is ideal for situations where a wide area needs to be covered with a smaller number of transmitters, particularly for services such as mobile video streaming or hybrid broadcasting, where viewers can watch content on different devices (televisions, mobile phones, tablets) simultaneously.

In practice, FeMBMS is capable of supporting high-quality transmission without compromising on bandwidth, which is particularly important in regions with limited spectrum resources. This technology therefore significantly increases network capacity whilst enabling the provision of higher-quality services.

11.2.2 The duplex gap in the 700 MHz band

One of the key elements for optimising spectrum within FeMBMS is the utilisation **of the duplex gap in the 700 MHz band**. The duplex gap is a free frequency space located between the frequencies designated for uplink and downlink in mobile networks. This space is often unused, providing an excellent opportunity for the deployment of technologies such as FeMBMS.

České Radiokomunikace carried out tests at 746 MHz (channel 55), which lies precisely within this duplex gap, and these tests demonstrated that the 700 MHz band can be effectively utilised for television broadcasting using 5G Broadcast technology, which is closely linked to FeMBMS. The tests showed that this part of the spectrum can be used without significant interference with mobile networks, paving the way for wider use of these frequencies for the distribution of multimedia content. This step could significantly improve the availability and quality of services within hybrid broadcasting systems that combine television broadcasting and mobile networks.

The technical parameters of the tests, which involved transmissions from two Prague transmitters (Žižkov and Strahov), demonstrated that broadcasting in the duplex gap can deliver high performance and a stable signal even in densely populated areas. The signal was broadcast with an effective radiated power (ERP) of 32 kW at Žižkov and 2 kW at Strahov, ensuring sufficient coverage and broadcast quality for mobile devices without the need to use mobile data.

11.2.3 Dynamic bandwidth allocation

One of the most important aspects of FeMBMS technology is its ability to manage the spectrum dynamically. This means that bandwidth can be allocated flexibly according to current broadcasting needs and the number of active users. For example, if there is higher demand for certain services (such as watching live sports) during a particular time period, FeMBMS can adjust the network capacity to provide sufficient bandwidth for these services without overloading the network.

Dynamic bandwidth allocation is essential for the efficient management of available frequencies, particularly in densely populated areas where there are significant fluctuations in demand for television and multimedia content. This flexibility enables service providers to optimise their transmission capacity according to current conditions, leading to better use of the spectrum, higher service quality and a reduction in overall costs.

This ability to dynamically manage resources also helps prevent network congestion, which is particularly useful when broadcasting major live events or when there is a surge in the number of users viewing content on mobile devices. Furthermore, flexible bandwidth management minimises outages and ensures consistent transmission quality, which is essential for users.

11.3 Spectrum optimisation and maximising coverage

11.3.1 Use of SFN (Single Frequency Network)

A Single Frequency Network (SFN) is an advanced broadcasting technology that enables the transmission of an identical signal from multiple transmitters on the same frequency. This technology is essential for optimising spectrum in bands such as the 600 MHz band, where it provides effective coverage of large geographical areas with minimal demand for additional frequencies. In practice, this means that multiple transmitters cover different areas, but as they all broadcast on the same frequency, there is no interference and the signal from different locations combines into a single coherent transmission.

This has a significant impact on signal quality and the optimisation of spectrum utilisation, as it enables large areas to be served with fewer transmission resources. SFN also reduces the need to build separate transmitters for each geographical area, thereby significantly reducing both infrastructure costs and energy consumption.

The success of this technology was confirmed during 5G Broadcast trials carried out in Prague at the Žižkov and Strahov transmitters. Both transmitters were able to broadcast a synchronised signal within a single-frequency network, achieving stable, high-quality coverage of urban areas with a minimum number of outages and no interference. This demonstrates the potential of SFN for the efficient use of lower frequencies, such as 600 MHz, particularly when combined with advanced broadcasting standards such as FeMBMS.

11.3.2 Minimising interference with other services

When utilising lower frequency bands, such as 600 MHz, it is necessary to ensure that there is no interference with other broadcasting services or mobile networks operating in adjacent bands. As a broadcasting technology, FeMBMS can be effectively integrated with other services thanks to advanced transmission control methods and sophisticated modulation. In combination with **the duplex gap in the 700 MHz band**, it is possible to ensure that broadcasting services do not conflict with mobile networks that utilise frequencies for both uplink and downlink.

FeMBMS technology utilises sophisticated methods for frequency management and minimising interference between transmitters, which leads to an improvement in overall transmission quality and a reduction in the risk of interference with other services. This is particularly important in densely populated urban areas, where mobile services often utilise adjacent bands and where it is necessary to ensure that television broadcasting and mobile services can operate concurrently without interruption.

11.3.3 Maximising coverage

One of the main advantages of the 600 MHz band is its ability to achieve long-range coverage at relatively low transmitter power. This means that a large area can be covered with fewer transmitters, which is particularly useful in sparsely populated rural areas. In these areas, building a denser network of transmitters would be uneconomical, but the use of lower frequencies makes it possible to achieve reliable coverage at minimal cost.

Combined with **SFN** technology, which reduces the need for additional transmission frequencies, this achieves optimal spectrum utilisation, which not only reduces long-term operating costs but also ensures high-quality transmission even across large areas. The **dynamic bandwidth allocation** technology, which is part of FeMBMS, allows bandwidth to be adapted to current needs, leading to more efficient use of the spectrum even during periods of peak network load.

Maximising coverage and optimising spectrum usage through these technologies is essential to ensuring that television and multimedia broadcasting can be delivered to a high standard of quality, both in rural areas and in urban regions where high capacity and transmission quality are required.

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