5G BROADCAST AND EVOLUTION TOWARDS NEW RADIO: PERSPECTIVES FOR MEDIA DELIVERY TO MOBILE DEVICES

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ABSTRACT

The new features introduced in the broadcast/multicast profile of 3GPP Rel-14 and, more recently, Rel-16 represent a very promising opportunity to address the technical and business challenges of the entire media sector (not restricted to the broadcast ecosystem only) since they allow, in principle, a close synergy between network operators and content providers in using the network resources more efficiently while reaching wider audiences. In this respect, the new framework outlines new horizons in different vertical sectors and opens possibilities for new markets in the future of content delivery. However, although the standardization process for ‘5G Terrestrial Broadcast’ has been concluded, in the current state-of-the-art some features, crucial for the full commercial deployment and proliferation of this technology, are still missing. With reference to the Italian scenario, the present paper aims to critically investigate all these aspects, proposing some deployment models that could be attractive for all the involved players in the media chain. Finally, a way forward for further requirements that could be fulfilled in future 3GPP standards is proposed and discussed.

INTRODUCTION

In recent years, significant work has been carried out in the standardization process of the ‘5G broadcast profile’ of 3GPP Rel-14 [1] and Rel-16 [2], by the broadcasters’ community and the mobile industry. However, these efforts will be successful only if all the relevant players will be able to unlock the full potential of the FeMBMS technology (Further enhanced Multimedia Broadcast Multicast Service), for a cost effective and high quality content delivery.

After identifying key areas which may benefit from a “5G Broadcast” approach, the paper tries to give an answer to the question: “are broadcasters ready to exploit the opportunities offered by this new technology?” The study starts from the analysis of possible collaborative scenarios that are foreseen between BNOs (Broadcast Network Operators) and MNOs (Mobile Network Operators) with particular attention to the solution leveraging DVB-I as a service layer, currently under consideration in DVB (Digital Video Broadcasting). Finally, the impact of this solution from a commercial point of view and what is still missing in terms of regulation and standardisation is investigated, with a particular eye on the features that need to be addressed in future 3GPP standards.

KEY AREAS OF INTEREST FOR 5G BROADCAST TO MOBILE DEVICES

It is well acknowledged that mobile data traffic, consumed by people using smartphones, laptops and new devices proliferating on the market, is exponentially increasing. As reported in [3], in fact, the traffic per month is expected to reach 226 Exabytes in 2026. As of today, smartphones generate most of the mobile data traffic (about 95%).

Network offloading for popular live content

Video traffic currently represents about 66% of all the mobile data traffic, a share that is forecast to increase to 77% in 2026 [3]. As a consequence, in order to meet the increasing customer demands related to new products and services (on demand/live/personalized), combined with the growth in the subscriber base, network resources are continuously put under pressure with the risk of tremendous overloads that would inevitably lead to critical network failures.

In the aforementioned circumstances, a 5G broadcast/multicast network solution could prove its effectiveness, since part of the traffic (i.e., heavy streaming of live popular contents, sport events, concerts, shows, …) would be offloaded, hence minimizing the congestion in the network.

Unlimited video data consumption in mobility

A crucial aspect of 5G broadcast is the capability to deliver digital terrestrial television to mobile and in-mobility users (in-car, on smartphone, tablets...) by means of broadcast networks (i.e. a network operated by a BNO) used in downlink only mode, enabling consumers to receive unlimited data with a defined Quality of Service (QoS) in a "Receive Only Mode" (ROM). In practice, this means enabling a Free-To-Air (FTA) reception, without a SIM Card and without contractual obligation with a service provider or network operator, therefore offering to broadcasters a significant opportunity to increase their customer reach.

In fact, as of today, streaming of live/linear TV programs to mobile phones is provided by broadband networks (i.e. an eMBB service from MNO), but the consumption of these streams may be limited in time due to fixed data caps in users' billing plans. The availability of video content that does not affect this data capacity is expected to be very appealing for the users, especially for the streaming of long lasting live programs, such as sports events or concerts.

Coverage in rural areas

The possibility to employ broadcast infrastructures proves to be particularly useful to reach remote areas, where the densification of the mobile infrastructure could potentially not provide a significant return on investments for mobile network operators. In this regard, 5G broadcast could be useful in bridging the digital divide.

Frequency spectrum efficiency

The combined broadcasting/multicasting approach via overlay networks would improve the frequency spectrum efficiency, avoiding sending the same information hundreds of thousands of times to the end users (i.e., as it actually happens with unicast IP streaming). As a direct consequence, the deployment and operational costs will be substantially reduced.

DEPLOYMENT SCENARIOS FOR COEXISTENCE OF EXISTING AND FUTURE TERRESTRIAL BROADCAST SERVICES WITH 5G

The most important enhancements introduced to cope with broadcast requirements have been first seen in FeMBMS profile of Rel-14 providing, in addition to FTA e ROM services, the possibility to dedicate 100% of the available radio resources to broadcast transmission (standalone mode), thus overcoming the limit of 60% specified in previous eMBMS releases, and the definition of a longer cyclic prefix (CP) of 200 μs, to cover Inter Site Distances (ISD) up to about 60 km in a Single Frequency Network (SFN) scenario. Further improvements, specified in Rel-16, include a 100 μs Cyclic Prefix (CP) for high mobility (i.e., 250 km/h); a 300 μs CP targeting fixed rooftop reception and a more robust Cell Acquisition Subframe (CAS) for reliable signal acquisition and synchronisation.

These new functionalities allow 5G Broadcast to run on terrestrial broadcast networks, complementing the MNO's personalised services and network infrastructures. Combining the strengths of the two network architectures and using each technology to its highest potential would allow 5G broadcast to achieve coverage over very large areas in a cost-efficient way. This synergy would also help 5G technology to meet the media companies' requirements for the distribution of linear contents (e.g., live, scheduled programmes, TV, radio, etc.) to mobile and portable devices (i.e., smartphones, tablets, and vehicles) and, possibly, enrich those services with non-linear contents (on-demand, advertising, podcasts, immersive experiences, etc.).

Multiple deployment options are viable, depending on several factors related, for example, to commercial/business agreement between the involved parties, or to the spectrum availability. In this respect, we envisage two principal ones, that may in the real cases be adapted to cover the various service requirements: Network-level cooperation and Service-level cooperation.

Network-level cooperation

The first deployment option requires a cooperation between terrestrial broadcast and cellular network infrastructures. This approach has been deeply investigated in our previous paper [4] by means of simulative analysis on theoretical, regular networks and confirmed in a real case in the area around Turin (Italy).

Figure 1 - Network-level cooperation

It was shown that the broadcast network could provide TV services to mobile users in suburban/rural areas and in the vicinity of the transmitters. For urban areas located farther away from the broadcast transmitters, instead, a mobile network is needed to complement the coverage. This cooperation model could offer a significant reduction in implementation costs compared to a pure country-wide cellular network, given that such solution would require a much smaller number of transmitters to cover the same area. Figure 1 illustrates this scenario: BNOs and MNOs provide the same services in the same frequency channel, for outdoor and in-mobility devices. Conversely, when at home, devices may rely on alternative delivery option, such as fixed broadband connectivity and WiFi (e.g., OTT). With reference to the impacts on the involved players, this solution allows:

- BNOs to use the existing infrastructure (with limited investment on additional sites) while increasing their reach of FTA contents to mobile devices;
- MNOs to achieve savings in network resources by off-loading broadcast video traffic, thus increasing the availability of more valuable resources;
- the end-user to receive TV services without consuming data from their plans and without the need of a contract from a specific operator (no authentication required).

For this solution to be applicable, though, new detailed contractual agreement models between BNOs, Service Providers (SPs) and MNOs need to be defined.

Service-level cooperation

Another deployment scenario would see the BNO and the MNO each running their own separate network, while cooperating at a service level to offer a hybrid broadcast/multicast/unicast service distribution. This solution could guarantee service continuity in potentially challenging scenarios, such as the indoor reception and/or the urban areas where the 5G Broadcast signal could not be available.

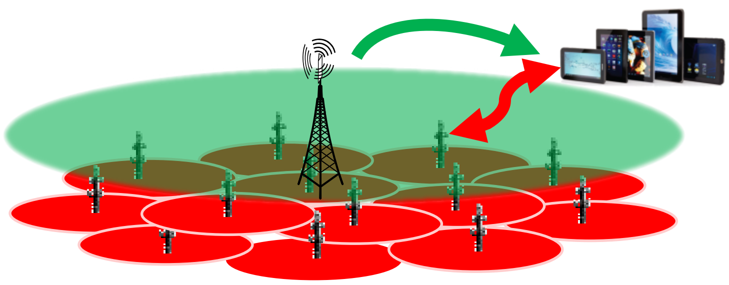

Figure 2 - Service - level cooperation

Figure 2 illustrates this scenario, where different frequencies are allocated to the BNO and the MNO to provide the users complementary services: when the broadcast services provided by BNO are not available to the users, these can be (automatically) requested in unicast to the MNO.

For the best user-experience of the broadcast service, the switch from the broadcast network to the mobile one should be automatic and seamless for the user (e.g., the authorisation to use the data when out of the BN reach could be done once). This type of cooperation opens up the way to other possible applications that might benefit from the presence of the synchronisation between the broadcast and mobile network delivery. For example, it could be used to retrieve personalized content on demand along with broadcast linear channels (e.g., previous episodes, multi-camera view, targeted advertising, etc.). In this sense, 5G Broadcast and 5GMS (5G Media Streaming [5-7]) unicast delivery, integrated in a unified service layer, would allow mobile devices to flexibly consume the services in an optimal and cost-efficient way, overcoming the limitations imposed by a single (mobile or broadcast) distribution means.

Again, with reference to the impacts on the involved players, this solution allows:

- the Service providers to decrease CDN costs in the region where service is provided by BNO;
- the end-user to receive broadcast services in a limited area without data charges on his contract; the SIM-card and an active tariff are needed for coverage extension. This could be also part of a cooperation agreement between the service provider and the MNOs.

The missing layer: DVB-I and 5G

To have a completely seamless switching and, hence, an optimal user experience, a common service layer is needed, able to signal both broadcast and unicast services and to facilitate the synchronization and the stream-switching within the client.

Opportunely, the DVB consortium already worked to standardize and improve such a signalling and discovery layer: the DVB-I specification [8]. Released in November 2020, this specification supports discovery and delivery of TV services over IP networks with a user experience comparable to the one we are accustomed to on traditional broadcast networks. With the aim to address also hybrid receivers (e.g., connected TV sets), the specification also covers signalling of broadcast service instances, which can then be merged with IP service instances in a unique service list. This allows broadcasters to expand their traditional broadcast offering with additional services (e.g., event-based) delivered only over the Internet, exposing an integrated TV offering in a coherent and organised service list.

In the context of the present paper, as described in Figure 3, an integrated service layer leveraging DVB-I, with inclusion of services delivered via 5G media technologies as an integral part of the overall broadcasters' service offering, can be adopted to enable seamless and operator-independent consumption of linear TV services on mobile devices. With this approach, a DVB-I compatible app on a mobile device would discover the supported delivery options among those signalled in the DVB-I service list and, then, select as a first choice the 5G Broadcast signal (where available) to consume the TV service. In case of signal degradation (e.g., indoor or outside the coverage area), the device would be able to switch seamlessly to the unicast stream (via 5GMS if supported, otherwise via OTT over 5G) using the information provided in the service list.

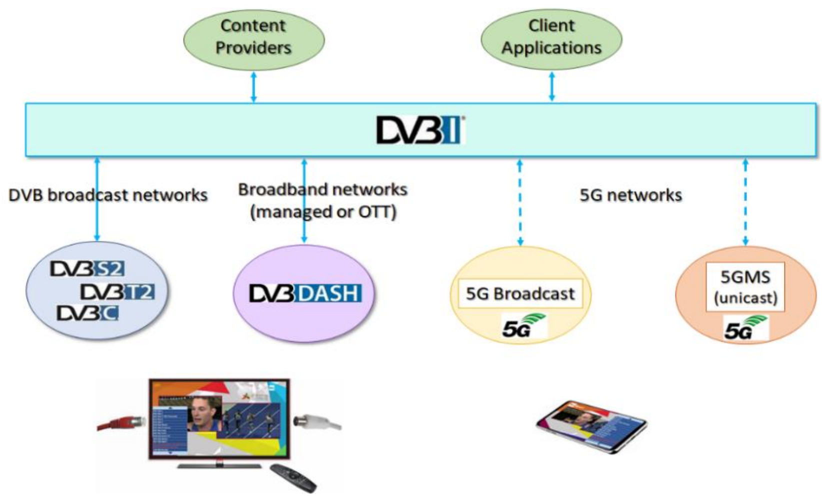

Figure 3 - DVB-I as an integrated service layer

To guarantee the correct operation of the whole system, a collaboration model between Service Providers, BNOs and MNOs needs to be identified to generate the streams and service lists properly. Despite this, the model itself offers much more flexibility over the network cooperation one, as it is based on two independently operated infrastructures and the switching between the two delivery networks is governed entirely by the client application.

While the DVB-I specification currently covers the existing DVB ecosystem (i.e., the two leftmost circles in Figure 3), DVB is currently working on a possible extension of the specification to include also 5G Broadcast and 5GMS delivery among the supported delivery options, possibly reusing 'content provider and client'-side interfaces and APIs as defined by 3GPP.

COST ASSESSMENT OF PROPOSED SCENARIOS FOR MEDIA DELIVERY: AN ITALIAN CASE STUDY

In order to evaluate the costs associated with the proposed network scenarios, with respect to a country-wide mobile solution, the preliminary step for this work was to derive the required number of sites to provide ‘full coverage’ over a whole country: in the specific case, the Italian territory. In the following, as a practical reference for this comparison, the parameters of an existing RAI DTT (Digital Terrestrial Television) network are used[1].

Assuming the use of the same number of transmitting sites that are currently deployed for the provisioning of RAI’s DTT Public service Multiplex, the starting point for the cost assessment is to group the existing broadcast transmitters in three main categories: Low Power Low Tower (LPLT), Medium Power Medium Tower (MPMT) and High Power, High Tower (HPHT), according their Effective Radiated Power (ERP), following the same classification as reported in [9].

Table [1] shows that the considered DTT network is basically composed for 94.3% of LPLT, for 4.2% of MPMT and for the final 1.41% of HPHT.

Network categorization	**LPLT**	**MPMT**	**HPHT**	
ERP range [watts]	< 1 kW	1 - 10 kW	10 - 100 kW	> 100 kW
Service area [km^2]	31	630	3120	4490
Transmitter type (average) (*)	100 W	5 kW	25 kW	105 kW
No. of transmitters	1890	85	28	2

(*) http://www.catastofrequenze.agcom.it/catasto/pubblico

Table 1: DTT Network for RAI-MUX1

The Italian territory, which spans over an area of approximately 301.338 km^2, is composed by 1/3 of mountains (~100.000 km^2), while the remaining part is made up of a mixture of flat land and hills, classified as rural/suburban (~170.000 km^2) and urban areas (~32.000 km^2).

With reference to the network categorization described above and taking into account the typical placement of the sites (i.e., HPHT transmitters located at higher altitude, while MPMTs located on flat-lands/hills), the service area (provided in Table 1) for each category of transmitter (assuming a hexagonal coverage area) has been derived following the approach reported in [4]. In that work, an intensive simulative analysis on a theoretical network was carried out to evaluate the minimum transmitter ERP (as a function of the inter-site distance – ISD) required to achieve a SINR threshold of 10 dB[2] for different network configurations, environments (suburban, urban), transmitter’s heights and Cyclic Prefixes (CPs).

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[1] It is worth pointing out that the proposed study is not intended to give a detailed economic analysis; rather, a rough assessment of the order of magnitude of expenditures based on available information concerning today’s situation. They can, however, give an idea of the expected costs for the analysed solutions in the future.

[2] Resulting in a spectral efficiency of about 2.5 bit/s/Hz, allowing for the delivery of 10-15 Full-HD programmes coded in HEVC within an 8-10 MHz frequency slot.

Calculations show that the DTT network of transmitters reported in Table [1] can provide most of the coverage, with HPHTs and MPMTs covering almost all the suburban/rural areas of the Italian territory. Regarding LPLT transmitters, since most of them are used to provide the services in mountain areas, for the sake of simplicity, it could be assumed that about 2/3 of these transmitters are used for this purpose, while the remaining ones are used to complete part the coverage (about 20.000 km^2) in suburban/rural areas not reached by HPHT and MPMT networks. In this scenario, the MNOs' sites are required to cover only the remaining portion of the urban area (approx. 24.000 km^2).

In summary, the DTT network of transmitters reported in Table [1], is able to cover almost all the suburban/rural areas (~150.000 km^2) of the Italian territory by using HPHT and MPMT towers, while the remaining part will be covered by LPLTs of the broadcast operator. Only a portion of urban areas (approx. 24.000 km^2) will be covered by the mobile network.

Table [2] provides some details on the number of towers necessary in the hybrid approach (existing DTT transmitters and additional MNO's sites): the required number of further mobile towers ranges between 1730 to 3000, depending on the considered ERP. A pure MNO solution would instead require about 5500 mobile sites for covering suburban/rural areas plus some thousands of mobile sites to complete the urban area coverage.

Table 2 - Network dimensioning tailored to the Italian territory

Type of territory	**Mountain area**	**Suburban /rural**	**Urban**
Area	~100000 km^2	~170000 km^2	~32000 km^2
DTT existing sites (HPHT, MPMT, LPLT)	covered with 2/3 of LPLT	HPHT+MPMT+ 1/3 LPLT	25% of the area covered by DTT transmitters. Requested about 1730 to 3000 mobile sites (*)
MNO's sites	-	About 5500 mobile sites (if ISD = 6 km is considered)	2300 to 4100 mobile sites (*)

(*) depending on the ERP, an ISD of 3 km or 4 km is considered.

The next step is to assess the costs in terms of Capex and Opex expenses. The principal elements that contribute to the Opex costs are: energy consumption, heat dissipation, site rental and maintenance. Similarly, the Capex are referred to the equipment cost and the tower cost plus tower installation cost. Other costs related to frequency planning, backhaul infrastructure, spectrum and additional costs are out of scope of this paper.

With the assumptions made so far, the input figures required to assess the final Opex and Capex costs include the number of sites composing the network and, for each site, the power of the transmitter and the type of site.

Starting from the analysis provided in [9] but taking into account only the costs related to Opex (as it is assumed to consider the existing and full operational BNOs and MNOs networks) in Table 3 the costs associated to the two network solutions are reported. These figures show that the Opex costs of the cooperative approach are in the order of 35% of those of a pure mobile network.

Type of network	Cooperative (DTT + mobile)	Mobile only
Suburban/rural	About 12.5 M€/year (DTT)	About 46.5M€/year (mobile)
Urban	6 -10 M€/year	8-15 M€/year
Total	**~18.5-22.5 M€/year**	**~54.5-61.5M€/year**

Table 3 - Network costs

MISSING STEPS FOR 5G BROADCAST FULL DEPLOYMENT

In order to facilitate and foster the use of 5G broadcast technology in the media sector for enabling the potential markets, offering a win-win approach for all stakeholders along the media value chain, regulatory and spectrum issues need to be properly addressed.

Spectrum allocation

One aspect that needs particular attention is related to spectrum allocation for 5G Broadcast. The 700 MHz frequency band allocates 20 MHz for Supplemental Down Link, which could, in principle, be used for Down Link Only. In addition, being 5G Broadcast a broadcasting technology, also the DTT sub-700 MHz band could be considered.

In a network-level cooperative scenario, both BNOs (in a standalone-dedicated broadcast mode) and MNOs could use the same frequency allocation to deploy linear TV and radio services, in a SFN configuration. In a *service-based cooperative scenario*, instead, BNOs could cover most of the territory and the largest part of the service would be operated in a dedicated broadcast channel, while the service provided by MNO (to complete the broadcast coverage or/and to retrieve personalized content) could be deployed using the unicast-only FDD bands or in a mixed 0-80% broadcast carrier and unicast [3].

DTT channel raster

Recently, a normative work item was approved at 3GPP [10] for developing, in Rel. 17, a 5G Broadcast option to be operated in 6, 7 and 8 MHz channel rasters. This represents a significant achievement given that, as of today, current 5G broadcast based on LTE only supports the same system bandwidths as LTE unicast (i.e., 1.4, 3, 5, 10, 15 and 20 MHz), not compatible with Geneva-06 rules.

This new option will allow the co-existence, in the sub-700 MHz band, of current DTT transmissions in some channels and 5G Broadcast in others, without disturbing each other, facilitating the introduction of the technology in different countries, in respect of the regulations.

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[3] MNOs may deploy a 5G Broadcast service running in non-dedicated carriers as an FTA service on MNO bands (FDD) in a mixed carrier with up to 80% of capacity, according to the specifications defined in Rel-16.

5G Broadcast terminals

In terms of hardware resources, what is still missing, at this moment of writing, is the availability of chipsets in user devices implementing 5G broadcast functionalities. 5G broadcast chipsets are not available and/or 5G Broadcast functionality not enabled by MNOs and handset manufactures, despite the fact that needed tools in addition to the standard 5G functionalities are minimal.

Moreover, even if considerable study efforts have been made to promote 5G broadcast technology, both from a physical layer standpoint as well as a system architecture perspective, what is still lacking, in order to allow, in the near future, its full deployment and proliferation, is an in-depth analysis of the possibility to design and integrate compact broadband antennas for digital television reception on mobile terminals. The requirement of operating on the whole range of the lower part of Ultra-High Frequency (UHF) band is quite challenging[4], since the limited sizes of typical mobile devices and, consequently, limited volume available for the antennas, conflict with the requirement to cover the DTT band with a fair performance.

To overcome the above issues, Rai CRITS, in collaboration with LINKS Foundation and the Polytechnic of Turin, are investigating (see [11] for preliminary details) the possibility to excite the characteristic modes of the ground layers and metal shielding of the entire device (a.k.a., the ‘chassis’) by means of properly-shaped coupling structures. This allows to exploit the whole planar dimension of the device. This study is carried out by means of simulative electromagnetic analysis and also laboratory tests on experimental prototypes (fig. 4). The implemented models will enable the study of the behaviour of the return loss curves for the different configurations (i.e., small and big smartphones, tablets) and to evaluate the matching components needed to ensure a sufficiently good efficiency across the whole DTT band. The antenna configuration and the typical mobile device handling (e.g., horizontal, while watching TV) have implications regarding link margin statistics. The antenna patterns have been measured in the lab by means of a benchtop very near field scanner.

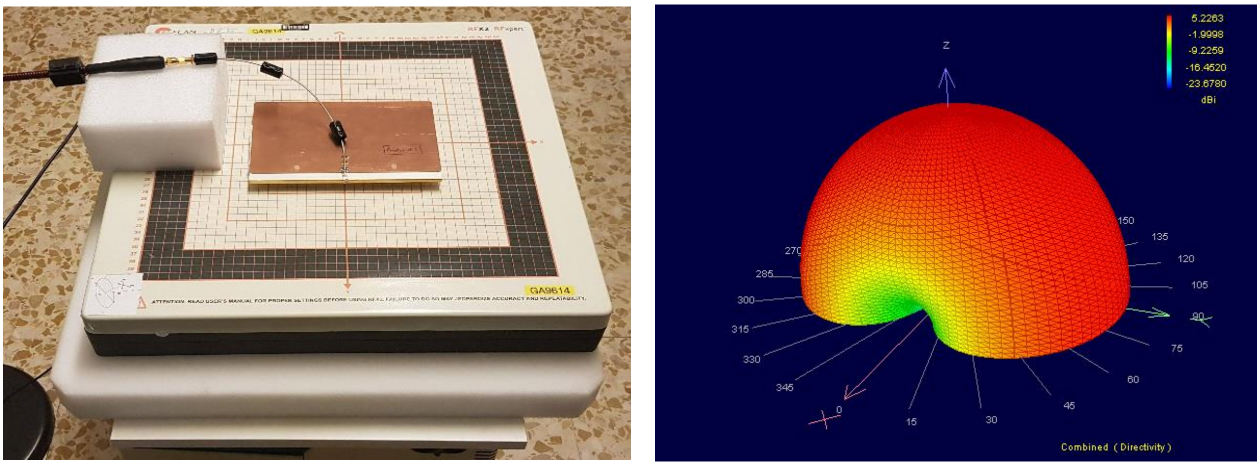

Figure 4 – Laboratory characterization of an experimental antenna prototype (left) – Antenna radiation pattern (right)

[4] Of course, if the requirement of operation in the full UHF lower band is relaxed, the typical Planar Inverted-F Antenna (PIFA) commonly used in mobile communications could be adopted.

FUTURE PERSPECTIVES FOR 'NEW RADIO' MBMS

We are at a point where the standardization process for LTE-based 5G Broadcast technology has been concluded, while future efforts for supporting further enhancements to the specifications are expected to be included in future 5G 'New Radio' MBMS (Multimedia Broadcast Multicast Service) standards. However, the design of a New Radio broadcast profile should aim at fulfilling new requirements that could result evident following a significant use and market penetration of the LTE-based 5G Broadcast technology. At present, indeed, the potential introduction of a New Radio broadcast standard would be based on unclear needs and would potentially destabilize progress with LTE-based 5G Terrestrial Broadcast deployment.

From the standardization point of view, Rel. 16 has been completed and broadly covers all broadcast requirements. Further to the introduction in Rel. 17 of a 5G Broadcast option to be operated in 6, 7 and 8 MHz channel rasters, efforts for improving system performance in terms of efficiency and reliability could be already part of the standardization work for Release 18. These enhancements should be devoted to increase coverage and spectral efficiency, also through the reduction of the overhead, to introduce time interleaving and proper reference signal (RS) design, to support new 5G core network in standalone broadcast deployment.

On the other side, 5G-New Radio (NR) air interface standardized in 3GPP Releases 15/16, although offering a more flexible and scalable design than LTE, in order to satisfy a wider range of use case requirements, frequency bands and deployment options, only supports user-specific unicast transmissions. i.e. transmission modes and core functionality not complying with broadcaster's requirements. A multicast mode is currently under development in 3GPP Rel-17 MBS (Multicast-Broadcast Service), but it is limited to supporting general multicast and broadcast communication services (e.g. transparent IPv4/IPv6 multicast delivery, IPTV, IoT applications, V2X applications, public safety…) relevant for distribution over 5G mobile networks. Media services delivered over stand-alone broadcast downlink only network (BNO), employing large SFN areas in a Free-to-Air reception, and receive-only devices are indeed out of scope. If it will become evident the benefits offered by NR features for the broadcast delivery of media services, for the 5G NR specification to be extended by a High - Power broadcast mode, additions to the current 3GPP standard should include, among others, an extended and scalable NR numerology, not necessarily following the $2^{\mu} \cdot 15$ kHz, $\mu \in \mathbb{N}$ raster, to improve mobility support in a HPHT scenario.

CONCLUSIONS

5G Broadcast represents an important opportunity for media companies to provide their content offer also to viewers who are mobile. Its flexibility of configuration allows multiple scenarios for exploitation, that could match the requirements of the whole value chain: from content provider to user, passing through the Broadcast and Mobile Network operator.

With the adoption of a coordinated introductory model among the main stakeholders, 5G Broadcast can offer the possibility to efficiently deliver live TV services to large audiences of mobile users. Typically, a mobile TV offer could consist of sport events, shows, movie premieres, news, contents whose value is significantly dependent on the live fruition. In addition to this, 5G Broadcast could offer potential benefits for delivering a heterogeneous set of push services to large number of devices, e.g. populating the terminal with recommended VoD programs, software updates and massive download of data (maps, …) for vehicles.

Finally, 5G Broadcast enables a wide variety of services that could be offered to final users, independently from the contract with the mobile operator, which in any case can provide a completion of the coverage of linear mobile TV services and enrich them with added-value personalised content.

The paper presents various scenarios and implementation strategies, highlighting the importance of chipsets and terminals support as principal enablers of 5G Terrestrial Broadcast ecosystem.

REFERENCES

[1] 3GPP TR 38.913 v14.3.0, "Study on scenarios and requirements for next generation access technologies", August 2017.

[2] 3GPP TR 36.976 v16.0.0, "Overall description of LTE-based 5G terrestrial broadcast", March 2020.

[3] Ericsson Mobility Report "Mobile data traffic outlook" (2020): https://www.ericsson.com/4adc87/assets/local/mobility-report/documents/2020/november-2020-ericsson-mobility-report.pdf

[4] A. De Vita, R. Gaffoglio, V. Mignone, A. Morello: Long term perspectives of TV convergence towards 5G: mobile and fixed applications" IBC 2017- Amsterdam.

[5] 3GPP TS 26.117, "5G Media Streaming (5GMS); Speech and audio profiles", March 2020.

[6] 3GPP TS 26.511, "5G Media Streaming (5GMS); Profiles, codecs and formats", June 2019.

[7] 3GPP TS 26.512, "5G Media Streaming (5GMS); Protocols", June 2019.

[8]ETSI TS 103 770, "Digital Video Broadcasting (DVB); Service Discovery and Programme Metadata for DVB-I", November 2020.

[9] M. Lombardo, "Cost analysis of orchestrated 5G networks for broadcasting", EBU Tech. Review, March 2019.

[10] RP-210835, "New WID on new bands and bandwidth allocation for LTE based 5G terrestrial broadcast", EBU, 3GPP TSG RAN #91-e, March 2021.

[11] R. Gaffoglio, A. De Vita, B. Sacco, G. Giordanengo, M. Zucchi and G. Vecchi, "Compact antennas for digital TV reception on mobile terminals" COMSOL Conference, October 2020