सत्यमेव जयते

TECHNICAL REPORT
on
DIRECT BROADCASTING TO MOBILE DEVICES

ISO 9001:2015

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Lastly, I acknowledge that this report draws upon global best practices and incorporates stakeholder feedback to address the challenges and opportunities in broadcasting technology implementation. I earnestly hope this technical report will enhance comprehension of the candidate technologies available for direct to mobile broadcasting and the challenges associated with their implementation, thereby facilitating the deployment of future broadcasting initiatives in the country.

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Abstract

In today's digitally connected world, the demand for accessing live television content directly on mobile devices such as smartphones and tablets has surged dramatically. As consumers increasingly rely on handheld devices for entertainment, there is a growing need for broadcasting technologies capable of delivering live TV content without requiring an internet connection. This report extensively evaluates various candidate technologies and their readiness to meet this evolving demand.

Among the technologies examined are 5G Broadcast, ATSC 3.0, DVB-T2, ISDB-T, and DTMB-A. These technologies are "*Digital Terrestrial Television (DTT)*" technologies and present unique advantages and challenges in delivering live television content to mobile devices. While primarily catering to fixed television sets, these technologies also have the potential to reach mobile devices through specially designed receivers or dongles. Accordingly, this report prefers the term "*Digital Terrestrial Transmission to Mobile (DTT2M)*" to describe these technologies' ability to deliver broadcast content to handheld devices.

The report also examines the deployment scenario of these candidate technologies and presents a comparison on various parameters. It highlights that among these technologies, only 5G Broadcast and ATSC 3.0 are IP-based and strong contenders for India. Detailed comparisons of these two technologies for various aspects of transmitters and receivers are provided.

In addition to evaluating existing technologies, this report explores an innovative approach based on the TEC Standard on Converged Gateway Node. This approach enables the delivery of live and on-demand content to existing handsets without the need for specialized hardware or app installations, making it truly "*Direct to Mobile (D2M)*".

Despite the promise of these technologies, several challenges must be addressed for widespread adoption. The report further examines the challenges in rolling out DTT2M services in India. One significant challenge is the lack of commercially available mobile handsets supporting these broadcasting standards. Without a robust ecosystem of affordable smartphones compatible with DTT2M technologies, the adoption of these technologies may be hindered. Additionally, the integration of DTT2M services with existing mobile networks poses technical and regulatory challenges that must be navigated. Policy aspects may also be addressed to enable smooth rollout of these services in India.

Ultimately, the success of DTT2M services hinges on consumer preferences and market dynamics. By offering an alternative to internet streaming for viewing live television on mobile devices, DTT2M services have the potential to reshape the media landscape in India. As consumers increasingly demand access to live TV content on the go, the adoption of DTT2M technologies presents an opportunity for innovation and growth in the broadcasting industry.

1. Introduction

Television broadcasting in India commenced on September 15, 1959, with experimental transmission of terrestrial TV signals. A regular TV broadcast service was initiated in Delhi in 1965 under the supervision of All India Radio (AIR) and was later extended to other cities in the 1970s. In 1976, TV broadcasting was separated from AIR with the establishment of Doordarshan (DD). Initially, it was exclusively terrestrial TV broadcasting under the jurisdiction of Doordarshan and primarily conducted in analog transmission mode. According to available information, Analog TV Transmitters served approximately 88% of the Indian population. The significant expansion of terrestrial TV services occurred before the Asian Games in Delhi in 1982 when the colour transmission was introduced, and numerous transmitters were installed throughout the country.

The limitations posed by the analog terrestrial television platform, such as limited frequency capacity, necessitated a new and more efficient Digital Terrestrial TV (DTT) transmission system to meet future demands and facilitate the launch of new services. In this digitization journey of Doordarshan, the Telecom Regulatory Authority of India (TRAI) recommended the introduction of digital terrestrial transmission broadcast services in a phased manner in 2017. Accordingly, Doordarshan commenced Digital Terrestrial Television broadcasting in 19 cities using DVB-T2 technology.

Subsequently, analog terrestrial TV broadcasting was phased out globally due to poor reception quality, inefficient spectrum utilization, limited frequency capacity, and the obsolescence of analog technologies. In India, the national broadcaster, Doordarshan, phased out the last set of obsolete Analog Terrestrial TV transmitters by March 2022.

DTT channels could be received on mobile devices TV by using DVB-T2 Dongles in USB-on-the-go (OTG) enabled Smartphones, Tablets/laptops, etc. The channels could also be viewed on Fixed TV Sets by using Indoor/Outdoor antennas on integrated digital TV (iDTV) Sets or using DTT Set-Top Boxes. Doordarshan provided DD National, DD News, DD Bharati, DD Sports, and DD Regional/DD Kisan channels. With the advent of 4G services in India and subsequent 5G launch, subscribers migrated to view OTT content on smartphones (without the need for an external dongle), leading to the eventual shutdown of DTT broadcasting based on the DVB-T2 technology in 2022 in India due to lack of viewership.

Subsequently, discussions have arisen regarding the offering of digital TV content broadcast to mobile devices, allowing the broadcast of video and other multimedia content directly to mobile phones without needing an active internet connection. This concept, called Direct to Mobile (D2M), can occur through various transmission mediums, including terrestrial (Digital Terrestrial TV to Mobile devices, or DTT2M), and satellite (Digital Satellite TV to Mobile devices, or DST2M). Thanks to advancements in terrestrial technologies, the DTT2M service can leverage existing operator 5G infrastructure, through WLAN medium, or as an overlay through over-the-top (OTT) applications.

The following is a conceptual diagram of such a service:

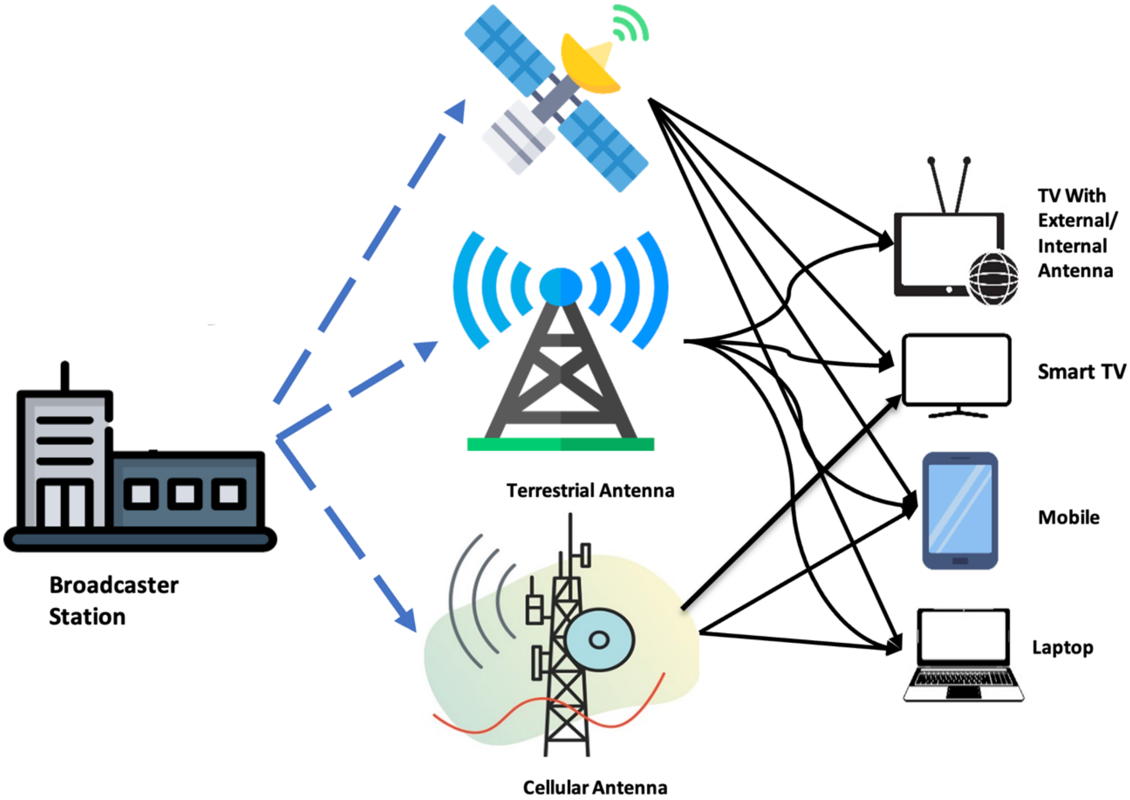

Figure 1: Direct to Mobile delivery methods

While broadcast systems initially targeted fixed television, most of them progressively evolved to also deliver broadcast services to mobile devices, starting as early as the first-generation DTT standards that included DVB-H and DVB-SH in Europe, T-DMB in Korea, 1-Seg in Japan, followed by MediaFLO (a proprietary technology developed by Qualcomm), ATSC-Mobile in the United States, and CMMB (China Mobile Multimedia Broadcasting). However, all these technologies were acknowledged as failures due to a lack of market acceptance. Rather than being technology-bound, the lack of market acceptance was mainly due to the absence of receiving devices resulting from the fact that first-generation standards were not suitable for mobile usage. Therefore, there were no available devices in the market, including built-in tuners and UHF antennas, which could have facilitated an easier transition towards multimedia broadcasting. The absence of a business model was an additional factor. Mobile television broadcasting requires deep collaboration between the broadcasting and telecommunications industries, which, at that time, could not foresee tangible mutual benefits.

Despite the unconvincing first attempts to introduce mobile television in the broadcast world, second-generation terrestrial broadcast systems were developed with similar hopes and built on top of IP. Technologies like DVB-T2 from Europe, ATSC 3.0 from North America, ISDB-T, etc., discussed in this report, all targeted the delivery of services to mobile devices. Designed for both fixed and mobile reception, second-generation DTTB standards blur the distinction between digital terrestrial television and multimedia broadcasting systems. At the same time, the distinctions between digital terrestrial television and multimedia broadcasting receivers also progressively disappear, since most televisions are now connected, and all handheld devices – even low-cost ones – are equipped with HD or higher resolution screens.

This paradigm shift sets the scene for the momentum toward alignment with mobile systems. Paradoxically, despite the many technological advances, major challenges remain for market adoption of broadcast capabilities in mobile devices, especially when originating from the broadcasting systems:

- Mobile devices must integrate specialized hardware to support the broadcasting standards, which furthermore vary from region to region, requiring device manufacturers to build different models for each region, thus reducing potential economies of scale.

- The whole ecosystem would need to adapt to a situation where the new broadcast-reception capability in mobile devices allows end users to consume zero-rated content over free-to-air broadcast networks, potentially impacting the business models of mobile network operators.

The implementation of D2M must consider international experiences, investment requirements, consumer demands, potential use cases, deployment models, emission targets, local manufacturing for import requirements, spectrum demands, etc. It also needs to consider the present broadcasting scenario of the country where terrestrial transmission is provided only by the public broadcaster with dwindling subscriptions, whereas consumers have alternate delivery platforms (e.g., OTT, with increasing subscription) to receive the same content with a better experience. There are also both active and passive operator infrastructures that can be leveraged to offer converged broadcast-broadband service, which can offer a better experience bringing in new 5G monetization avenues while minimizing incremental energy consumption. This report aims to summarize the pros and cons of different approaches and candidate technologies to help make informed decision-making in that regard.

2. Digital Broadcasting to Mobile Handheld Devices

ITU-R recommends broadcasting as a form of radio communication in which transmissions are intended for direct reception by the general public; these may include sound transmissions, television transmissions and other types of transmission [1].

According to TRAI, "Broadcasting means distribution of audio and video signals to a widely dispersed audience". Broadcasting as a mass communication media is a powerful tool to inform and educate the masses in a vast country like India [2].

Further, TRAI defines "Broadcasting services" as the dissemination of any form of communication like signs, signals, writing, pictures, images and sounds of all kinds by transmission of electromagnetic waves through space or through cables intended to be received by the general public either directly or indirectly and all its grammatical variations and cognate expressions shall be construed accordingly [3].

2.1 Methods of broadcasting live TV content

2.1.1 Terrestrial Broadcasting (DTT)

Terrestrial Broadcast refers to a Broadcast service that is transmitted via free-to-air or subscription-based terrestrial wireless transmission, whether in analog or digital form. Terrestrial television or over-the-air television (OTA) is a type of television broadcasting in which the signal transmission occurs via radio waves from the terrestrial (Earth-based) transmitter of a TV station to a TV receiver having an antenna. For the avoidance of doubt, it does not include Broadcast via a cable service or by satellite. Terrestrial broadcasting can provide wider coverage, especially in remote areas using conventional HPHT networks.

According to TRAI, "Terrestrial Broadcasting means the dissemination of any form of communication like signs, signals, writing, pictures, images, video and sounds of all kinds by transmission of electro-magnetic waves through space using Earth based transmitters intended to be received by the general public" [3].

2.1.2 Cable television

Cable television is a system of delivering television programming to consumers via radio frequency (RF) signals transmitted through coaxial cables, or in more recent systems, light pulses through fiber-optic cables.

2.1.3 Satellite broadcasting (DTH)

Satellite broadcasting is the distribution of multimedia content or broadcast signals originating from TV or radio stations or through a satellite network. Direct-to-home (DTH) Broadcasting Service refers to the distribution of multi-channel TV programs by using a satellite system.

2.1.4 IPTV

IPTV broadcasting stands for internet protocol television broadcasting and uses the technology that delivers live television programs over the internet instead of antennas, satellite dishes, or fiber-optic cables.

According to the ITU-T definition [ITU-T Y.1910], IPTV is defined as multimedia services such as television/ video/ audio/ text/ graphics/ data delivered over IP-based networks managed to provide the required level of quality of service and experience, security, interactivity, and reliability [4].

The Department of Telecommunication DOT defines IPTV as "An IPTV (Internet Protocol Television) service (or technology) is the new convergence service (or technology) of the telecommunications and broadcasting through QoS controlled Broadband Convergence IP Network including wire and wireless for the managed, controlled and secured delivery of a considerable number of multimedia contents such as Video, Audio, data, and applications processed by platform to a customer via Television, PDA Cellular, and Mobile TV terminal with STB module or similar device" [5].

2.2 Advantages of Digital Terrestrial Television

Digital terrestrial television (DTT) is a technology that allows land-based television stations to broadcast their content in a digital format through radio waves. DTT has many benefits over the previous analog television, such as:

(a) It provides more efficient use of limited radio spectrum bandwidth (over analog), which means more television channels can be transmitted on the same frequency.

(b) It offers better-quality images and sounds with less interference, ghosting, and snowing.

(c) It supports different digital TV standards, such as standard definition (SDTV), high definition (HDTV), and ultra-high definition (UHDTV).

(d) It enables the reception of signals on mobile and portable devices, such as smartphones, tablets, smart TVs, and laptops.

(e) It reduces the operating costs for service providers after the initial upgrade costs.

(f) It creates opportunities for local content production, job creation, and creativity.

2.3 Desired features of Direct to Mobile (D2M) Broadcasting

D2M broadcasting should enable the following features and functionalities:

(a) **Mobile-Centric Content Delivery:** D2M should be designed with mobile devices as the primary platform, aiming to deliver content optimized for smartphones and tablets. However, low frequencies present implementation challenges in smartphone design due to antenna length requirements.

(b) **Seamless Content Delivery:** D2M should deliver multimedia content seamlessly and instantly, eliminating buffering or waiting times. However, achieving this requires a dedicated infrastructure and significant investments.

(c) **Over-the-Air Transmission:** D2M should utilize over-the-air (OTA) transmission to deliver content directly to mobile devices, eliminating the need for continuous internet connectivity and making it ideal for on-the-go entertainment.

(d) **Hybrid Broadcast/Broadband Integration:** D2M should combine OTA broadcast with broadband internet delivery, resulting in a hybrid approach that enhances content delivery and ensures consistent user experiences. Integrating terrestrial broadcasting with other technologies, such as satellite broadcasting and IP-based streaming, should create a flexible distribution system enabling newer use cases.

(e) **Real-Time Content:** D2M should enable access to live, real-time events, providing flexibility and variety in content consumption.

(f) **Interactive Services:** D2M should enable interactive features such as personalized advertisement delivery, datacasting, interactive applications, and additional information alongside the main content. However, these technologies should require a reverse path through the internet.

(g) **Targeted Advertising:** D2M should deliver targeted advertisements to specific user segments based on location and demographics.

(h) **Multilingual Support:** D2M should support multiple audio tracks and subtitles, allowing content delivery in different languages to cater to diverse audiences.

(i) **Emergency Alert System (EAS):** D2M should integrate with emergency alert systems to deliver critical information and public safety alerts directly to mobile users, also available on cellular networks.

(j) **Scalability and Future-Readiness:** D2M should be designed to be scalable and adaptable to future technological advancements, ensuring compatibility with evolving mobile devices and networks.

(k) **Content Protection and Security:** D2M should include measures for content protection and digital rights management to safeguard intellectual property and prevent unauthorized access.

2.4 D2M versus DDT2M

While D2M broadcasting represents an ideal scenario, currently there are no technologies specifically designated as D2M. The term D2M is occasionally linked with Digital Terrestrial Transmission (DTT) technologies, primarily serving fixed television sets but also accessible via mobile devices. This can be achieved either through specially designed handset receivers or by attaching dongles or similar receiving devices to existing handsets. Therefore, this report opts to use the term "**Digital Terrestrial Transmission to Mobile (DTT2M)**" instead of Direct to Mobile (D2M) for these technologies. Additionally, the report discusses an innovative approach based on the TEC Standard on Converged Gateway Node, facilitating the delivery of live and on-demand content to existing handsets without the need for special hardware or app installations. This approach can be considered truly D2M.

2.5 Transmitter requirements for DTT2M

Following are some general considerations and potential transmitter requirements:

(a) **Transmit power and coverage:** Broadcasting systems must cover wide areas to reach large audiences, necessitating transmitters with adequate power output and coverage capabilities, commonly found in High-Power High-Tower (HPHT) and Medium-Power Medium-Tower (MPMT) configurations.

(b) **Antenna design:** Transmitters require well-designed antennas to efficiently radiate broadcasting signals. Antenna systems should be optimized for the frequency bands used and the desired coverage area, typically employing omnidirectional antennas.

(c) **Energy efficiency:** Transmitters should prioritize energy efficiency to minimize environmental impact and operational costs while meeting emission targets. Systems that can utilize existing broadband infrastructure (common in Low-Power Low-Tower [LPLT] setups) to complement broadcasting needs tend to score higher in energy efficiency.

2.6 Receiver Requirements for DTT2M

The signals can be received on any device like a fixed TV receiver, handheld terminal, etc. This report focuses on mainly mobile handheld devices such as Mobiles and Tablets.

(a) **Frequency bands:** DTT2M terrestrial broadcasting may likely use specific frequency bands allocated for broadcasting services. Receivers must be capable of tuning into these frequencies to receive the broadcasting signals. For operation in India, the receiver must be capable of operating in the Indian UHF band (470-582 MHz), defined as Band 108 (470 – 698 MHz) in 3GPP. Parts of Europe have the range 612-652 MHz for broadcast, defined as Band 107 by 3GPP.

(b) **Antenna compatibility:** Receivers should have antennas designed to receive signals in the frequency bands used for DTT2M. These antennas may be integrated into the device or be external, depending on the application. The antenna gain may be severely limiting the system's efficiency. The integration of antennas into the device will indirectly influence the form factor of the devices.

(c) **Decoding capabilities:** DTT2M terrestrial broadcasting might use different codecs and compression techniques. Receivers should support the relevant codecs to decode the audio and video content accurately.

(d) **Error correction and resilience:** Broadcasting systems require robust error correction and resilience mechanisms to handle transmission errors. Receivers should be equipped to handle and correct errors in the received signals to ensure a seamless viewing or listening experience.

(e) **Low latency:** To support real-time or near-real-time services like live broadcasting, receivers should have low latency to minimize delays between the transmission and the reception of the content.

(f) **Security features:** Broadcasting services may require content protection mechanisms (e.g., DRM) to prevent unauthorized access or content piracy. Receivers should support these security features to ensure that the content is only accessible by authorized users.

(g) **Interoperability:** To ensure compatibility with various broadcasting networks and services, receivers should adhere to globally harmonized industry standards and specifications.

(h) **Software update capability:** As technology evolves, receivers need to have the ability to receive software updates to stay current with the latest features, bug fixes, and security patches.

(i) **RF tuner:** A receiver is required to select and amplify a specific channel or frequency of the many signals picked up by an antenna and convert it to a fixed frequency, which is suitable for further processing, usually by an intermediate frequency (IF) amplifier. The RF tuner should be able to reject the unwanted stations and improve the signal-to-noise ratio. The RF tuner should also be compatible with the broadcasting standards used for the transmission, such as 3GPP 5G Broadcast, ATSC 3.0, DTMB-A, DVB-T2, and ISDB-T.

(j) **Conditional Access/Authorization:** It should have the capability of the conditional access facility.

(k) **Battery efficiency:** Since DTT2M will be just one of the services received in the mobile device, the technology must use mobile battery resources efficiently.

However, it may be noted that the Receiver requirement should consider implementation issues with 3GPP-based devices related to power consumption, antenna design (including form factor), and in-device co-existence (IDC) that are critical for the design of mobile devices.

3. Candidate Technologies for DTT2M

Digital terrestrial television (DTTV or DTT, or DTTB with "broadcasting") is a technology for transmitting television content directly to consumers' residences via radio waves in a digital format. Digital Terrestrial Television to Mobile (DTT2M) extends this distribution through terrestrial systems to mobile devices such as smartphones or tablets. DTT technologies optimize TV spectrum usage and offer superior service quality compared to analog transmission. Exploiting the potential of DTT2M entails business model adjustments for terrestrial broadcasters, potentially involving new partnerships and revenue streams such as advertising. Implementing DTT2M services could yield commercial benefits, necessitating careful spectrum management considerations. This chapter evaluates various technologies for delivering DTT2M services.

3.1 3GPP - 5G MBS and 5G Broadcast

The 3rd Generation Partnership Project (3GPP) serves as a collaborative force in the realm of telecommunications standards, established in 1998 to develop Open Standards for cellular networks. It was formed through joint efforts of standardization bodies like ETSI, ARIB, TTC, ATIS, TTA, TSDSI, and CCSA to unify global mobile communication systems. Over the years, 3GPP's regular releases have introduced advancements in data rates, spectral efficiency, multimedia capabilities, and the Internet of Things. Its standards extend beyond mobile phones, facilitating applications in smart cities, connected vehicles, and critical communications. Through global standardization efforts, 3GPP fosters innovation and compatibility, contributing to seamless mobile experiences worldwide. TEC regularly adopts these globally harmonized standards into national standards to support Indian network deployments.

Initially designed for mobile point-to-point voice communications, the mobile industry, much like the broadcast industry, has witnessed a shift in user preferences towards streaming and on-demand multimedia consumption. This shift has resulted in a surge in network traffic, prompting the need for network adaptation. Consequently, cellular broadcast technologies have evolved through several generations, culminating in practical 3GPP-based broadcast systems. For instance, in India, there is a clear trend toward enormous data volumes primarily driven by video-like data. This surge is attributed to the substantial rise in mobile phone usage, data consumption, connectivity, and the pursuit of seamless service delivery over the past decade.

The broadcast technologies developed by 3GPP aim to significantly enhance the speed of cellular networks while improving bandwidth, latency, and spectrum availability to enable better and wider coverage. These advancements are poised to benefit mobile devices, automotive applications, and the Internet of Things (IoT).

To cater to the different types of broadcasting needs, 3GPP defines different technologies:

(a) NR-waveform based 5G-MBS, for operation in operator spectrum,

(b) LTE-waveform-based 5G Broadcast or FeMBMS for operation in UHF spectrum with HPHT/MPMT/LPLT.

Fig. 2 (from ETRI) summarizes the evolution of these 3GPP technologies across a timeline. It also characterizes the continuously evolving nature of these standards for addressing new use cases.

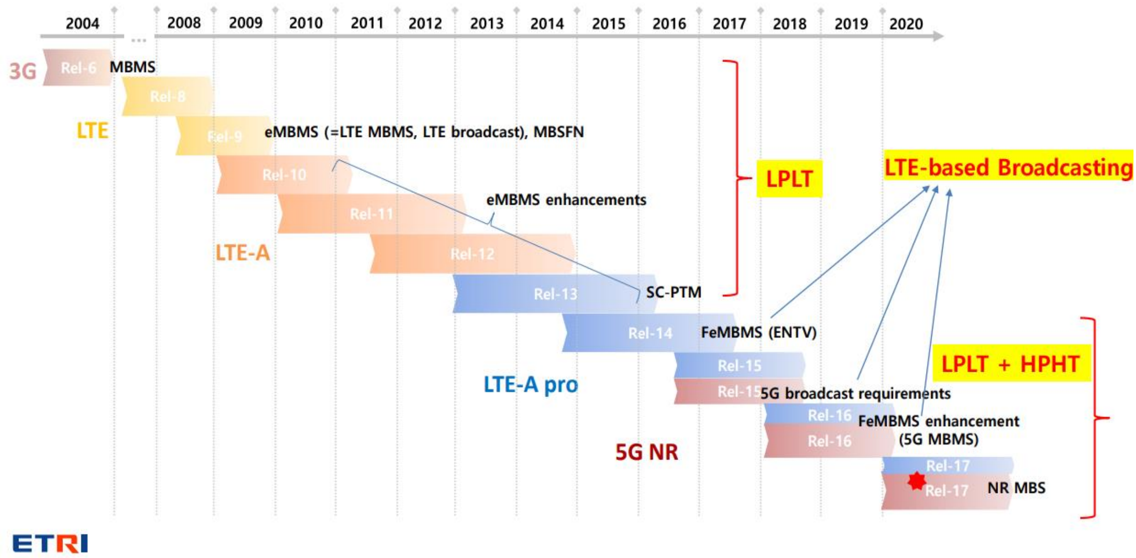

Fig. 2: 3GPP Broadcast Evolution from 3G to 5G *[source: ETRI]*

Unicast and multicast/broadcast are two distinct methods of data transmission utilized in 5G broadcasting. Consequently, 3GPP has introduced two separate solutions, which may enable DTT2M service across releases.

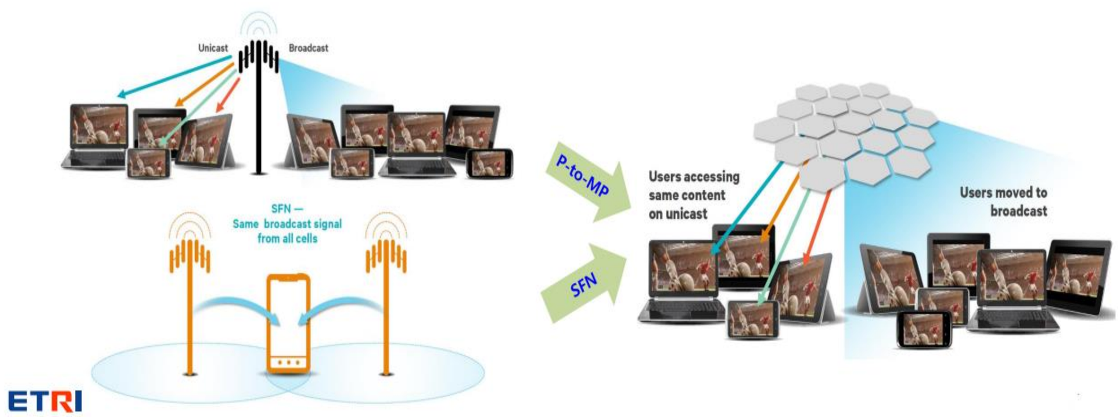

Fig. 3: 3GPP Broadcast Features *[source: ETRI]*

Unicast functions as a one-to-one communication method where data is uniquely addressed to a particular user. This method is commonly employed in cellular networks (OTT) for activities such as streaming video, file downloading, and making phone calls. 3GPP-based broadcast and multicast service delivery (LTE Broadcast)/(Evolved multimedia broadcast multicast services [eMBMS]) operate within the mobile operator's cellular spectrum.

Multicast/Broadcast operates as a one-to-many communication method, addressing data simultaneously to multiple users within the network. This method is utilized for broadcasting live TV, issuing emergency alerts, and distributing updates to a group of devices. A broadcast/multicast solution (5G Broadcast)/(Further evolved multimedia broadcast multicast services [FeMBMS]) is designed for operation within the broadcast UHF spectrum.

Along with the support for single frequency network (SFN), the 3GPP 5G system defines two modes of broadcast communication addressing diverse ecosystem, deployment, and use case requirements: 5G standalone broadcast and mixed-mode multicast (Fig. 4).

5G standalone broadcast (or 5G Broadcast) is a dedicated broadcast-only network that can address the needs of broadcasters and content providers, giving them access to broader audiences via efficient content delivery to both fixed and mobile devices. It can be deployed in existing UHF spectrum and reuse existing cellular modem building blocks. 5G standalone broadcast supports receive-only mode, downlink-only, dedicated broadcast spectrum, and more.

Mixed-mode multicast is a low-power network that supports dynamic mode switching between unicast and broadcast to deliver identical content more efficiently. It can support broader 5G use cases, such as efficient eMBB delivery, SW/FW update, IoT, V2X, and public safety.

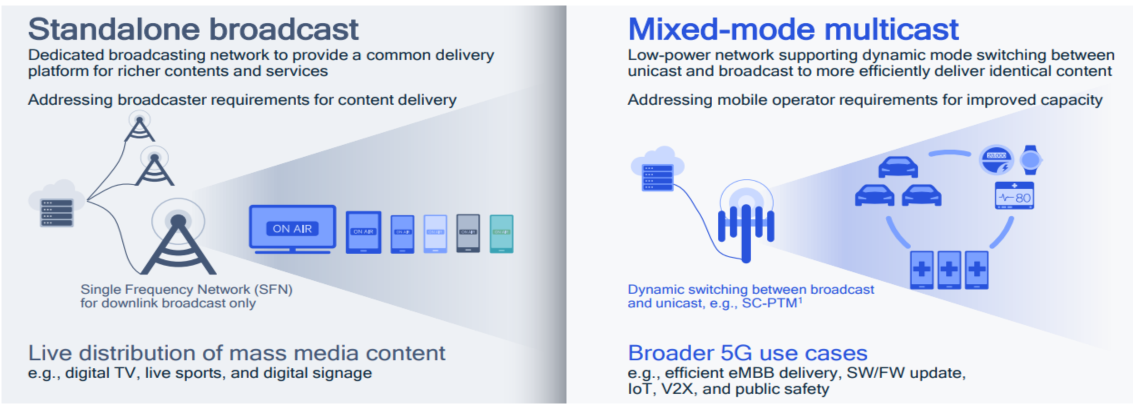

Fig. 4: Broadcast solutions from 3GPP *[Source: Qualcomm]*

With that background, the two broad categories of solutions available for broadcast applications from 3GPP are examined next.

3.1.1 5G MBS (based on NR)

The "5G MBS / 5MBS" feature, provided by 3GPP 5G Release 17, supports broadcast service delivery and multicast service delivery well integrated with unicast cellular communication (for operation in operator-licensed spectrum). 5G MBS is considered efficient and effective for many broadcast and multicast services, such as mission-critical, public safety, group communication, IoT, software upgrades, and infotainment services, among others.

i. 5G MBS Architecture

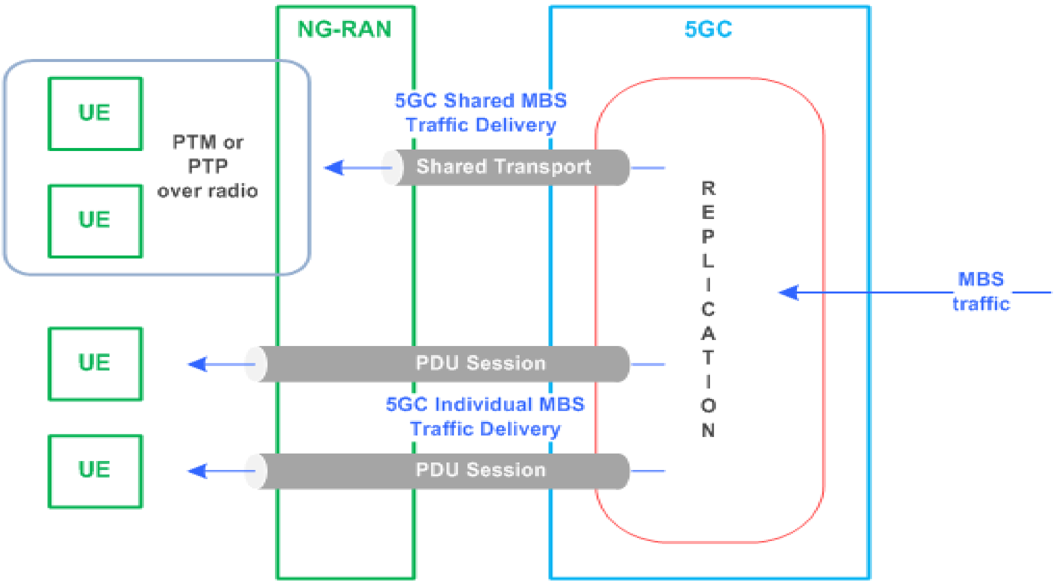

Fig. 5: 5G System architecture for Multicast and Broadcast Service
[Source: - IEEE]

An important consideration in defining MBS architecture is the support of MBS services in the legacy (NR Release 15 and 16) 5G nodes. Therefore, two delivery methods are defined to support MBS. The first one is the 5GC shared MBS traffic delivery method, where 5GC receives a single copy of MBS data packets and delivers a single copy of those MBS packets to a Next Generation RAN (NG-RAN) node, which is then delivered to one or multiple UEs. The second one is the 5GC Individual MBS traffic delivery method, applicable only to multicast. In this case, a single copy of MBS data packets received by 5GC is delivered as separate copies, each delivered to individual UEs via pe-UE Packet Data Unit (PDU) sessions. The NG-RAN decides whether to transmit the MBS data packets in the Point-to-Point (PTP) or the Point-to-Multipoint (PTM) delivery method. Where the former delivers separate copies of MBS data packets over the radio interface to each UE, the latter delivers a single copy of MBS data packets over the radio interface to multiple UEs.

ii. 5G MBS Key Features

(a) A group scheduling mechanism is implemented to enable User Equipment (UEs) to receive MBS service while simultaneously operating with unicast reception.

(b) Multicast/broadcast delivery in 5GC is facilitated through shared delivery methods.

(c) Reliability enhancements include dynamically changing multicast service delivery between Point-to-Multipoint (PTM) and Point-to-Point (PTP), implementing Automatic Repeat Request (ARQ), Hybrid Automatic Repeat Request (HARQ), etc.

(d) Support for service continuity and lossless handover is provided.

(e) For MBS, high reliability and low latency services require dynamic adaptation of service delivery modes to meet QoS constraints, along with approaches for UEs to provide feedback and avail retransmission to ensure reception reliability.

(f) QoS handling involves differentiating between multiple streams of MBS service based on their QoS requirements, mapping them to appropriate MBS QoS flows, and assigning them to suitable radio bearers or logical channels at the radio protocol level for enforcing the QoS requirements.

(g) Service area coverage varies for different Broadcast and Multicast services. While some applications like V2X require shorter coverage, others like IPTV need broader coverage. MBS has no standardized support for Single Frequency Networks (SFN), and the service transmission area is limited to a single cell or an area of multiple cells based on network configuration to meet diverse service requirements. Additionally, service continuity is ensured during UE handover between geographic regions, with efforts made to minimize latency exceeding the packet delay budget to maintain the quality of user experience.

3.1.2 5G Broadcast (a standalone broadcast based on LTE FeMBMS)

5G standalone broadcast refers to a dedicated broadcast-only network that operates independently of cellular networks. This network is designed to cater to the evolving requirements of broadcasters and content providers, enabling them to reach wider audiences through efficient content delivery to both fixed and mobile devices. The support for broadcast/multicast technology in 3GPP has a long history, dating back to the era of 3G with the introduction of UMTS (Universal Mobile Telecommunications Service). During this time, Multimedia Broadcast/Multicast Service (**MBMS**) architecture and protocols were established to facilitate broadcast/multicast use cases within 2G and 3G networks. Despite these efforts, commercial success was limited due to low media consumption rates at that time, leading to insufficient ecosystem support. Nevertheless, this initiative laid the groundwork for addressing broadcast/multicast services within 3GPP networks, setting the stage for future advancements in this domain.

With the emergence of 4G and the introduction of the LTE (Long-Term Evolution) standard tailored for wireless broadband communication, significant improvements were made to the MBMS system. These enhancements capitalized on the advantages offered by LTE radio access technology, including Orthogonal Frequency Division Multiplexing (OFDM) and Carrier Aggregation (CA). The technical specification work for these advancements took place from 3GPP Release 9 to Release 16. The upgraded version of MBMS, leveraging LTE technology, was designated as **eMBMS** (evolved MBMS) in Releases 8 and 9. In Release 14, a further evolved version, known as **FeMBMS** (Further evolved MBMS), based on LTE-Advanced was introduced. Commonly referred to as "enhanced TV" (enTV) within the industry, FeMBMS extends its capabilities to support new services and fulfills most of the requirements set by broadcasters for enabling digital terrestrial television broadcasting using cellular radio infrastructure.

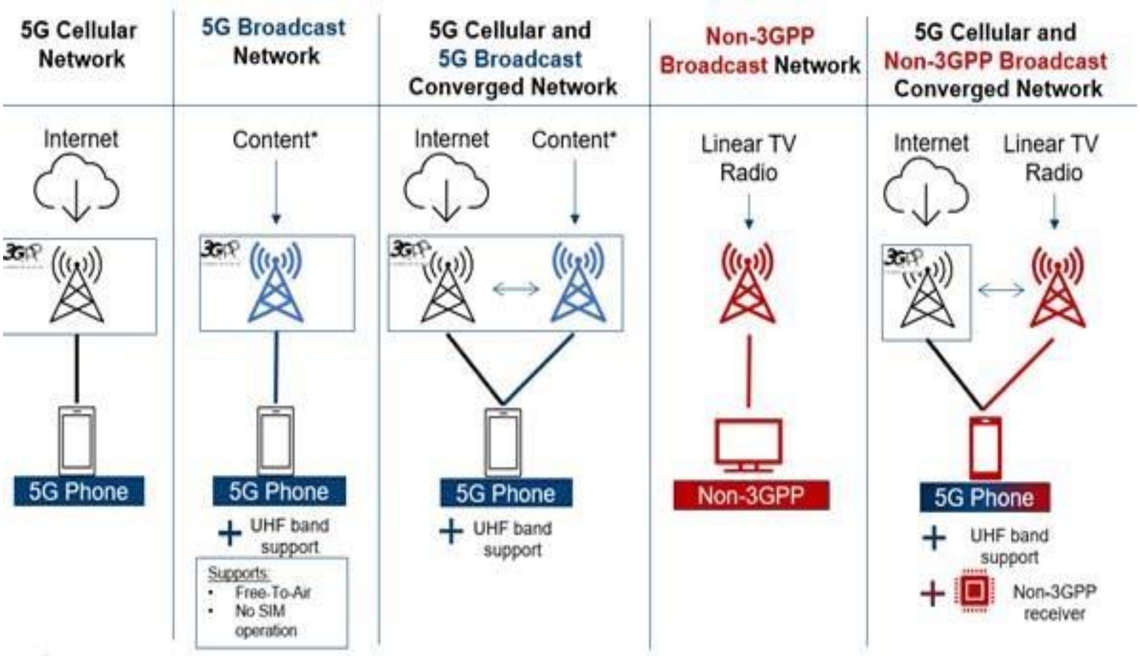

Fig. 6: The evolution of 5G Broadcast in 3GPP across Releases.
[Source: Qualcomm]

eMBMS, a feature of the 4G LTE standard, enables operators to dedicate a segment of their spectrum for multicast content delivery. LTE Broadcast, utilizing eMBMS, enhances user experience by minimizing buffering, congestion, and latency while also streamlining content delivery for operators and service providers. It facilitates broadcast transmission across multiple cells through single-frequency network configurations. Target applications include mobile TV, radio broadcasting, live streaming video services, file delivery, and emergency alerts.

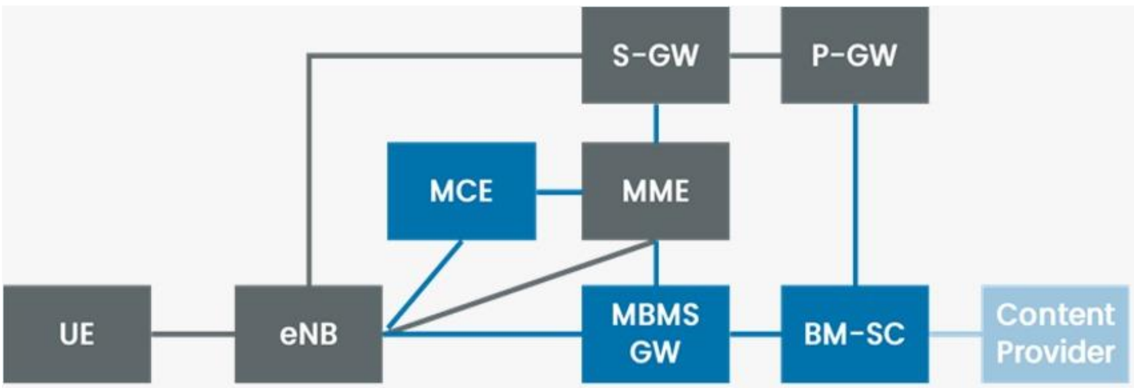

Fig. 7: eMBMS Architecture
[Source: https://www.3gpp.org/technologies/broadcast-multicast1]

eMBMS introduced the concept of MBMS Single Frequency Network (MBSFN) for delivering broadcast/multicast services. MBSFN involves transmitting identical waveforms simultaneously across a cluster of cells covering a specific geographic area. Single Cell Point to Multipoint (SC-PTM) allows adjusting the broadcast/multicast coverage down to a single cell level and dynamically allocating radio resources for each cell.

The requirements for stand-alone broadcast – i.e. relying on a broadcast-only network, for downlink-only traffic, and independent from cellular networks – were fully met in 3GPP Release 16 and include the UHF band 108 (470 to 698 MHz) since Release 18. This mode enables broadcast deployments using existing UHF spectrum and television broadcast infrastructure such as Medium-Power Medium-Tower (MPMT) and High-Power High-Tower (HPHT) networks. Since the signal is distributed only once to all receiving devices, there is no excessive network utilization based on the number of receiving devices per cell, so the quality of the programs is not reduced due to many devices.

The motivation behind 5G Broadcast was to facilitate broadcast operation for receivers compatible with cellular modems, prompting 3GPP to evolve eMBMS rather than pursue entirely new designs. Consequently, compared to other broadcasting systems, the required enhancements to mobile device hardware for supporting 5G Broadcast are minimal, as many components are already integrated into existing 4G/5G modems. This standard is primarily aimed at traditional broadcasters equipped with broadcast network infrastructure and UHF spectrum assets. In its current (Release 17) version, it encompasses:

(a) Single Frequency Networks (SFN) with large inter-site distances (up to 125 km).

(b) High mobility reception up to 250 km/hr.

(c) “Transparent delivery”, allowing the use of media codecs and protocols defined outside 3GPP.

(d) 6, 7, and 8 MHz channel bandwidth in addition to the previously specified 1.4, 3, 5, 10, 15, and 20 MHz.

In addition, 5G Broadcast primarily targets mobility use cases. In the context of free-to-air broadcast in the 5G standalone broadcast mode, it does not mandate network support for unicast, nor does it necessitate devices to have a SIM card or a cellular subscription. Although unicast is not obligatory, 5G Broadcast can also be integrated with unicast to provide a hybrid user experience, leveraging the strengths of both unicast and broadcast technologies.

As a result, 5G Broadcast has garnered worldwide interest from broadcasters, regulators, and cellular operators alike due to its utilization of existing broadcast and broadband infrastructure and its capability to operate in the UHF spectrum through SFN and other advancements.

3.1.3 Features of 5G Broadcasting

(a) **Frequency Bands:** 5G broadcast services are defined band-agnostically and can be delivered over various frequency bands, including sub-6 GHz and millimeter-wave (mm-Wave) bands. The choice of frequency band depends on the specific use case, network architecture, and local regulations. 5G Broadcast services are designed to be delivered over the UHF bands.

(b) **Modulation Schemes:** 5G broadcast services can use various modulation schemes, such as 16-QAM, 64-QAM, and 256-QAM, to encode the multimedia content for transmission over the network.

(c) **Core Network Architecture:** The core network architecture for Terrestrial Broadcasting in 5G Era services includes a broadcast/multicast service center (BM-SC), responsible for managing the delivery of broadcast/multicast content over the network.

(d) **Media Delivery Methods:** 5G broadcast services can use various media delivery methods, such as File Delivery over Unidirectional Transport (FLUTE), MPEG-2 Transport Stream (TS), and MPEG-DASH, to deliver multimedia content to end-users.

(e) **Latency:** 5G broadcast services are designed to have low latency, typically between 10 and 100 milliseconds, to enable real-time multimedia experiences such as live streaming of sports events or concerts.

(f) **Quality of Service (QoS):** Terrestrial Broadcasting in 5G Era services support various QoS levels, including best-effort and guaranteed bit rate, to ensure that the multimedia content is delivered with the appropriate level of quality and reliability.

(g) **Security:** Terrestrial broadcasting in 5G Era services is designed with various security features, such as encryption and authentication, to ensure the privacy and integrity of the multimedia content and the network.

3.1.4 Architecture of Broadcasting over 5G

The 5G Broadcast System architecture, outlined in Fig. 8, involves several key entities:

(a) A 5G Broadcast TV/Radio Content Service Provider operates a head-end to deliver linear television and radio services.

(b) A 5G Broadcast TV/Radio Service Application runs on devices equipped with a 5G Broadcast Receiver.

(c) A 5G Broadcast System operator manages 5G Broadcast Transmitters for devices, including 5G Broadcast Receivers.

(d) A 5G Broadcast TV/Radio Content Service Provider offers services via the 5G Broadcast System.

(e) A 5G Broadcast TV/Radio Service Application accesses services by communicating with the 5G Broadcast Receiver through dedicated 5G Broadcast Client APIs.

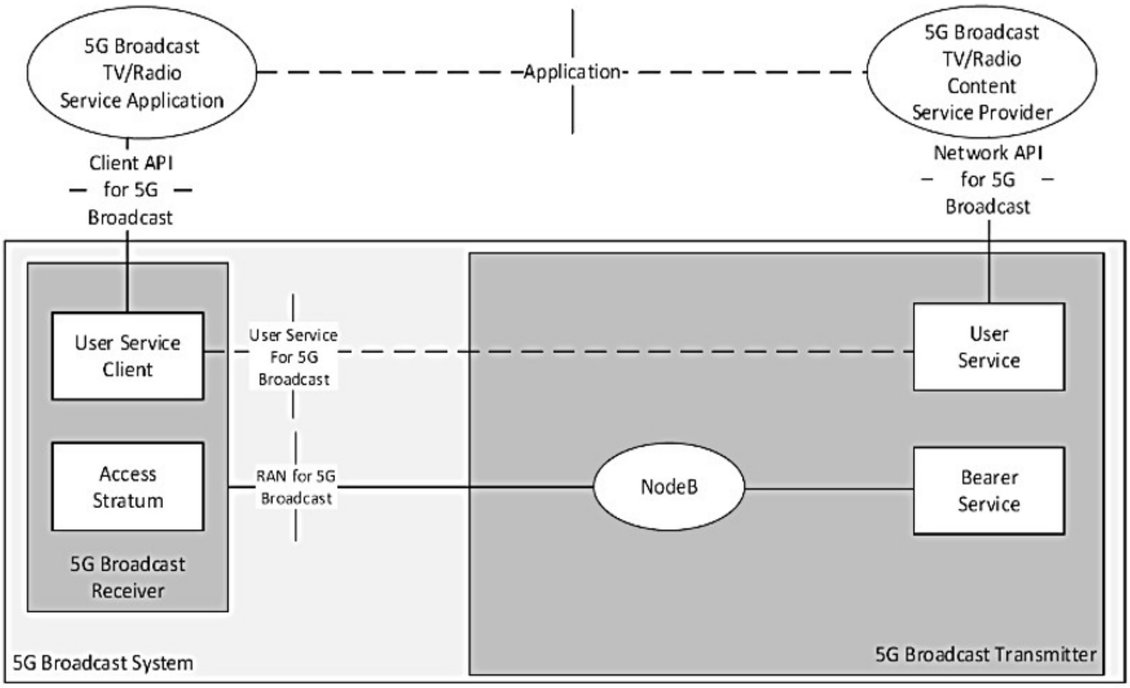

Fig. 8: Reference architecture for 5G Broadcast System
[Source: ETSI TS 103 720]

The 5G Broadcast Service comprises a Bearer Service and a User Service. The latter handles the announcement of 5G Broadcast User Services and facilitates their discovery and access. The former serves as the distribution channel for 5G Broadcast User Services, including a radio bearer. A RAN interface supports various features encompassing a NodeB in the 5G Broadcast Transmitter and an Access Stratum modem in the 5G Broadcast Receiver.

Additional information is available in ETSI TS 103 720 v2.

3.1.5 5G Broadcast standard references

(a) ETSI TS 103 720: 5G Broadcast System for linear TV and radio services; LTE- based 5G terrestrial broadcast systems – a profile of 3GPP specification containing the necessary parts to deploy 5G broadcast developed by the EBU.

(b) 3GPP TR 36.976: Overall description of LTE-based 5G broadcast (Release 16) – the overall description of enhanced TV (enTV) for 5G broadcast.

(c) Various 3GPP specifications of the 5G PHY supporting broadcast together with unicast in TS 36.211/TEC 25601:2020 , TS 36.212/ TEC 25002:2020,

(d) TS 36.213 TEC 25069: 2020. The Telecom Engineering Center (TEC) has adopted them into Indian standards.

(e) TSDSI TR 6015: Service Delivery using 5G Broadcast for TV, Radio, IPTV and File-casting.

3.1.6 Benefits of 5G Broadcast

The benefits of enabling new use cases for multiple stakeholders in the Indian market could be as follows:

(a) Distributing public and commercial linear TV, radio services, and live content, both free-to-air and encrypted, to 3GPP-compatible devices like smartphones, smart TVs, and in-car infotainment systems. The primary goal of 5G Broadcast is to supplement existing cable services, especially in areas where cable connections are not well established.

(b) Enabling personalized media offers by delivering linear broadcast content alongside catch-up or on-demand services using the same family of standards (3GPP). This approach aims to bridge the gap between broadband and broadcast services. For example, mobile network operators (MNOs) can utilize existing broadcasting resources, such as frequencies and infrastructure, to create new business opportunities.

(c) Integrating broadcast distribution of linear TV and radio services into existing media applications through 3GPP-defined APIs.

(d) Seamless integration with public safety broadcast services, including emergency broadcast messages, with integrated text/multimedia and the option for additional interactivity via broadband connectivity.

(e) Deployment flexibility with various tower types (e.g., high-power high-tower (HPHT), low-power low-tower (LPLT), medium-power medium-tower (MPMT)) depending on the scenario, application, and geographical considerations.

(f) 5G Broadcast is designed for hardware reuse of cellular modems, catering to broadcasters' needs such as high-power deployments, operation without a SIM card, support for UHF spectrum, and fixed reception.

(g) Integration with the 3GPP stack enables advanced features like emergency notifications and interactive broadcasts.

(h) The 5G Broadcast system inherits features from cellular systems, including support for multiple antennas and carrier aggregation.

(i) Ongoing work in 3GPP is defining new bands for introducing 6/7/8MHz channel bandwidths, independent of Release 18.

(j) Continuous evolution of the 5G Broadcast system in recent releases allows for further enhancements to address new use cases and requirements as they arise.

3.1.7 Deployment/Trial/Test Beds scenario in various countries

Table 1 below presents the Deployment/Trial/Test Beds scenario in various countries:

Country	Cities	Trial name	TMMB system (Terrestrial Multimedia Mobile Broadcasting)	Frequency range used	Date
China	Beijing, Shanghai	5G NR MBS Trial in Beijing and in Shanghai	5G new radio (NR) multicast and broadcast system (MBS)	758-768 MHz	October 2020/November 2021
	Nanjing	5G NR MBS Trial in Nanjing	5G new radio (NR) multicast and broadcast system (MBS)	Within the 700 MHz range	October 2021
Switzerland France Germany Italy Austria	Geneva Paris Stuttgart Turin Vienna	5G Broadcast of the Eurovision Song Contest 2022	LTE-based 5G Terrestrial Broadcast	600 MHz	April/May 2022
Germany	Stuttgart, Heilbronn	5G Media2Go	FeMBMS (Release 14) LTE- based 5G Terrestrial Broadcast LTE Unicast	622-630 MHz	October 2020/ September 2022
	Hamburg	5G Broadcast in Hamburg	LTE-based 5G Terrestrial Broadcast	574-582 MHz	October 2021/ December 2023
Austria	Vienna	Vienna field trials	FeMBMS (Release14) LTE-based 5G Terrestrial Broadcast	734-744 MHz 662-672 MHz 638-642 MHz	2020/2021 – Phase 1 2021/2023 – Phase 2
Italy	Aosta Valley	LTE-based 5G Broadcast trial in Aosta Valley	LTE-based 5G Terrestrial Broadcast	726-734 MHz	November 2021/ June 2022
Denmark	Copenhagen	LTE based 5G Terrestrial Broadcast field trials in Denmark	LTE-based 5G Terrestrial Broadcast	617-622 MHz	June/July 2022
Spain	Barcelona	5G-B trial during MWC in 2020, 2022, and 2023	FeMBMS (Release 14) FeMBMS (Release 16), eMBMS (Release 12)	750-755 MHz 617-627 MHz 617- 622 MHz	[Feb.] 2020/ [Feb.] 2022/ [Feb.] 2023
Italy	Turin and	Rai Way Trial of	FeMBMS	743-748	July

	Palermo	5G Broadcast network and services in the 700 MHz band in the cities of Turin and Palermo	(Release 16) and seamless switching broadband/bro ad cast	MHz (SDL-B2)	2022/Jul y 2023
Italy	Lissone (Monza-Brianza)	EI-Towers 5G-B field Trial in Lissone (MB)	FeMBMS (Release 16)	738-743 MHz (SDL-B1)	March 2023
USA	Boston	Transmit LTE-based 5G Broadcast over a licensed ATSC 3.0 TV broadcast facility	FeMBMS (Release 16)	UHF TV band	Ongoing
China	Chengdu	5G broadcast pilot project	FeMBMS (Release 16)	630-638 MHz	Ongoing
Brazil	Rio	5G Broadcast streaming demonstration	FeMBMS (Release 16)	UHF TV band	February 2023
Switzerland	Geneva	5G Broadcast based hybrid content distribution	FeMBMS (Release 16)	UHF TV band	April 2023

Table 1: Deployment/Trial/Test Beds scenario in various countries
[Source: Qualcomm]

3.2 ATSC 3.0

ATSC 3.0 was developed by the Advanced Television Systems Committee (ATSC) to address the evolving landscape of media consumption and technological advancements in the digital age. Also known as NextGen TV, it is an IP-based digital television broadcasting standard deployed in the US and South Korea. It features the recent digital modulation techniques also used for DVB-T2. The transition from analog to digital broadcasting was facilitated by ATSC 1.0, revolutionizing television with improved picture and sound quality. However, the rapid progress of technology and changing viewer habits necessitated a more versatile and feature-rich standard, leading to the development of ATSC 3.0.

ATSC 3.0 introduces a host of transformative features. It enables broadcasters to deliver Ultra High Definition (UHD) and High Dynamic Range (HDR) content, offering viewers a captivating visual experience that was previously unattainable. The standard's enhanced audio capabilities enable the efficient delivery of rich and life-like soundscapes and personalized audio experiences to consumers and include accessibility features that deliver a far richer experience for hearing and visually impaired audiences.

One of ATSC 3.0's aspects is its interactivity. ATSC 3.0 relies on internet-based feedback channels i.e. interactivity needs availability of internet. Viewers can now engage with content through interactive features, opening doors to personalized experiences, engaging advertisements, and more. Moreover, the standard embraces datacasting, allowing broadcasters to transmit non-broadcast data over the airwaves, enhancing emergency alerts, software updates, and targeted advertising.

ATSC 3.0 harmoniously merges traditional broadcasting with broadband internet, resulting in hybrid services that offer a seamless blend of linear television and internet-based content. This adaptability caters to various devices, from conventional TVs to mobile devices, ensuring a consistent and versatile viewer experience.

3.2.1 Features of ATSC 3.0

(a) **Mobile Reception:** ATSC 3.0 standard supports mobile reception. This implementation is at a prototype stage that allows users to receive multimedia content directly on their smartphones and tablets having a separate chipset.

(b) **Ultra-High Definition (UHD) Video:** ATSC 3.0 enables the transmission of UHD video content, providing a superior visual experience on mobile devices.

(c) **High Dynamic Range (HDR):** The standard supports the delivery of accurate HDR video, enhancing color depth and brightness for a more immersive viewing experience on mobile screens.

(d) **Immersive Audio:** ATSC 3.0 supports object-based audio, delivering immersive, personalized, and accessible sound experiences on mobile devices.

(e) **Interactive Content:** ATSC 3.0 allows for the delivery of interactive content, including interactive advertisements and additional information, alongside the main broadcast. ATSC 3.0 relies on an internet-based feedback channel.

(f) **Robust Error Correction:** The standard includes advanced error correction techniques, ensuring reliable reception even in challenging mobile environments.

(g) **Broadcast Internet Integration:** ATSC 3.0 integrates broadcast and broadband networks, enabling hybrid services that combine OTA and internet-based content.

(h) **Scalability:** The standard is designed to be scalable to various screen sizes and resolutions, ensuring a consistent user experience across different mobile devices.

(i) **Personalized Content Delivery:** ATSC 3.0 enables personalized content recommendations based on user preferences, enhancing content discovery on mobile devices.

(j) **Advanced Emergency Alerts:** The standard enhances emergency alert systems with geo-targeted and multimedia alerts for public safety on mobile devices.

(k) **Energy Efficiency:** ATSC 3.0 incorporates energy-saving technologies, optimizing power consumption in both broadcasting stations and mobile devices.

(l) **Adaptive Bitrate Streaming:** The standard supports adaptive bitrate streaming, adjusting the video quality based on network conditions for smooth playback on mobile devices.

(m) **Mobile App Integration:** ATSC 3.0 allows integration with mobile apps, enabling interactive features and complementary content on mobile devices.

(n) **Data Offloading:** The broadcast offload to non-3GPP network feature is still under discussion and normative architecture work is yet to begin in 3GPP.

(o) **Real-time Broadcast:** ATSC 3.0 ensures real-time delivery of live events and broadcasts, enabling users to watch sports, news, and other events on their mobile devices in real time.

3.2.2 Architecture of ATSC 3.0

The architecture of ATSC 3.0 is structured in layers to ensure efficient and seamless content delivery to mobile devices, offering users an immersive multimedia experience on their smartphones and tablets. At its foundation is the Physical Layer (PHY), responsible for transmitting and receiving data through the airwaves using OFDM modulation. The Link Layer (LL) manages the connection between transmitting and receiving devices, overseeing link adaptation and resource allocation. Above this, the Protocol Layer (PL) handles data packets, error correction, and retransmission protocols to ensure dependable data delivery.

The Management and Protocols Layer (MPL) takes charge of service discovery, signaling, and the management of various protocols. The Presentation Layer (PLS) decodes and presents multimedia content, offering audio, video, and more. The Application Framework (AF) lays the groundwork for interactive applications and services, while the Application Layer (AL) manages interactive content delivery, personalized recommendations, and user interactions.

Enabling the integration of broadcast and internet-based services, the Broadcast Internet Protocol (BIP) facilitates the delivery of IP-based content over broadcast channels. Service Layer Multiplexing combines diverse services like audio, video, and data into a unified transport stream, and Service Protection and Security handle content encryption and digital rights management for secure delivery.

The Broadcast Internet Integration layer manages the harmonious integration of broadcast and broadband networks, facilitating hybrid services. The Emergency Alert System (EAS) ensures efficient delivery of emergency alerts to mobile devices, enhancing user safety. The Electronic Service Guide (ESG) provides interactive access to program schedules and information, enriching user engagement. The Interactive Application Execution Environment executes interactive applications on receiver devices, enhancing interactivity.

Fig. 9 shows the block diagram of ATSC 3.0.

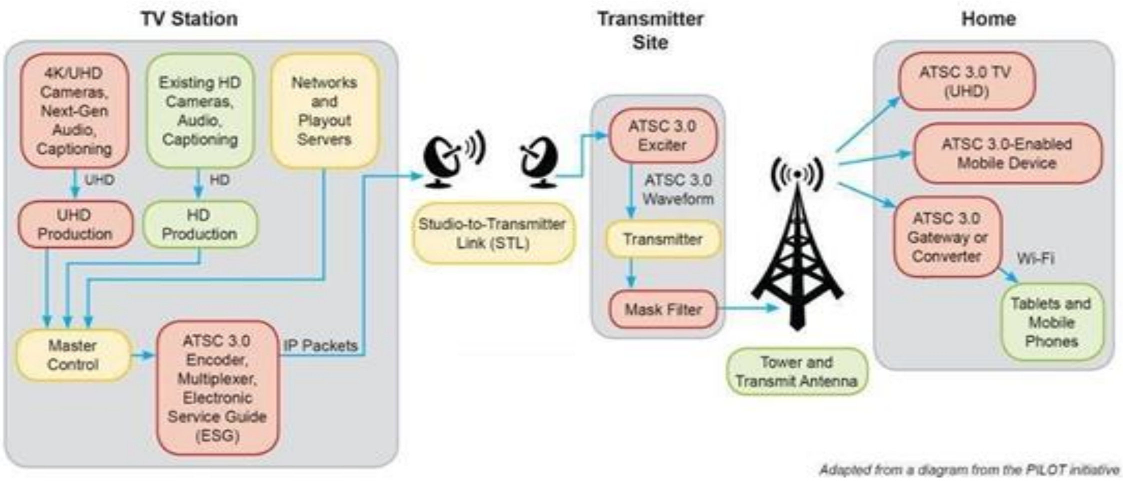

Fig. 9: Block diagram of ATSC3.0

[Source: https://www.atsc.org/atsc-documents/type/3-0-standards/]

Serving as a communication hub, Middleware manages interactions between the different layers and components of the ATSC 3.0 system. Altogether, these layers create a comprehensive architecture that optimizes content delivery, interactivity, security, and integration, offering a robust platform for delivering multimedia content seamlessly to mobile devices.

3.2.3 Advantages of ATSC 3.0

(a) ATSC 3.0 is a TV broadcast system deployed in the USA and South Korea.

(b) ATSC 3.0's optimized time and frequency interleaving provides significant performance benefits in harsh fading environments.

(c) ATSC 3.0 has advanced BICM (bit-interleaved coded modulation) efficiency.

(d) It has the ability to add future enhancements using the "bootstrap signal" that allows "gaps" in the transmission to be used by future extensions of the standard.

(e) Being IP-based, it can send digital data for software over-the-air updates.

(f) Layered Division Multiplexing (LDM) mode allows the same frequency spectrum to transmit high-resolution video for Fixed TV and robust lower-resolution video for mobile devices in the same spectrum.

3.2.4 Deployment/Trials/Test beds scenario in various countries

Country	Cities	Trial name	TMMB system (Terrestrial Multimedia Mobile Broadcasting)	Frequency range used	Date
USA	Texas, New York, Alabama, Michigan, Colorado, Ohio	Currently in the process of deploying ATSC 3.0. Some broadcasters Sinclair Broadcast Group, Nexstar Media Group, and Tegna have launched the network.		UHF	2023
Canada	Toronto	Broadcast-Broadband Convergence B²C Lab, Humber College [first and only ATSC 3.0 experimental broadcasting	Lab has deployed a custom multiple transmitter/ antenna ATSC 3.0 over-the-air test bed covering the	UHF	

		license in Canada]	Toronto area.		
South Korea	PyeongChang	launched ATSC 3.0 in 2017 to deliver better video and audio quality to OTA viewers in its largest urban areas, to promote its 4K capabilities. Some trial attempts were made to deliver two streams; one for fixed TV and the other for mobile. But now, only fixed TV stream is available and no D2M is commercially launched.		700 MHz	2017/2018
Brazil	Rio	"TV 3.0" project It aims to improve the quality of television broadcasting in Brazil using ATSC 3.0 technologies. TV 3.0 in Brazil is still under early development now and ATSC3.0 is being only studied/verified as one of candidate PHY technologies.	FeMBMS (Release 16)	UHF TV band	February 2023
India	New Delhi (Trail)	Prasar Bharati HPHT and 8 LPLT broadcasting in SFN mode on Kartavya Path.	Video received on prototype mobile phone with ATSC 3.0 receiver inbuilt; and on normal Android phones with USB dongle receiver.	538 MHz	2024
Jamaica	Throughout	Television		UHF	2022

	the country	Jamaica limited (TVJ) launched ATSC 3.0 digital TV transmission services in 2022.			

Table 2: Deployment/Trials/Test beds scenario in various countries

3.3 DVB-T2 and DVB-I

Digital Video Broadcasting - Terrestrial 2 (DVB-T2) is a European technology and is an advanced digital television broadcasting standard representing a significant evolution from its predecessor, DVB-T. Developed by the Digital Video Broadcasting Project (DVB), DVB-T2 is designed to address the growing demand for higher-quality video, improved spectrum efficiency, and enhanced transmission robustness in terrestrial broadcasting.

DVB-T2 builds upon the success of DVB-T, which played a crucial role in the global transition from analog to digital television broadcasting. DVB-T revolutionized television by providing better image quality, more channels, and interactive features. However, as technology continued to progress, the need for even more efficient and advanced broadcasting capabilities became evident.

DVB-T2 has been adopted by numerous countries as their preferred digital television broadcasting standard. Its enhanced capabilities and improved efficiency make it well-suited to the demands of modern broadcasting, offering viewers an enriched and immersive television experience while allowing broadcasters to deliver a broader range of content and services.

3.3.1 Features of DVB-T2

(a) The DVB-T2 specification incorporates the latest advancements in modulation and error-protection techniques, resulting in increased bit-rate capacity and enhanced signal robustness. These improvements are achieved through detailed changes in physical layer features, network configuration, and performance optimization.

(b) It features a frame structure with a unique identification symbol that enables quick channel scanning and signal acquisition. Additionally, this symbol indicates certain fundamental frame-structure parameters.

(c) The system utilizes rotated constellations, serving as a form of modulation diversity. This facilitates the reception of higher-code-rate signals even in challenging transmission channels.

(d) Special techniques are employed to reduce the peak-to-average ratio of the transmitted signal.

(e) An option is available to extend the transmitted signal by incorporating Future-Extension Frames (FEFs). These FEFs are unspecified portions of the signal that first-generation receivers can ignore, but they provide a compatible pathway for future upgrades.

3.3.2 Conceptual Architecture of DVB-T2

At its core, the architecture comprises distinct layers to facilitate seamless data transmission and reception. The Physical Layer (PHY) forms the foundation, utilizing DVB-T2 modulation (COFDM) for transmitting and receiving data over the airwaves. The Link Layer (LL) manages the connection between transmitting and receiving devices, incorporating error correction and diversity techniques to enhance reliability. The Protocol Layer (PL) oversees data packet management, error correction, and retransmission protocols, ensuring dependable data delivery.

An essential component is the Adaptation Layer, serving as an interface where content intended for mobile devices is extracted or transcoded from the DVB-T2 stream. This allows for efficient delivery of content tailored for mobile consumption. Additionally, the architecture includes Mobile Data Offloading, enabling mobile network operators to directly provide popular content to mobile devices, thereby alleviating traffic from cellular networks. The Interactive Application Framework establishes the groundwork for interactive applications and services, while Mobile App Integration offers the potential for mobile apps to access supplementary interactive content and services. Middleware plays a pivotal role in managing communication between the various layers and system components. Content Protection and Security handles critical tasks, including content encryption and digital rights management, ensuring secure and protected content delivery. The architecture also features Service Layer Multiplexing, consolidating diverse services like audio, video, and data into a unified transport stream.

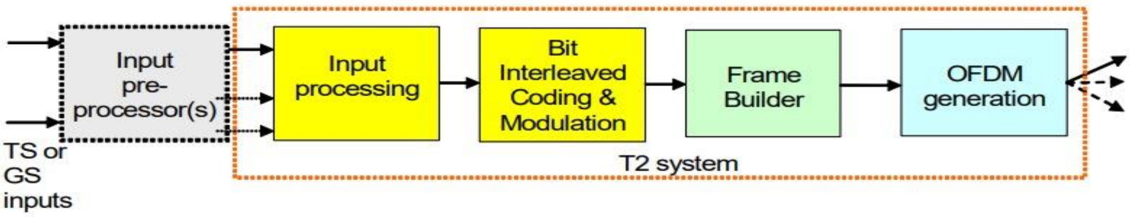

Fig. 10: DVB T-2 System Block Diagram
[Source ETSI EN 302 755 V1.2.1 (2010-10)]

Fig. 10 depicts the generic block diagram of the T2 system. The system input(s) can include one or multiple MPEG-2 Transport Streams (TS) or one or more Generic Streams. The Input Pre-Processor, although not part of the T2 system, may feature a Service splitter or de-multiplexer for Transport Streams (TS) to separate the services into logical data streams, which serve as T2 system inputs. These logical data streams are then transmitted through individual Physical Layer Pipes (PLPs).

The typical system output comprises a single signal intended for transmission on a single RF channel. Additionally, the system can generate a secondary set of output signals designed for transmission to a separate set of antennas in MISO transmission mode.

3.3.3 DVB-T2 deployment scenario

Doordarshan started Digital Terrestrial Television services with DVB-T2 in 19 cities in India in 2016. DTT channels could be received using DVB-T2 Dongles in OTG-enabled smartphones, tablets, laptops, etc. The channels could also be viewed on Fixed TV sets using Indoor/Outdoor antenna on integrated digital TV (iDTV) sets or DTT set-top boxes. Doordarshan offered DD National, DD News, DD Bharati, DD Sports, and DD Regional/DD Kisan channels, relayed from DTT transmitters installed in these select cities. With the offering of 4G services in India and the corresponding 5G launch, the subscribers migrated to view OTT content on smartphones (without the need for an external dongle), and the DVB-T2 service had to be shut down in 2022 due to a lack of viewership and due to a lack of device ecosystem development.

3.3.4 Interworking at the Service Layer (DVB-I over 5G)

The past five to ten years have seen DVB focusing heavily on IP-centric solutions to facilitate the migration of broadcasters to IP-based distribution and consumption that, beyond representing a significant challenge, brings a new wave of opportunities for the broadcast industry. The different topologies and market specificities from country to country came as an additional challenge, especially considering the large number of countries using DVB technologies, implying heterogeneous ways to manage such migrations. This particularly complex issue gave birth to the DVB-I service discovery solution, used in conjunction with DVB-DASH for service delivery via the Internet.

DVB-I (Internet) is a service layer specification that defines the metadata for the discovery – via the Internet – of services and service lists available through either broadband or broadcast networks. This metadata, provided in a common XML format, is used by receivers such as connected TVs, smartphones, or tablets to populate the channel list and retrieve the electronic program guide (EPG) for linear services as well as on-demand content. Conceptually, it is equivalent to DVB-SI (DVB Service Information) and PSI (Programme-Specific Information) carried in a broadcast MPEG-2 TS.

DVB-I is also an umbrella term sometimes used to refer to the services discovered using the DVB-I discovery mechanism and delivered via the internet, typically using DVB-DASH (Dynamic Adaptive Streaming over HTTP). DVB-DASH is a profile of the MPEG-DASH standard to support Adaptive Bit Rate (ABR) streaming over HTTP with a high degree of interoperability and low-latency support. However, DVB-I services are not limited only to DVB-DASH delivery: DVB-I services include any service that can be discovered using DVB-I and is available via one or more delivery mechanisms, called service instances, including DVB-DASH, DVB broadcast, and 5G technologies, as will be described later.

Service layer collaboration, for instance between broadcast and broadband, appears when broadcast content is interlinked with other content received over bi-directional broadband networks. Typical applications of service layer collaboration between broadcast and broadband are the Interactive Broadcast-Broadband (IBB) systems such as HbbTV (Hybrid Broadcast Broadband Television), Hybrid cast, HTML5-based Smart TV Platform, or Ginga middleware. Such systems maximize the user experience by providing high-quality, flexible, interactive, and personalized services such as additional information on available services (enhanced EPG), additional services for minorities or with improved accessibility features, and access to non-linear broadcasting (catch-up TV). The DVB-I service layer is the most recent of such systems to be released.

Concretely, DVB-I allows services delivered from any network type (broadcast and broadband networks) to be discovered in a fully transparent manner on the end-user side (refer to Fig. 11). This network-agnostic approach allows broadcasters to adopt a flexible and hybrid use of the most appropriate or cost-effective delivery network according, for instance, to the popularity of services or the country's topology and whether services target high-density or more rural areas. It also allows countries to evolve at their own pace in their migration journey and include new networks in the content delivery 'mix' as they become relevant. Combining existing terrestrial and satellite DVB-T/T2/S2 broadcast networks with the broadband infrastructure can be leveraged to foster interactivity and innovative ways to monetize content.

DVB-I was recently enhanced to support 5G technologies and it is now acknowledged as having a role to play in the ways the 3GPP system can interwork with non-3GPP ones. DVB-I services may contain HbbTV applications, or the HbbTV applications may run DVB-I clients – and its most recent update made possible collaboration with non-DVB networks, such as 3GPP ones. One potential benefit is the ability to support integrated DVB-I hybrid services, i.e., services for which the basic broadcast distribution is augmented with 5G unicast for extended service coverage, lower distribution costs, improved quality, or additional user experiences.

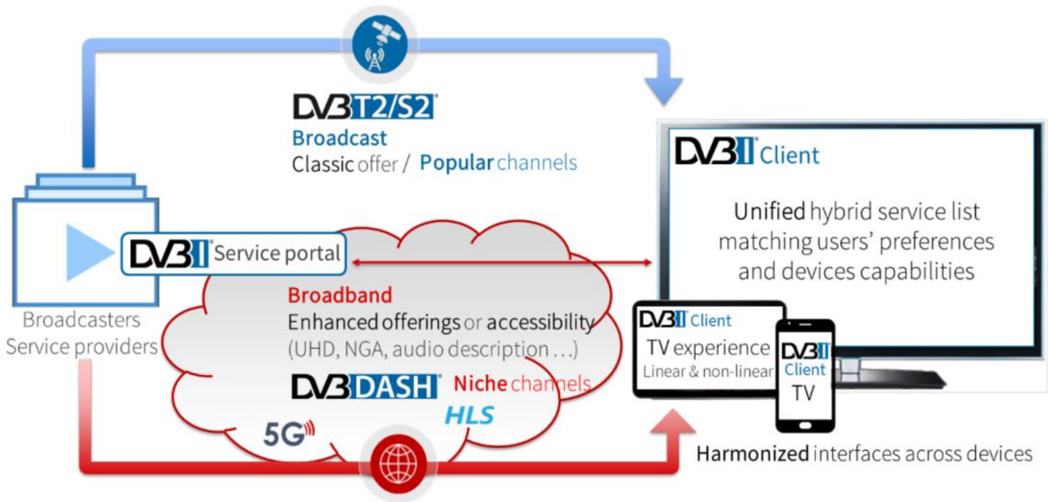

Fig. 11: DVB-I Use for IP Migrations or for Offerings Enhancements
[Source: https://bandaancha.eu/articulos/mediaset-adoptara-dvb-i-fusionando-tdt-10246]

DVB first published commercial requirements for supporting DVB-I services over 5G networks in DVB Bluebook C100. This document provides a set of 70 technical and procedural requirements developed based on six guiding use cases. These requirements outline specifications to support different Release-16-based 5G operation modes, including 5G Broadcast and 5G Media Streaming (5GMS), for the following purposes:

(a) Delivering DVB-I Services over a 5G Broadcast System as defined in TS 103 720.

(b) Delivering DVB-I Services over a 5GMS System as defined in TS 126 501.

(c) Delivering a DVB-I Service simultaneously over regular unicast, 5G Broadcast, and 5GMS as independent service instances, potentially providing different bitrates, latencies, etc.

(d) Delivering Hybrid DVB-I Services using 5G networks, defined as:

- Describing the DVB-I service in a DVB-I service list.
- Distributing a basic DVB-I service via 5G Broadcast.
- Augmenting the service with ordinary unicast or 5GMS.

A Joint Task Force (JTF) between DVB and the 5G Media Action Group (5G-MAG) produced a Technical Report, TR 103 972 v1.1.1, published by ETSI in July 2023. This report mapped commercial use cases and requirements from DVB BlueBook C100 into deployment guidelines. In clause 5.1, a DVB-I over 5G reference architecture is defined, focusing on leveraging existing interfaces, reference points, and APIs from DVB and 5G specifications to establish services. The commercial requirements for DVB-I over 5G were summarized into the following three scenarios based on this reference architecture:

(a) Stand-alone DVB-I Service using 5G Broadcast,

(b) DVB-I Service using 5G Media Streaming, and

(c) DVB-I Service offerings simultaneously over broadcast and unicast.

TR 103 972 provides references to relevant specifications for implementation and documents recommended configurations for each scenario. Minimal gaps in existing DVB, 3GPP, or ETSI specifications are identified, thanks to the original DVB-I design's independence from the access layer.

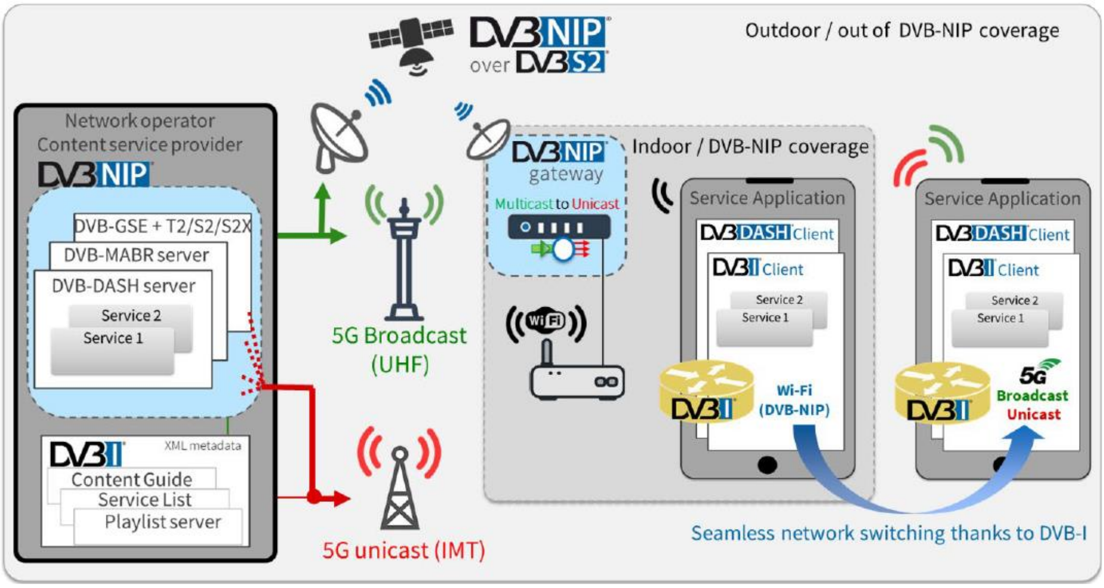

Fig. 12: Possible use of DVB-I over 5G in combination with DVB-NIP.
[Source: DVB [42]]

Transitionally, combined solutions utilizing both 5G and DVB networks can seamlessly coexist, leveraging their strengths. DVB-I's extension to support 5G technologies enables this. In low connectivity areas, DVB-NIP over existing satellite links (DVB-S2) can reach legacy devices via Wi-Fi hotspots, particularly indoors, without requiring device adaptation. Such a combination could alleviate the current spectral efficiency disadvantage of 5G by eliminating the need to consider indoor coverage in the link budget, thereby reducing the number of required transmission towers [42]. End users experience seamless integration due to DVB-I's facilitation of interworking between heterogeneous distribution networks at the service layer [25-32].

3.4 ISDB-T systems family

Integrated Services Digital Broadcasting - Terrestrial (ISDB-T) is a digital television broadcasting standard that originated in Japan and has since been adopted by several countries in Latin America and other regions. Developed by the Japanese government and industry, ISDB-T represents a significant advancement over analog broadcasting, offering improved image and sound quality.

ISDB-T has played a vital role in the digitalization of television broadcasting, particularly in the countries where it has been adopted. Its capabilities have contributed to the improved broadcasting quality, expanded services, and greater access to information and entertainment for viewers.

ISDB-T is designed to provide high-quality digital broadcasting signals with better resistance to interference compared to analog TV signals. It uses advanced modulation techniques and error correction to ensure that the transmitted signal is received accurately by the receiver [11, 12].

3.4.1 Features of ISDB-T

(a) **High-quality service flexibility:** ISDB-T adopts flexible multiplex technology (MPEG-2 systems) and efficient video/audio coding systems (MPEG-2 and MPEG AAC), enabling support for various broadcasting services like HDTV, HDTV+SDTV, and Multi-channel SDTV.

(b) **Robustness and reception flexibility:** ISDB-T addresses degradation factors in the VHF/UHF band, such as thermal noise, multi-path interference, urban noise, and fading of mobile/portable reception, by employing an OFDM transmission system with "Time Interleave" technology.

(c) ISDB-T provides benefits such as lower transmitter power requirements, indoor antenna reception feasibility, and mobile/portable reception capabilities.

(d) **Effective frequency resource utilization:** The OFDM transmission system in ISDB-T facilitates the creation of a Single Frequency Network (SFN), allowing for frequency resource conservation for relay transmitters, the use of the same frequency for multiple transmitters within the same network, and seamless program reception by mobile or portable devices without changing the receiving channel.

(e) **Mobility and portability:** ISDB-T employs Segmented OFDM transmission technology to enable fixed, mobile, or portable reception services within the same bandwidth, facilitating services like the "One-seg" service, which utilizes a single segment in the bandwidth and can be easily integrated into mobile phones, portable PDAs, USB tuners, etc.

(f) **One-seg service:** One-seg service utilizes a single segment within the same bandwidth, eliminating the need for additional transmitters and reducing frequency resource usage and infrastructure costs. Additionally, the narrow-band reception of One-seg receivers conserves power consumption, enabling long-time reception.

(g) **Commonality:** ISDB-T reduces receiver costs by utilizing backend technology shared with satellite, terrestrial, and cable systems. This allows for the integration of receivers equipped with both satellite and terrestrial tuners.

(h) **Utilization for disaster prevention:** ISDB-T facilitates disaster prevention efforts through its portability and the inclusion of the Emergency Warning Broadband System (EWBS) function, aiding in timely emergency broadcasts.

3.4.2 Architecture of ISDB-T

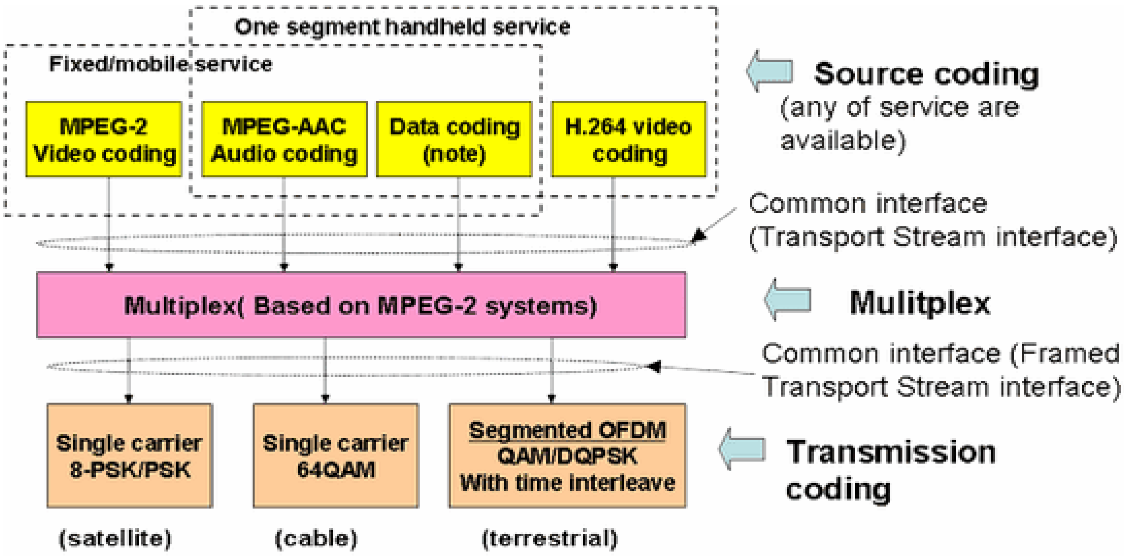

Fig. 13: Structure of Japan's Digital Broadcasting system
[Source- https://www.dibeg.org/techp/structure/]

The ISDB-T architecture consists of multiple interconnected layers, each with specific functions to ensure seamless digital broadcast operations. At its foundation, the Physical Layer (PHY) employs OFDM modulation to transmit and receive data over the airwaves. Above this, the Data Link Layer handles the link establishment and management to facilitate efficient data transfer. The Transport Layer is responsible for packetization and error correction to ensure dependable data transmission. The Service Layer Multiplexing combines audio, video, and data services into a unified transport stream, while the Presentation Layer decodes and presents audio and video content. The Application Layer manages interactive services, datacasting, and applications, supported by the Interactive Application Framework that provides the basis for interactive applications. These applications are executed by the Interactive Application (IA) Execution Environment on receiver devices, and their data is combined with audio and video through the IA Composition Engine. Ensuring synchronization of audio and video streams is the role of Media Synchronization. Middleware manages communication between different system layers and components, while Content Protection and Security handle encryption and digital rights management. The Network Layer oversees hybrid broadcast/broadband integration, and the Emergency Alert System (EAS) is in place for delivering crucial alerts to mobile devices. Finally, the Electronic Program Guide (EPG) offers users interactive access to program schedules and information. Together, these elements form the comprehensive ISDB-T architecture, enabling a rich and secure digital broadcast experience.

3.4.3 Advanced ISDB-T

Japan Broadcasting Corporation (NHK) has been conducting research and development on large-capacity transmission technologies for next-generation digital terrestrial television broadcasting (DTTB) systems. In this work, a transmission system inherited from ISDB-T has been developed, which can provide both fixed reception and mobile reception services. The transmission system was developed to provide 4K/8K UHDTV broadcasting for fixed reception and HDTV broadcasting for mobile reception in one channel (6 MHz bandwidth).

Advanced ISDB-T is the next leap of ISDB-T to enable offering far beyond the existing services, such as the provision of Ultra HD-based service on both broadcast and Integrated Broadcast-Broadband. This system is a tentative scheme to reply to the Brazil TV3.0 project. Advanced ISDB-T is based on the candidate technologies for the next-generation DTTB standard in Japan.

3.4.4 Features of Advanced ISDB-T

(a) Advanced ISDB-T is an evolution of the current ISDB-T standard, which is adopted in Brazil and other countries.

(b) Advanced ISDB-T aims to provide various and flexible services with high efficiency, such as UltraHD, interactive, and mobile services.

(c) Advanced ISDB-T is compatible with the current ISDB-T system and can cover the requirements for both Brazil and Japan.

(d) Compared to the current ISDB-T standard, the transmission capacity of the advanced ISDB-T can be increased by approximately 10 Mbps with the same required carrier-to-noise ratio (CNR), and the required CNR can be improved by approximately 7 dB with the same transmission capacity.

(e) The transmission capacity can be further increased by using a MIMO technology, which enables the transmission of two independent signals using two antennas in both transmitter and receiver sides.

(f) The advanced ISDB-T can transmit one UltraHD 4K service by using high efficiency video coding (HEVC) in a single 6-MHz channel for fixed single-input single-output (SISO) reception. For versatile video coding (VVC), it is expected that an UltraHD 8K service can be transmitted by using the MIMO system.

3.4.5 Architecture of Advanced ISDB-T

The architecture of advanced ISDB-T, the next-generation digital TV system being developed in Japan, is based on the current ISDB-T standard, which is adopted in Brazil and a few other countries. Advanced ISDB-T aims to provide various and flexible services with high efficiency, such as UltraHD, interactive, and mobile services.

Advanced ISDB-T can transmit up to three layers (layers A, B, and C) with different transmission capacities and robustness. Each layer can be used for different types of services, such as fixed, mobile, or interactive services. Advanced ISDB-T uses IP and HTML5 application environments to enable rich and complex services, such as emergency warnings, social network services, and e-commerce. IP and HTML5 also allow for easy integration of broadcast and broadband services. Advanced ISDB-T employs state-of-the-art technologies, such as low-density parity-check (LDPC) codes, 2×2 multiple-input multiple-output (MIMO) transmission, and scalable video coding (SVC). These technologies improve the spectrum efficiency, transmission rate, and quality of the system. Advanced ISDB-T is compatible with the current ISDB-T system and can cover the requirements of both Brazil and Japan.

3.4.6 ISDB-T deployment Scenario

ISDB-T is still under development and the target countries are Japan, the Philippines, Brazil, Peru, and Chile. The device ecosystem will be challenging since it is not a worldwide targeted technology [38].

3.5 DTMB-A

The Digital Terrestrial Multimedia Broadcast - Audio (DTMB-A) system is a digital broadcasting technology developed by China to provide advanced audio services within its digital television framework. It is an extension of the Digital Terrestrial Multimedia Broadcast (DTMB) standard, which was adopted as the national digital television standard in China. DTMB is based on the European DVB-T standard and was chosen as China's digital television standard due to its ability to deliver efficient and robust terrestrial broadcasting in a diverse geographical and population landscape.

DTMB-A focuses on enhancing audio services by delivering high-quality and immersive sound experiences to viewers. This system aims to improve audio quality, support multiple audio channels, and provide compatibility with various audio codecs. It complements the video capabilities of the DTMB standard with advanced audio features, catering to the evolving preferences of modern audiences.

3.5.1 Architecture of DTMB-A

The architecture of DTMB-A (Digital Terrestrial Multimedia Broadcast) comprises several essential components to facilitate efficient and reliable content delivery. At its core lies the Physical Layer, which utilizes OFDM (Orthogonal Frequency Division Multiplexing) modulation to divide bandwidth into narrowband channels, enhancing efficiency and resistance to interference. The Medium Access Control Layer manages resource access through TDMA (Time Division Multiple Access), ensuring fair allocation of radio resources among users. The Packet Layer encapsulates data into packets, incorporating error correction coding to mitigate transmission errors.

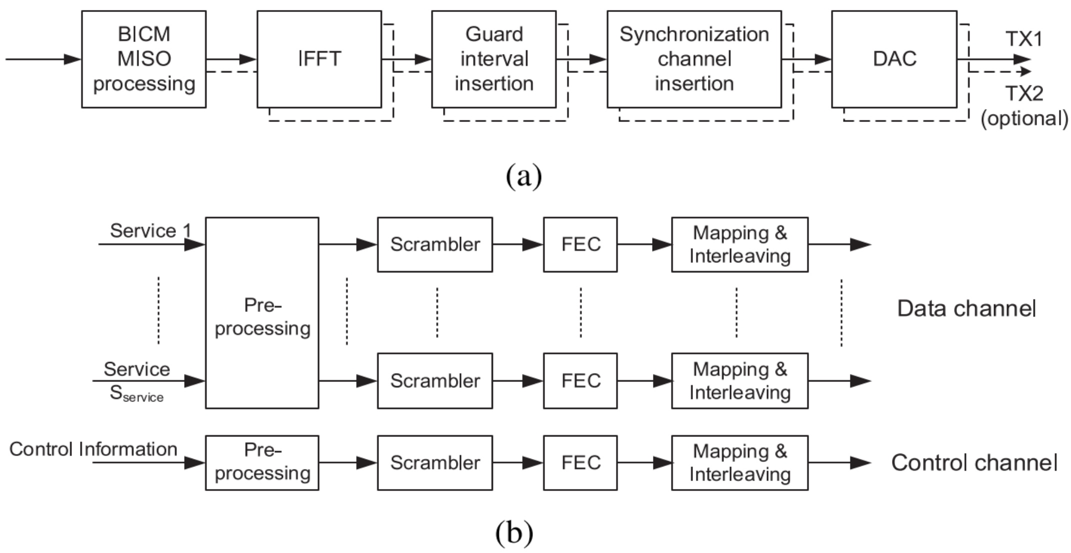

Fig. 14: DTMB-A system architecture: (a) Transmitter structure; (b) LDPC- based bit interleaved and coded modulation (LDPC-BICM)

[Source: https://www.researchgate.net/figure/DTMB-A-system-architecture-a-Transmitter-structure]

The functional block diagram of the DTMB-A transmitter structure, depicted in Fig. 14, focuses on the LDPC-based bit interleaved and coded modulation block, with optional transmit diversity. As illustrated in Fig. 14 the DTMB-A system supports three parallel logic transmission channels: the data channel, the control channel, and the synchronization channel.

The data channel carries all service data, initially randomized by a scrambling code and converted to a bit stream after forward error correction (FEC) coding. The bit stream is then mapped to constellation symbols based on the chosen modulation mode. After time-domain interleaving, the constellation symbols are assigned to frequency domain subcarriers and transformed to the time domain using inverse fast Fourier transform (IFFT). Utilizing TDS-OFDM technology, the data frame includes a specially designed frame header comprising two identical multi-carrier pseudo-noise (PN-MC) sequences. Considering the first PN-MC sequence as the cyclic prefix of the second one aligns the guard interval (GI) length with a single PN-MC sequence length, enhancing channel estimation precision and simplifying receiver implementation. Each data frame within the data channel can employ distinct channel coding and modulation schemes, allowing for configuration based on specific service requirements in practical scenarios.

3.5.2 DTMB-A deployment scenario

Presently, DTMB/DTMB-A standards have been deployed and operationalised in mainland China, Hong Kong, and Macao as well as other countries, such as Laos, Cuba, Cambodia, East Timor, and Pakistan. DTMB/DTMB-A mobile transmission system was applied successfully during the Beijing Olympic Games [39].

4. Comparison of DTT Technologies

Table 3 provides a comparison between the technical features of Digital Terrestrial Transmission Technologies.

Characteristics		**5G Broadcast**	**ATSC 3.0**	**DVB-T/T2**	**DTMB-A**	**ISDB-T**
SFN/MFN		Supported	Supported	Supported	Supported	Supported
Spectrum		UHF	UHF	UHF	UHF	UHF
Transmission parameter Signaling		Carrier Acquisition subframe (CAS), Multicast Channel (MCH) for both control and user plane	Bootstrap, Preamble symbol, L1 signaling	Preamble symbol P1	Service Channel signaling is Carried by control channel in the super frame	TMCC Pilot carriers
Technology status		Being deployed	Being deployed for NextGen TV services	Deployed	Not deployed	Japan launched “One-seg” (brand-name of D2M) using ISDB-T almost 10 years ago.
Targeted regions/ Countries		Worldwide	US, KR, Jamaica, India (Trail)	EMEA, Columbia, Australia, Malaysia, Indonesia	China	Japan, Brazil, Peru, Chile, Philippines
Transport Layer		IP based	IP based	MPEG-2 based	MPEG based	MPEG-2 based
NavIC support		Yes	No	No	No	No
Adopted as Indian Standard		Yes	No (Recommended by TSDSI)	No	No	No
Interworking with cellular network		Yes	Yes at Application layer	No	No	No
Ecosystem readiness Infrastructure/ End user devices	Fixed	*R/*R	*R/*R	*R/*R	*R/*R	*R/*R
	Mobile Handset	*R/*R	*R/**NR	*R/**NR	*R/**NR	*R/**NR

Mobile Integration complexity	RF	Change required	Change required	NA	NA	NA
	Base band	Low effort (Software/ firmware upgrades required)	Higher effort (Hardware Software upgrades required)	NA	NA	NA

*R *Ready (Readiness is assessed based on the available market offerings and accessibility).*

***NR* *Not Ready (Non-readiness is defined by the ecosystem willingness or readiness to support in relation to support of the standard based on the expected Bill of Materials (BoM) for the stakeholders).*

Table 3: Comparison between the technical features of DTT Technologies

4.1 Comparison between 5G Broadcast and ATSC 3.0

India is considering D2M enablement into devices and is evaluating between 3GPP 5G Broadcast and ATSC 3.0. These two are also IP-based technologies for DTT, while others are non-IP-based. Tables 4 and 5 summarise the ecosystem readiness of these two technologies for transmitter and receiving device aspects respectively.

Feature	3GPP 5G Broadcast	ATSC 3.0
Net data rate (on 8 MHz) (Depending on bandwidth, antenna height, Tx power and Modulation Coding Scheme MCS)	About 16 Mbps	About 16 Mbps
Channels supported	12-14 SD	12-14 SD
Spectrum	UHF & IMT	UHF
NavIC support	Yes	No
Interworking with Cellular	Yes	No
DVB-I Integration	Yes	No
Technology status	Trial networks across 30+ countries	Operational networks in 3+ countries offering TV services
Reverse path	Possible at RAN level	Possible at Core level
Service continuity (for ex- Wifi- handover)	Yes (Native support)	No
Leveraging existing infrastructure	Core of existing cellular mobile networks could be reused "as is"; but 5G	Existing high-power high-tower (HPHT) transmitters of Doordarshan would

	Broadcast baseband card and RF elements for UHF will be required at the RAN end	require upgradation alongwith installing a large number of low-power low-tower (LPLT) transmitters for indoor coverage

Table 4: Comparison between 5G Broadcast and ATSC 3.0 on transmitter aspects

Feature	**3GPP 5G Broadcast**	**ATSC 3.0**
Handset readiness	>612 MHz: Commercial grade 526-612 MHz: Reference designs <526 MHz: Not available	470-608 MHz: Reference designs
Support for the existing handset	Addressed through native service continuity e.g. Wifi offload	External Dongle is commercially available
Integrated modem	Available	Not available
Technology	ASIC	SDR
Technology node	3 nm	28 nm
RF Chain	Single	Multiple
In-device coexistence (IDC) issues	No	To be confirmed
Reference designs	Available	Available

Table 5: Comparison between 5G Broadcast and ATSC 3.0 on receiving device aspects

Note: Since this report only evaluates the technical benefits, the challenges of IPR are not compared.

5. Potential Challenges & Device Ecosystem Requirements

This section explores the potential challenges that should be addressed for the successful implementation of DTT2M in the country. It also explores the requirements of a robust device ecosystem necessary for DTT2M.

5.1 Potential Challenges in DTT2M rollout

i. Limited Interactivity:

Standalone terrestrial broadcasting functions as a one-way communication channel, lacking interactivity or two-way communication. This restricts the ability to offer personalized content or receive viewer feedback. To address this, technologies capable of utilizing reverse paths from existing technologies, like mobile broadband or home/office internet, can enable the necessary interactivity.

ii. Mobile Handset Availability:

Current DTT deployments primarily serve fixed television viewers or mobile handsets with external dongles, as mobile handsets compatible with these technologies are not yet commercially available. To achieve a real D2M experience, integrating DTT technology into mobile form factor devices like smartphones and tablets is essential, preventing a recurrence of the DVB-T2 failure. Challenges related to a robust device ecosystem are discussed in the following sub-section.

iii. Infrastructure Rollout:

DTT service transmission can leverage existing infrastructure to varying degrees depending on the selected technology, but additional infrastructure rollout will be necessary in all cases. For 5G Broadcast, the core of existing cellular mobile networks can be reused "as is" but specific elements like baseband cards and UHF RF elements will be required at the RAN end. For ATSC 3.0, upgrading existing high-power high-tower (HPHT) transmitters of Doordarshan and installing numerous low-power low-tower transmitters (LPLT) for indoor coverage will be necessary.

iv. Regulatory Standards:

Currently, TEC has developed Conformance Testing and Certification only for 3GPP-based standards. A similar framework will have to be developed for technologies other than 5G Broadcast.

v. Possible Interference:

Concerns exist regarding potential interference in existing mobile services from DTT broadcasts in the UHF band. Studies on coexistence between non-3GPP DTT services and existing cellular mobile services will help address these concerns.

vi. Spectrum Allocation:

Spectrum allocation in the UHF band for terrestrial broadcasting networks could be sensitive but crucial for the rollout of DTT2M services.

vii. Competitive Access Service:

While proponents claim DTT2M services will complement those of telecom service providers (TSPs), the latter argue that DTT2M services are access services and will directly compete with cellular mobile services. The term 'offloading mobile networks' implies that DTT2M will be utilized to provide services (video content streaming) currently offered on mobile networks. During consultations, the TSPs informed that video traffic constitutes approximately 60% to 70% of mobile network traffic and that their 5G networks have sufficient capacity to handle video traffic as the present utilization averages around 15% only.

viii. Level Playing Field:

Considering the commercial nature of DTT2M services and their perceived competition with cellular mobile services as access services, during consultations, the TSPs urged to maintain a level playing field between various services (i.e., IMT, DTT2M) in matters relating to the assignment of resources, such as spectrum, and the obligations relating to the provisioning of services, to avoid creating regulatory arbitrage.

5.2 Device Ecosystem

The success of DTT2M services will depend to a large extent on the ready availability of compatible low-cost, affordable smartphones operating on the Indian UHF band. The experience with DVB-T2 broadcast in the country shows that the users may not prefer external attachments such as dongles for receiving the broadcast signals. For having a robust device ecosystem for DTT2M, the following aspects require consideration:

(a) The antenna design of handsets needs optimisation due to the small form factor of mobile devices, which must accommodate antennas for a wide range of frequencies. Incorporating larger antennas for UHF frequencies requires further study.

(b) Mobile devices will require chipsets that support broadcasting for broadcast reception. While 5G Broadcast addresses this by reusing 5G silicon within the same chipset, ATSC 3.0 solutions use add-on chipsets.

(c) The chip ecosystem must be robust.

(d) None of the trials of any technology utilized the latest commercially available off-the-shelf-mobile devices. Instead, perhaps prototypes or dongles attached to devices were used.

(e) Aspects such as device power consumption and battery utilization require further consideration.

(f) The impact of DTT2M technologies on Specific Absorption Rate (SAR), Electromagnetic Fields (EMF), etc., of devices necessitates further study.

(g) No major handset or mobile device manufacturer currently supports any DTT2M technology or has commercially launched a product/model supporting DTT2M.

(h) Implementing D2M technologies entails changes in both hardware and software, potentially increasing handset costs. Given India's ambition to be a key player in the Global Value Chain for mobile device supply, it's vital to maintain competitiveness through standardized global market catering and economies of scale.

6. D2M Broadcasting via Converged Gateway Node

TEC Standard for Generic Requirements (GR) of "Converged Gateway Node for Delivering Broadcast Content to Portable Devices through Wireless LAN" (TEC 57040:2023) provides a ready solution to enable the dissemination of broadcast content to portable as well as fixed devices. This solution is based on the concept of a converged access node, which receives the linear television and other audio-video content through conventional modes such as satellite, cable, or terrestrial, then demodulates, decodes, and finally streams the content in appropriate formats over WLAN/Wi-Fi. The signals can also be transmitted over long distances using the GPON network and finally distributed through the local Wi-Fi access points. On-demand and localised content can also be provided optionally through a local content server. The content is consumed by end-users using browsers on smartphones, laptops, and smart TV sets by accessing a web portal through the WLAN/Wi-Fi without consuming mobile/internet data and without requiring any additional hardware, app, or plugins.

Fig. 15 shows the conceptual diagram of the Converged Gateway Node.

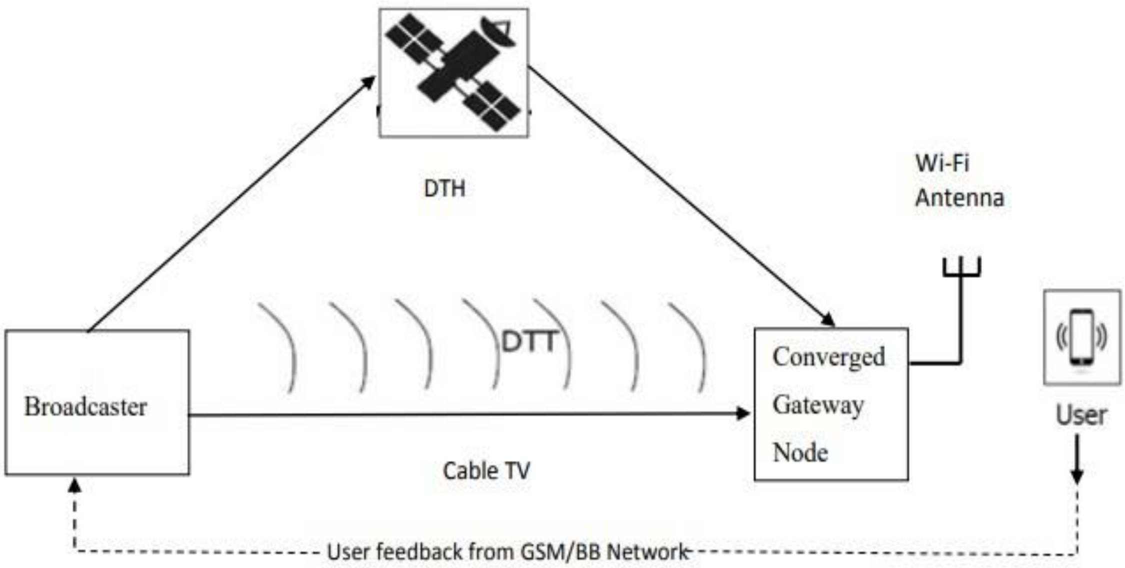

Fig. 15: Conceptual diagram
[Source: TEC GR (TEC 57040:2023)]

6.1 Architecture of the Converged Gateway Node

Fig. 16 presents the functional blocks, briefly explained as follows:

i. Integrated Receiver Decoder (IRD)

IRD receives the broadcast signals through various modes such as satellite (DTH), Cable TV, and terrestrial. These signals are amplified and converted into a suitable band for consumption by demodulation devices. A demodulation device tunes only to a particular frequency and can receive only a certain number of channels, so multiple such devices are required to cater to all satellite and terrestrial channels. It further converts the signals to baseband signals containing multiple TV or radio channels and streams them out.

ii. Video and Media Server

To make the streams generated by the IRD playable by any industry standard browser, the Video & Media Server transcodes the UDP streams into HTML-compatible streams. Also, it ingests the streams and breaks them down into files that can be hosted over HTML using a web server. This allows the end-users to consume the audio/video content on their existing mobile phones using web browsers without requiring any specialized software or plugins. Having to install third-party plugins or players is not only an inconvenience but also a risk factor for the users.

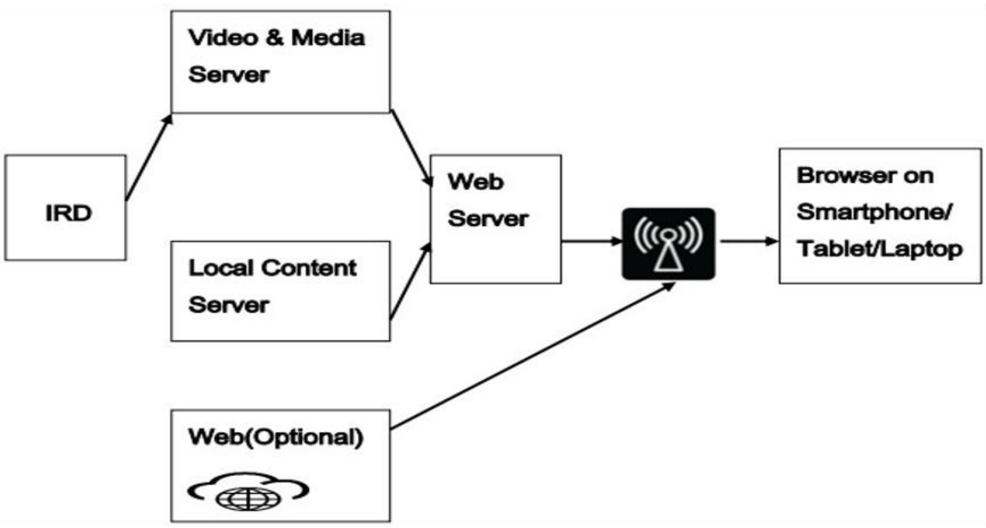

Fig.16: Functional block diagram
[Source: TEC GR (TEC 57040:2023)]

iii. Self-Learning Web Server

The web server serves a dual purpose: First, it functions as an HTML/Web server, delivering audio/video content to the end users' browsers. Second, it analyzes user viewership statistics to compile a list of the most watched/desired channels. Initially, a selected number of channels are streamed, and then, the self-learning algorithm refines the list over time, ultimately determining the most desired channels at a given location. This approach reduces costs by minimizing the number of demodulating devices in the IRD.

iv. Local Content Server

A local content server is optional and can be used to offer on-demand as well as localised content.

v. End-User Browser

End-user experience is at the heart of any solution or product. The users are not required to install any app or plugin on their smartphones, laptops, or tablets. They can simply connect to a Wi-Fi access point and visit the web portal using the appropriate link. There, they get a list of channels chosen by the self-learning algorithm and can play their desired content directly in the browser. It may be noted that the receiver uses Wi-Fi for last-mile connectivity, it does not consume internet data.

6.2 Advantages of the Converged Gateway Node

(a) This solution is technology agnostic and supports input RF streams based on DVB-S/S2 /DVB-C /DVB-T/T2 standards. It can also support other technologies as mentioned above like ATSC 3.0, 5G Broadcast, or any other emerging technology.

(b) The handset ecosystem is not a constraint as the signals can be received on any device supporting WiFi interface. This includes smart TV sets, existing mobile handsets, laptops, tablets, etc.

(c) The solution can be quickly deployed without any massive infrastructure rollout.

(d) It provides an indigenous and cost-effective solution for D2M.

(e) The Converged Gateway Node can be used in various scenarios such as rural areas through BharatNet, Wi-Fi access points through PM-WANI, high footfall places such as shopping malls, airports, and tourist places, and for entertainment in moving vehicles such as state road transport buses, city buses, and trains.

7. Conclusion

In an increasingly connected world, mobile devices such as smartphones and tablets have become indispensable to our daily lives. Users seek to access broadcasting services directly on their smartphones or similar mobile devices. While streaming over the internet is one option, advancements in technology have introduced other methods capable of delivering broadcast content directly to mobile handsets without the need for an internet connection. Although a significant number of consumers would continue watching television through traditional means such as DTH and cable TV on fixed television sets, the rapidly growing segment of mobile audiences using handheld devices will be served by these emerging technologies in addition to internet streaming.

Listening to live radio while on the move has been available for many years, with many listeners receiving signals through FM receivers in their cars. Mobile handsets equipped with FM radio functionality are also readily available in the market, allowing consumers to choose between live streaming and direct radio reception on their devices. In India, direct reception of live television channels on mobile handsets was possible to a limited extent through the digital terrestrial broadcasting of a few Doordarshan channels in 19 cities using DVB-T2 technology, which could be received on existing mobile handsets with the use of an external dongle and the installation of an app.

This report evaluates the technological features and readiness status of various candidate technologies that could deliver live television content to mobile devices. It covers the details of 5G Broadcast/Multicast Service (MBMS) based on 3GPP Rel.-18, ATSC 3.0, DVB-T2 system, ISDB-T, and DTMB-A. All these technologies are Digital Terrestrial Transmission technologies, which mainly cater to fixed television sets but can also be received by mobile devices, either through specially designed handset receivers or by attaching dongles or similar receiving devices to existing handsets. Accordingly, this report prefers to use the term "Digital Terrestrial Transmission to Mobile (DTT2M)" instead of Direct to Mobile (D2M) for these technologies. The report also covers the innovative approach based on the TEC Standard on Converged Gateway Node, which enables delivery of live as well as on-demand content to existing handsets without requiring any special hardware or installation of any app and can be considered truly D2M.

Appropriate DTT2M standards will provide new avenues for delivering live television, driving innovation in the design and manufacturing of smartphones and similar terminal devices that can directly receive such broadcast signals. Currently, there are no commercially available mobile handsets for any of these broadcasting technologies or standards worldwide.

The success of enabling these approaches for consumption by mobile devices, particularly smartphones or tablets, relies on developing an ecosystem for open-market, low-cost, affordable smartphones operating on the Indian UHF band. Despite mature underlying technologies for converged services (e.g., 5G Broadcast, ATSC 3.0, DVB-T/T2), the ecosystem for devices in this band is yet to be developed. The ability of DTT2M operators to develop this device ecosystem and broadcast to tens of millions of open-market mobile devices will ultimately define the success of DTT2M in India. Scalability is crucial from both device and network perspectives to cater to mass viewership using mobile devices.

From a network perspective, UHF transmission on any new standard might necessitate a new nationwide network for indoor coverage, adding fiscal rollout challenges. The integration of smartphones that support these technologies brings in additional complexity. Challenges also exist for technologies like DTMB-A and ISDB-T, which are limited and are not in line with other global standards. DVB-T2 faced issues due to a lack of end-consumer device ecosystem development, leading to its discontinuation in the Doordarshan network in India. Considering these factors, a standard compatible with existing mobile handsets would be desirable for DTT2M, as it will offer cost-effectiveness and leverage the existing ecosystem support.

From a policy standpoint, DTT2M services will directly compete with terrestrial mobile services, as a significant portion of the live television streaming data traffic currently managed by Telecom Service Providers (TSPs) may shift to DTT2M services. Hence, TSPs are eager to ensure a level playing field. Moreover, the earmarking of spectrum for DTT2M services and its fair allocation will be crucial for their expansion in India.

From the consumers' perspective, DTT2M services will offer an option to the consumers to choose between internet streaming and DTT2M for viewing live television on their mobile handsets. Driven by market forces, the mobile handset market may see multiple products supporting DTT2M reception alongside those without this feature, akin to the current scenario for direct FM radio reception on mobile handsets. Ultimately, consumers will have the final say, making decisions based on individual preferences and experiences. The success of DTT2M services will also hinge on consumer choice in this regard.

In brief, the report evaluates technologies like 5G Broadcast, ATSC 3.0, and DVB-T2 for delivering live TV to mobile devices. DTT2M standards could revolutionize smartphone design. No commercial handsets support these standards yet. Success depends on developing an ecosystem for affordable smartphones. Ensuring compatibility with existing handsets is essential for cost-effectiveness and market acceptance. Challenges include network integration and competition with terrestrial mobile services. Ultimately, consumer choice will be pivotal in adoption.

Future work: While the current study focuses on the technological aspects of these technologies, further studies are required to analyse actual deployment scenarios, coexistence with other wireless services, spectrum requirements, commercial viability, and business opportunities of DTT2M technologies. Future research may consider addressing challenges such as content quality, security, in-device coexistence, and mobile battery consumption in these technologies.

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9. Abbreviations

3GPP:	Third Generation Partnership Project
4G:	Fourth Generation (mobile network)
5G- MAG:	5G Media Action Group
5G:	Fifth Generation (mobile network)
5GMS:	5G Media Streaming
ABR:	Adaptive Bit Rate
AAC:	Advanced Audio Coding
AF:	Application Framework
AIR:	All India Radio
AL:	Application Layer
APIs:	Application Programming Interfaces
ARIB:	Association of Radio Industries and Businesses (Japan)
ARQ:	Automatic Repeat Request
ATIS:	Alliance for Telecommunications Industry Solutions (USA)
ATSC:	Advanced Television Systems Committee
AVC:	Advanced Video Coding
BICM:	Bit-Interleaved Coded Modulation
BIP:	Broadcast Internet Protocol
BM-SC:	Broadcast/ Multicast Service Center
CAM:	Conditional Access Module
CAS:	Carrier Acquisition Subframe
CCSA:	China Communications Standards Association
CGN:	Converged Gateway Node
CMAS:	Commercial Mobile Alert System
CMMB:	China Mobile Multimedia Broad Casting
CNR:	Carrier-to-Noise Ratio
COFDM:	Coded Orthogonal Frequency Division Multiplexing
D2M:	Direct to Mobile
DASH:	Dynamic Adaptive Streaming over HTTP (MPEG-DASH)
DD:	Doordarshan
DOT:	Department of Telecommunication
DST2M:	Digital Satellite TV to Mobile Devices
DTH:	Direct-to-Home
DTMB-A:	Digital Terrestrial Multimedia Broadcast – Audio
DTT:	Digital Terrestrial Television
DTT2M:	Digital Terrestrial Television (or Transmission) to Mobile
DTTB:	Digital Terrestrial Television Broadcasting
DTTV:	Digital Terrestrial Television
DVB:	Digital Video Broadcasting
DVB-T2:	Digital Video Broadcasting Terrestrial 2
EAS:	Emergency Alert System
eMBMS:	Evolved Multimedia Broadcast Multicast Service
enTV:	Enhanced Television
EPG:	Electronic Program Guide

ESG: Electronic Service Guide
ETSI: European Telecommunications Standards Institute
FeMBMS: Further evolved Multimedia Broadcast Multicast Service
FLUTE: File Delivery Over Unidirectional Transport
GR: Generic Requirement
HARQ: Hybrid Automatic Repeat Request
HbbTV: Hybrid Broadcast Broadband Television
HD: High Definition
HDR: High Dynamic Range
HDTV: High Definition Television
HEVC: High Efficiency Video Coding
HPHT: High-Power High-Tower
HTTP: Hyper Text Transfer Protocol
IA: Interactive Application
IBB: Interactive Broadcast Broadband
IDC: In-Device Coexistence
IDTV: Integrated Digital TV
IF: Intermediate Frequency
IoT: Internet of Things
IP: Internet Protocol
IPTV: Internet Protocol Television
IRD: Integrated Receiver Decoder
ISDB-T: Integrated Services Digital Broadcasting – Terrestrial
ISDB-Tmm:Terrestrial Mobile Multimedia Broadcasting
JTF: Joint Task Force
LDM: Layered Division Multiplexing
LDPC: Low- Density Parity- Check
LL: Link Layer
LPLT: Low Power Low Tower
LTE: Long-Term Evolution (4G mobile network)
MAS: Multilingual Audio and Subtitles
MBMS: Multimedia Broadcast/Multicast Service
MBS: Multicast & Broadcasting
MBSFN: MBMS Single Frequency Network
MCH: Multicast Channel
MHz: Megahertz
MIB: Ministry of Information and Broadcasting
MIMO: Multiple-Input Multiple-Output
MISO: Multiple-Input, Single-Output
MNO: Mobile Network Operator
MNOs: Mobile Network Operators
MPEG-2: Moving Picture Experts Group-2
HE-AAC: High-Efficiency Advanced Audio Coding
MPMT: Medium-Power Medium-Tower
NG-RAN: Next Generation RAN
NHK: Japan Broadcasting Corporation

NR MBS: New Radio Multicast and Broadcast System
NR: New Radio (5G standard)
OFDM: Orthogonal Frequency Division Multiplexing
OTA: Over-The-Air
OTG: On-The-Go
OTT: Over-The-Top
PCD: Personalized Content Delivery
PDU: Packet Data Unit
PHY: Physical Layer
PL: Protocol Layer
PLP: Physical Layer Pipe
PSI: Programme- Specific Information
PTP: Point-to-Point
QAM: Quadrature Amplitude Modulation
QoS: Quality of Service
RAN: Radio Access Network
RF: Radio Frequency
RFT: RF tuner
RTB: Real-time Broadcast
SC-PTM: Single Cell Point to Multipoint
SDO: Standalone Downlink Only
SDTV: Standard Definition Television
SFN: Single Frequency Network
SISO: Single-Input Single-Output
SVC: Scalable Video Coding
TDMA: Time Division Multiple Access
TEC: Telecom Engineering Centre
TMMB: Terrestrial Multimedia Mobile Broadcasting
TPC: Transmit power and coverage
TRAI: Telecom Regulatory Authority of India
TS: Transport Stream
TSDSI: Telecommunications Standards Development Society (India)
TTC: Telecommunication Technology Committee (Japan)
TV: Television
UE: User Equipment
UHD: Ultra High Definition
UHDTV: Ultra-High Definition Television
UHF: Ultra High Frequency
UMTS: Universal Mobile Telecommunication Service
USA: United States of America
VVC: Versatile Video Coding

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