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EFFICIENT DELIVERY OF AUDIOVISUAL CONTENT TO MOBILE DEVICES COMBINING 5G BROADCAST AND CDN TECHNOLOGIES

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ABSTRACT

The '5G Broadcast profile' defined under the umbrella of 3GPP specifications, also known as FeMBMS, offers a new set of opportunities enabling innovative services and creating an impulse for advances of the entire media sector. Indeed, content providers and broadcast operators are actively involved in several worldwide research projects investigating to what extent 5G can represent the new paradigm in the media landscape for large-scale TV content delivery towards personal consumer devices. In this respect, the present paper aims at providing a comprehensive overview of an extensive trial showing the potentialities of the cutting-edge combination of 5G Broadcast and CDN technologies for linear broadcast and broadband distribution. The considered use cases refer to specific "Live Events": TV contents, including live streams captured by means of a 5G remote production and VR360 content for full immersive experiences, are distributed via 5G Broadcast to handheld devices and vehicular infotainment systems, implementing seamless switching between broadcast and broadband delivery to offer an uninterrupted viewer experience.

INTRODUCTION

In the last decades, the rapid developments in the communication technologies landscape have led to the entry of new players in the crowded and competitive arena of digital media platforms. Indeed, the massive diffusion of devices such as smartphones, tablets, laptops, Virtual Reality (VR) devices, Augmented Reality (AR) glasses and other type of advanced end points capable of interacting with the TV set in an increasingly "smart" way, has driven the whole content industry's ecosystem towards a more integrated, multimedia communication, able to accommodate the pervasive deployment of new value-added products and services, providing an improved and more immersive user experience. In the perspective to offer a plethora of the above services while reaching the largest number of end-users, media companies have started to focus on the cutting-edge technological opportunities offered by the 5G technology. Indeed, the new functionalities introduced in the broadcast/multicast profile of 3GPP Rel-14/16 [1],[2] also known as '5G Broadcast' could really represent a game changer in the future of content delivery as they could offer a competitive edge for all the stakeholders involved in the media value chain: content/service providers, mobile network operators (MNO), manufacturers and broadcast network operators (BNO). 5G Broadcast enables content and service providers to offer free-to-air media services to mobile consumer devices at guaranteed Quality of Service (QoS) regardless of the number of simultaneous viewers and without affecting the regular cellular

5G mobile network, hence mitigating Content Delivery Network (CDN) costs for popular live content. From MNOs perspective, 5G Broadcast allows to achieve savings in network resources by dynamically using broadcast mode, more efficient than unicast, to deliver linear/live video traffic to large audiences. From manufacturer's viewpoint, since limited hardware and firmware upgrades are required to enable 5G Broadcast functionalities in mobile terminals, this would mean new commercial challenges and market opportunities. 5G Broadcast mode is one of the most important enhancements defined in 3GPP Rel-14/16 standard: it is suitable to be used within conventional broadcast infrastructures and opens up to a commercial perspective for BNOs of new income from content providers for the distribution of services addressing terminals in mobility. The end-users could also benefit from reduced connection costs since they could receive TV services delivered by 5G Broadcast without consuming traffic from their monthly data plans and without the need of a contract with a specific operator. Also new consumer applications mainly targeting the automotive sector could take advantage of 5G Broadcast. As automobile manufacturers need safe and reliable communication systems to connect cars with devices, 5G Broadcast can help with over-the-air (OTA) real-time traffic and V2X delivery. Furthermore, it provides efficient delivery of public warnings messages such as urgent weather emergencies and community information [3]. Finally, in terms of energy consumption, broadcast technology is acknowledged as the most sustainable and environment-friendly alternative for the delivery of linear TV content, allowing the lowest CO_2 emission. In Europe, for example, Digital Terrestrial Television (DTT) is an order of magnitude less impacting than Over-The-Top (OTT) and managed IPTV services [4].

The large number of tests and trials [5-7] that are being carried out around the world demonstrate that there are all the conditions for this technology to meet future content distribution needs.

The present paper provides a comprehensive overview of an extensive 5G Broadcast deployment in Italy, covering Turin and Palermo cities with High Power High Tower (HPHT) transmitters in the Supplemental Downlink (SDL) 700 MHz frequency band, integrated with CDN distribution, deploying hybrid 5G Broadcast/Broadband services in the framework of the National project '5G Audiovisivo 2022' promoted and funded by the Ministry of Enterprises and Made in Italy[1] and co-ordinated by Rai Way.

AUDIOVISUAL CONTENT DISTRIBUTION TO MOBILE DEVICES: THE BROADCAST NETWORK

The distribution network architecture

The 5G Broadcast content distribution platform deployed within the project takes full advantage of the potential offered by the existing broadcaster's (Rai Way) terrestrial transmission network infrastructure, integrating the new functionalities developed in 3GPP Rel-14/16 [1,2] to enable the delivery of multimedia content to personal handheld devices in broadcast mode.

The Rai Way transport network simultaneously performs the functions of contribution, i.e., the exchange of programs between Rai regional offices and Production Centres in Rome, Milan, Turin and Naples, and distribution, i.e., the transport of national and regional radio and TV programs, including DTT, DAB and FM, to all broadcasting centres (over 2,000 sites). The main part of the network infrastructure for long-distance connections consists of

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[1] https://www.mimit.gov.it/en/

optical fibres, where the transport service is implemented in IP/MPLS-TE (Multiprotocol Label Switching - Traffic Engineering) technology.

As part of the '5G Audiovisivo 2022' project, the Rai Way's transport network has been used both to send the contribution video streams to the Rai Way Data Centre in Rome and to deliver the distribution stream to the 5G Broadcast transmitting sites (in Turin and Palermo). The core of the 5G Broadcast Network deployed for the scope of this project is the BSCC (5G Broadcast Service & Control Centre), provided by Rohde&Schwarz. The BSCC enables the delivery of multimedia content over 5G networks in broadcast mode, implementing the BM-SC (Broadcast/Multicast Service Centre) and MBMS GW (Multimedia Broadcast Multicast Service GateWay) instances. In addition to live and linear content, the BSCC allows for simultaneous delivery of different types of content, e.g., file-based, OTA updates and public alerts. These services are enabled by protocols defined in the 3GPP standards, such as FiLe delivery over Unidirectional Transport (FLUTE), dynamic adaptive streaming over HTTP (DASH), and HTTP live streaming (HLS). Collection, processing and distribution of the various live video streams has been provided by MainStreaming. A MainStreaming StreamLive dedicated machine, installed in Rai Way datacenter in Rome, was in charge of receiving the source streams, transcoding and/or packaging them and finally distributing them to both the BSCC server (for 5G Broadcast transmission) and the MainStreaming Global CDN caches (for broadband transmission), configured to serve customers from Points of Presence (PoP) placed in Italy and directly connected to the main Italian Internet Service Providers (ISP). For the coverage area of Turin, the streams coming from the BSCC located in Rome are then forwarded on the Rai Way IP/MPLS network to the Turin Regional Office and hence to Eremo Transmission Centre by means a direct fibre connection. In the same way, for the coverage area of Palermo, the streams from the BSCC are sent to Palermo Regional Office with a fibre connection and then, via radio link, to Palermo M. Pellegrino Transmission Centre. A schematic illustration of the network set-up is reported in Figure 1. This configuration is part of a Receive-Only-Mode (ROM) approach with HPHT topology. A Rohde&Schwarz TMU9EVO transmitter is installed at each site. In each transmitter, the FeMBMS physical layer is implemented according to 3GPP Rel-16 (and backwards compatible with Rel-14) by the R&S SDE900 and the R&S TCE901 exciter, which generates the COFDM waveform based on the I/Q data. The transmitters are then connected via RF cable to the antennas installed on the towers.

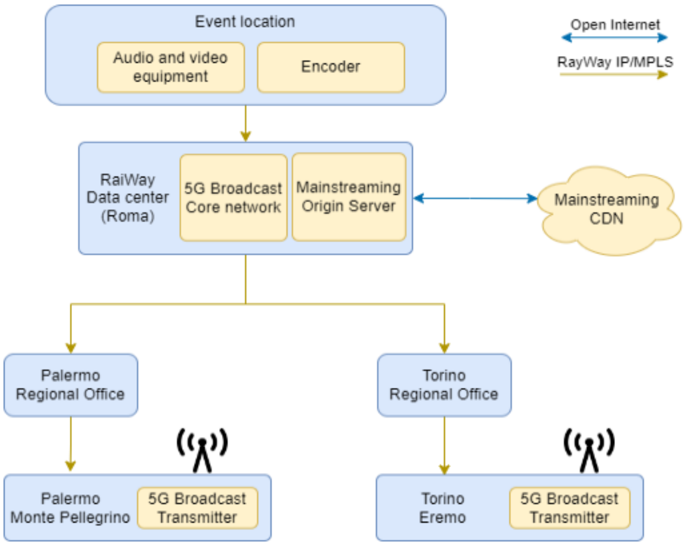


Figure 1 – Architecture of the network for 5G Broadcast and broadband stream distribution

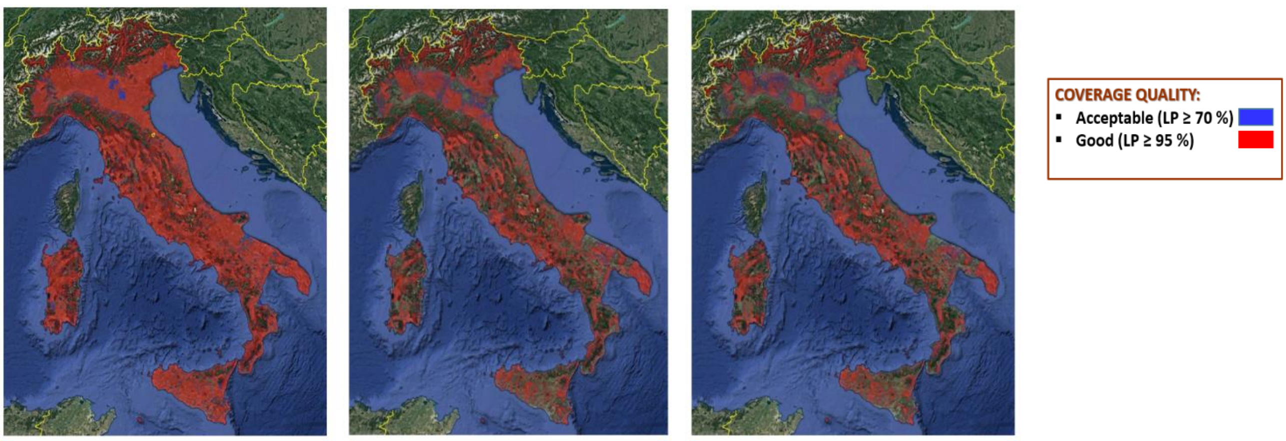
5G Broadcast Coverage predictions

Although the service coverage analysis carried out in this project is limited to the metropolitan areas of Palermo and Turin, an extensive preliminary simulative study was conducted in order to test the coverage achievable with the operative Rai Way's transmitting network on the whole Italian territory. With reference to outdoor mobile reception, pedestrian and vehicular reception scenarios have been investigated, while rooftop scenario has been considered for fixed reception, adopting, for both cases, the parameters shown in Table 1. The simulative analysis has been performed using the software module HTZ Communications (ATDI). This tool provides assessing the radioelectric coverage using a detailed Digital Terrain Model (DTM) and Recommendation ITU-R P.1812-6 [8] propagation model. Specifically, such a tool allows radioelectric evaluations to be made, taking into account the terrain profile and the alternation of rural/suburban and urban/dense urban environments.

	RX MOBILE OUTDOOR (pedestrian and vehicular scenarios)	RX FIXED (rooftop scenario)
MODULATION AND CODING SCHEME (MCS)	MCS 12	MCS 24
DTM RESOLUTION	50 m (with clutter)	200 m
RX ANTENNA HEIGHT	1.5 m	10 m
TIME VARIABILITY	50% for both useful and interfering areas	50% for useful area 10 % for interfering areas
CYCLIC PREFIX	200 µs	
C/N	13 dB (pedestrian, speed < 5 km/h) 18 dB (vehicular, speed < 80 km/h)	17 dB
RX ANTENNA GAIN	-5.8 dBi pedestrian(handheld) 3 dBi vehicular (car mounted)	13 dBi
RX ANTENNA DISCRIMINATION	Not present	ITU-R BT.419 Max XPD= 16 dB
LOCATION PROBABILITY	95%	
FREQUENCY	SDL @746 MHz	
ANTENNA PATTERN	omnidirectional	derived from the current RAI MUX

Table 1 – System parameters used for simulations

Considering the existing DTT network made up of about one thousand sites, the achievable coverage areas are shown in Figure 2 together with the three percentages of Location Probability (LP) of the served population on the whole Italian territory. It should be noted that these preliminary results, although quite promising, could be further improved by means a "fine tuning" of the sites and a proper optimization of their relative SFN "static delays" as well as an additional investment of sites in the most critical (urban/dense urban) areas.



FIXED ROOFTOP MCS 24	PEDESTRIAN HANDHELD MCS 12	VEHICULAR CAR MOUNTED MCS 12
LP@95% ~ 90%	**LP@ 95% ~ 65%**	**LP@ 95% ~ 60%**
LP@90% ~ 93%	LP@ 90% ~ 70%	LP@90% ~ 65%
LP@70% ~ 97%	LP@ 70% ~ 80%	LP@70% ~ 75%

Figure 2 – *Network coverage* (on top) and *Population coverage statistics* (on bottom) for Fixed rooftop (left), Handheld pedestrian (centre), Car mounted vehicular (right) scenarios

COMBINING 5G BROADCAST AND CDN TECHNOLOGIES FOR AN EFFICIENT DELIVERY OF LINEAR AUDIOVISUAL CONTENT TO MOBILE DEVICES

While network efficiency provided by 5G Broadcast in the context of content distribution to mobile devices is unrivalled with respect to unicast delivery, coverage guaranteed by HPHT sites alone may be insufficient in deep urban areas (far from the main transmitter [9]) or in fringe zones. In such areas, content availability can be anyway guaranteed through of the usage of 5G data connectivity (OTT, unicast): seamless switching between broadcast and broadband delivery can allow uninterrupted service consumption for a satisfactory Quality of Experience.

System architecture

Figure 3 shows the block diagram of the system architecture for content delivery to mobile devices deployed in the project, enabling seamless switching between 5G Broadcast and OTT unicast A/V streams.

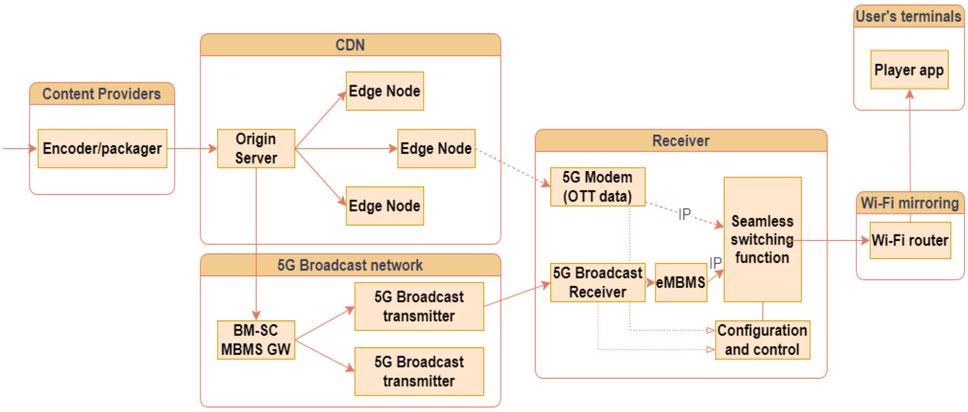


Figure 3 – System architecture

In particular, the core functions necessary to be deployed along the delivery chain to achieve the goal are:

- Use of ABR (Adaptive Bit-Rate) technologies, such as HLS or MPEG DASH, allowing delivery of the same encoded assets to both 5G Broadcast and OTT broadband paths and leveraging CDN distribution;
- A dedicated receiver-side application, capable of automatically switching to the broadband path when 5G Broadcast signal impairments are detected (and switching back to the 5G Broadcast signal as soon as it becomes available again), taking care of properly aligning the two streams in time.

The encoder/packager publishes in HLS the audio/video streams fed by content providers, making them available to the MainStreaming Origin Server and CDN. The same HLS segments also feed the BM-SC and MBMS GW implemented on Rohde&Schwarz BSCC, which encapsulates them as a FLUTE stream ready to be delivered via the nationwide Rai Way distribution network to the 5G Broadcast transmitters in Torino Eremo and Palermo Monte Pellegrino as outlined in previous section.

The receiver is based on a PC platform running an application developed by Politecnico di Milano, which extends the 5G-MAG Reference Tools [10]. A detailed receiver architecture is described below. According to the various use cases, audio/video content is consumed on the vehicular infotainment system or on personal devices (i.e., smartphones, tablets, VR viewers, etc.), connected via Wi-Fi to the receiver, by means of an Android app developed by Kinecar. Additional functions or variants to the general system architecture relevant to the specific use cases are described later in this paper.

Receiver-side integration and Seamless Switching

Seamless switching between 5G Broadcast and broadband networks is a topic already addressed by 5G-MAG Reference Tools [11], where video segments not received via 5G Broadcast are fetched from the CDN in time for the player's request or ORS/Nakolos solution [12], where content switching is triggered via a backend application in the cloud.

In this project, the integration between broadband and broadcast services has been achieved by means of an additional application level, named Seamless Switching Application (SSA) running on the receiver and developed by Politecnico di Milano: with respect to the above mentioned solutions, in this approach switching between 5G Broadcast and broadband networks is triggered by Signal-To-Noise Ratio (SNR) variations of the received 5G Broadcast signal, thus allowing to anticipate reception issues in mobility and providing a smooth and uninterrupted video streaming to the HLS client. The high-level architecture of the application consists of a HTTP server that responds to video streaming requests through three channels: the broadband (BB), the broadcast (BC), and the switching channel (BS). In this study, the BC source is provided by the Demodulator (version 1.2.2) and MBMS client (version 0.9.2) of the 5G-MAG Reference Tools [10]. The BS channel is managed by the application and enables manual or automatic switching between BB and BC according to specific commands or receiver conditions. This type of implementation allows simultaneous monitoring of the three streams (i.e., BC, BB and BS) on three different players, which is useful during field tests or demonstrations, showing what happens during broadband or broadcast reception discontinuities.

As sketched in Figure 4, the SSA server consists of four main processes that work in parallel once the application is launched:

1. The process “read_ssa_input_command” provides interpretation of commands from the terminal, e.g., status of the switching channel, enabling of automatic switching and parameters, setting the source of the BS channel, i.e., BB or BC.
2. The process “update_mutual_segment_offset” estimates periodically the presence of the two BB/BC channels (e.g., each 30 s), requests and interprets their manifest files and calculates the offset and thus the relative delay between the two streams. The information is essential for activating (i) seamless switching, allowing for the compensation of the relative delay, and (ii) automatic switching in case the stream tuned to the BS channel becomes no longer active.
3. The process “update_BC_modem_state” recovers periodically the SNR measured at the demodulator of the BC channel, when present, through the available Application Programming Interfaces (API). This measure is essential for guiding the automatic switching BC-to-BB when the SNR falls below a predefined threshold for preserving the continuous streaming or BB-to-BC

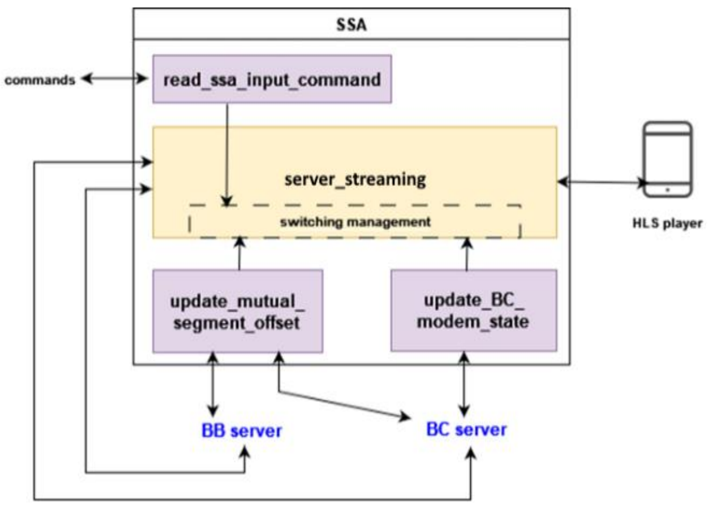


Figure 4 - Architecture of the Seamless Switching Application

when the SNR exceeds the threshold in order to reduce the traffic from the broadband network.

4. The process “server_streaming” handles the video streaming requests at the three channels: while the BB and BC ones are simple redirections to the original servers, the BS streaming is entirely regenerated by the application to appear as a new, independent source for the HLS client. Firstly, the streaming is aligned to the source with the highest delay for assuring the seamless switching and the other one is buffered if necessary.

LABORATORY TESTS AND FIELD TRIALS

In the framework of the project, extensive laboratory tests and field trials of 5G Broadcast functionalities to mobile devices have been carried out, to collect data about the achievable coverage and the required network configurations to guarantee a satisfactory QoS.

Laboratory tests

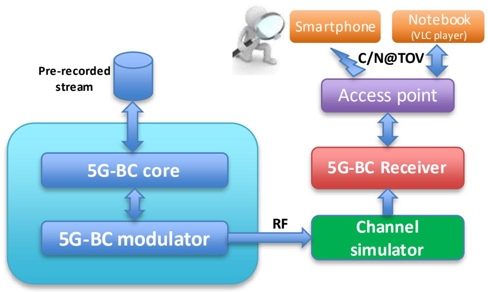


Figure 5 – Laboratory set up

Very extensive lab sessions allowed to gain a first-hand experience of the enormous potential of the system and to understand how mature the technology is for its rapid exploitation. The receiver tested during the laboratory session is the SDR (Software Defined Radio) receiver by Rohde&Schwarz. The measurement procedure adopted in all the tests carried out was to add up the selected degradation (AWGN, echoes, Doppler shift, etc.) and to observe the video until reaching the Threshold Of Visibility (TOV), which corresponds to less than one video/audio error in 30 s. The block diagram of the adopted test bench is reported in Figure 5. A huge amount of data has been collected during the lab tests: in this paper, for the sake of brevity, only the tests simulating the mobile channel aimed at verifying the maximum speed achievable by the system without compromising the reception are reported. Echo profiles, typical of a mobile outdoor reception, have been generated using a channel simulator. These profiles are defined in COST 207 [13]: in our tests, a 6 echoes profile, representing a Typical Urban scenario (TU6), has been used. The graph in Fig. 6 reports the estimated C/N@TOV versus speed (km/h) for the B2 channel (f = 745.5 MHz), which is the test frequency used during the project, in MCS12 (16QAM, code rate 0.42). The maximum achieved speed was around 80 km/h with SCS = 1.25 kHz and about 200 km/h with SCS = 2.5 kHz, acceptable for most mobile use cases.

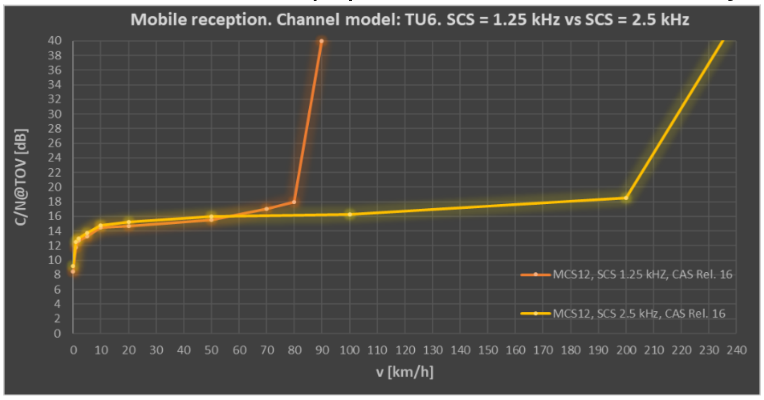


Figure 6 – Mobile reception performance, TU6

Field trials

For road measurements (see Fig. 7), an omnidirectional receiving antenna was mounted on the top of a van equipped with 5G Broadcast receiver (Rohde&Schwarz SDR receiver), RF recorder (Lumantek Weiver 2.0), GPS antennas for georeferencing of the measurements, monitors positioned in the headrests for observation of the received video and notebook with software designed by Rai CRITS for error detection and data logging of the electromagnetic field, vehicle speed and geographical position.

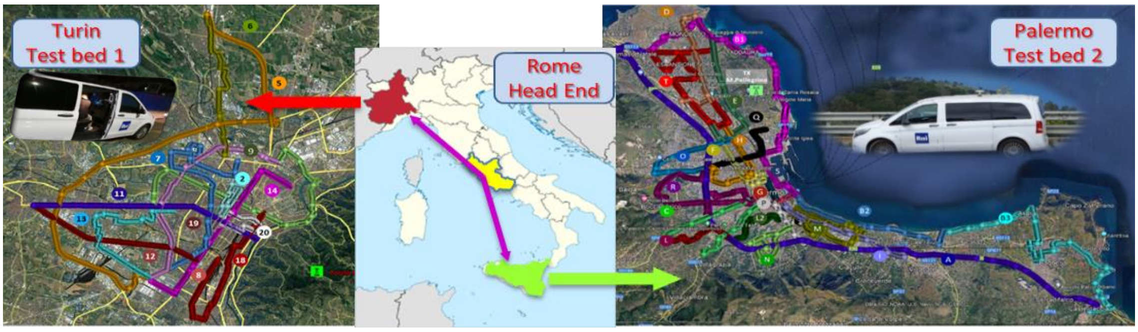


Figure 7 – Test-beds geographical context

Transmitting site	Torino – Eremo	Palermo – Pellegrino
Position	45°02'30'' N – 7°44'08'' E	39°09'46'' N – 13°21'30'' E
Height	626 (asl) - 400 (agl)	580 (asl) - 545 (agl)
Frequency (CF)	745.5 MHz (ch. B2, SDL band)	
P_{out} (conducted power)	500 W	
Antenna gain	15 dBd	11 dBd
Polarisation	Horizontal	
Modulation scheme	MCS12 (16QAM, rate 0.42)	
Subcarrier Spacing (SCS)	1.25 kHz (cyclic prefix = 220 μs)	
Bandwidth	5 MHz	
CAS	Release 16	
Bit-rate	4.83 Mbit/s	

Table 2 – Transmission parameters

The tests in the metropolitan areas of Turin and Palermo allowed us to evaluate the performance of the system in a densely populated area, characterized by the presence of tall buildings and other obstacles, which often prevent a receiver from having the direct view (line of sight) of the transmitting site. The tests have been carried out also on the motorways surrounding the towns, allowing to evaluate the performance of 5G Broadcast at rather high speeds. The modulation parameters used during these measurement campaigns are based on the results of the preliminary laboratory tests and are a trade-off between the required robustness in a mobile reception context and the available capacity. Table 2 shows the transmission parameters adopted in the two test-beds. The measurements have been divided into "routes" including both the urban and suburban parts of the test-beds (see Figure 7), trying to include the most significant and popular places (city centre, airport, stadiums, railway stations, theatres, ring road etc.). During the measurement campaign a software developed by Rai CRITS was used for the automatic acquisition of data in order to improve the quality of data collection, making them independent of operator errors. The system monitors the bit rate of the stream at the receiver output, a device identifies when the bit rate drops below a certain threshold and/or when the stream has errors in the cyclic redundancy code (CRC) and informs the acquisition software that geo-references the detected data. In order to correctly set the reception thresholds which allow to evaluate the coverage, laboratory tests and field measurements were carried out. Three possible states of the receiver have therefore been identified:

1. *Quasi Error Free (QEF) Reception*. The detected bit rate is greater than 95% of the expected value and at most two CRC errors are detected in 1 second (green colour on the coverage maps).
2. *Threshold reception*. The detected bit rate is greater than 95% of the expected value and three CRC errors are detected in 1 second (yellow colour on the coverage maps).

3. *No Reception*. The detected bit rate is less than 95% of the expected value or four or more CRC errors are detected in 1 second (red colour on the coverage maps). For the sake of brevity, only the main results of the measurement campaign in the Palermo test-bed are reported, considering that the Turin area has provided comparable results with respect to Palermo. The estimated overall coverage in terms of Quality of Experience (QoE) is 90.5%: this means that every 100 s, about 91 s were correctly received while 9 s showed some video and/or audio errors. If we consider only the urban area of Palermo, including the narrow streets of the city centre, the coverage is practically 100%. Starting from the power measurements at the input of the receiver, the Electro-Magnetic Field (EMF) at approximately 2 m (height of the van) has been calculated. Looking at the maps in Figure 8 (right side), note that the traffic lights colours system has been chosen in order to fix a kind of operating threshold in mobile reception. The idea was to find an EMF value granting over-threshold values in a percentage comparable to the measured available coverage. Data processing established that using a threshold of 60 dB(μV/m) provides the 90.1% of over-threshold values, very similar to the 90.5% of the QEF coverage. In Figure 8 it is evident the very close geographical correlation between the points where it was not possible to receive the signal (left side) and those where the EMF is less than 60 dB(μV/m) (right side). Figure 8 also shows the results of the coverage simulations obtained considering the transmitting parameters as in Table 1. In the maps, therefore, the areas in which the probability of reception is respectively 95% and 70% are shown in red and blue. The uncoloured areas are those in which no service is provided. As can be seen, a good agreement was found between the simulations and the measurements.

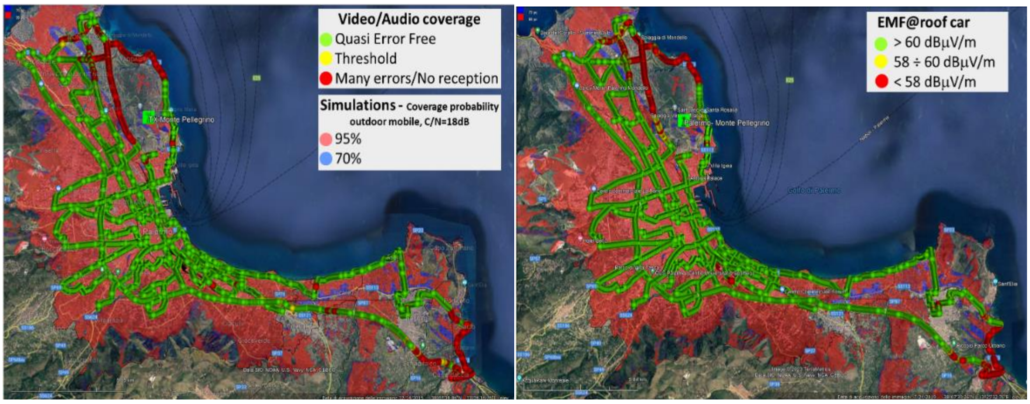


Figure 8 - Palermo test-bed: coverage and EMF

VALIDATION OF THE PROJECT USE CASES

The use cases enabled in the course of the '5G Audiovisivo' Project and demonstrated in a number of "live events" were tailored in order to assess specific aspects of the system performance.

Live distribution of 5G remote TV production

In this use case, live A/V contents, captured by wireless cameras and microphones connected by means of a 5G private network [14], are distributed via 5G Broadcast (complemented by Broadband in seamless switching modality) to end users, including those attending the live event. The specific main challenge in this use case is end-to-end latency. Latency reduction involves several aspects of the delivery chain, i.e.:

- Fine tuning of encoding and packaging profile parameters, such as GOP (Group of Pictures) and segment length. Further improvement would be made possible by means of chunked transfer encoding (i.e., Low Latency DASH).

- Efficient media ingest workflow to reduce the transfer latency to the Origin server.
- Fine tuning of the CDN configuration. In particular, in order to address latency requirements for viewers attending the live event, a dedicated local edge node of the CDN has been installed on site, connected to the same 5G private network used for the remote TV production (Fig. 9).

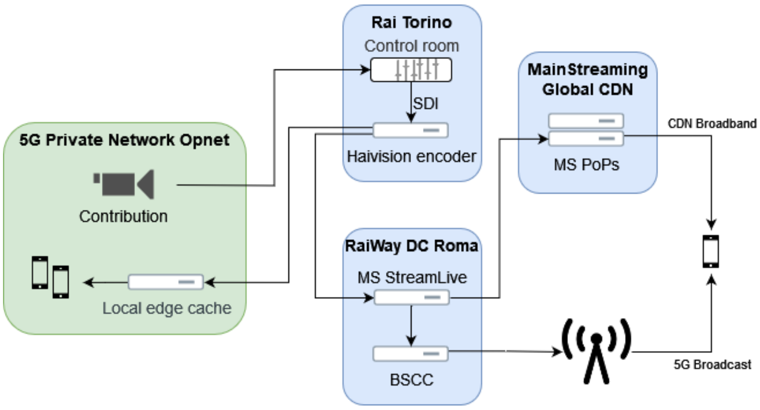


Figure 9 – Integration of a local edge cache

- Efficient BM-SC feeding. This latter aspect requires pushing the A/V streams from the CDN to the BM-SC rather than pulling them, with inherent buffering. In turn, this requires that a CDN node has direct network visibility, i.e., without firewalls, with the BM-SC (e.g., co-located).

During the same event, in a parallel demonstration, the same audio/video signal feed has been encoded as MPEG DASH and radiated in the event venue by a local Rohde&Schwarz 5G Broadcast transmitter to enable the reception on dedicated smartphone prototypes by Qualcomm.

Consumption on vehicular infotainment system

Conceived as a point of connection between media and automotive ecosystems, Kinecar (Fig. 10), designed by Kinecar srl, is a full-electric urban microcar equipped with multiple communication interfaces (Bluetooth, Wi-Fi, 4G/5G, V2X), digital entertainment and infotainment services (smartphone interface, Alexa connected car skills, digital radio, social media, vehicle information, navigation) and cloud-based platform for mobility services (telemetry, car key-sharing, real-time fleet monitoring). With a powerful infotainment system, Kinecar can be seen as a "device on wheels": on board the vehicle all apps and contents, including live and VOD streaming content, messaging and social apps, notification of potential collisions, driver attention monitoring and fatigue detection, in-car voice

Figure 10 – Kinecar: the connected and high-tech urban microcar

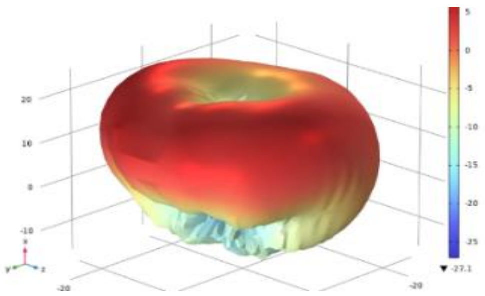


Figure 11 – Receiving antenna radiation pattern

recognition and control, are made available to the driver and passengers through a multimodal and adaptive Human Machine Interface (HMI) on touch screen displays.

Within the project, a dedicated Android app has been developed by Kinecar, allowing to connect to the receiver and consume the HLS A/V services either on the vehicular infotainment system or on passengers' personal devices connected to it, achieving service continuity thanks to seamless switching between 5G Broadcast and mobile broadband, when needed.

The specific main challenge in this use case is robust reception in mobility: addressing it has required a careful evaluation of the car-mounted receiving antenna performance (Fig. 11) as well as improvement of 5G Broadcast receiver's channel estimation and fine-tuning of the seamless switching function.

Consumption of VR360 services

This use case envisages the live distribution of an immersive VR360 content filmed during a ballet rehearsal. The event has been produced in Teatro Massimo in Palermo using multiple stereoscopic VR360 cameras, with insertion of pre-recorded VR360 contributions, which placed the narrator/actor in different points of the location, guaranteeing emotion, effectiveness and user's involvement. The captured VR360 video streams were first processed by Impersive stitching and coding system and then sent via Rai Way contribution network from the theatre to Mainstreaming Origin server located at the Rai Way Data Centre in Rome, and hence delivered to the 5G Broadcast network as described above. During the event, in areas specifically set up inside the theatre and in a high school, users wearing a headset VR viewer, connected via WiFi-6 to the 5G Broadcast receiver, could find themselves living an immersive VR experience and actively participating in the action. The main challenge in this use case is the delivery of high bit-rate streams: in order to provide a full immersive experience, the encoding bit-rate has to be adequately high. Preliminary laboratory tests have assessed that, given an input VR360 video with 3840x3840 resolution and HEVC encoding, an acceptable value for the bit-rate is about 10 Mbit/s.

CONCLUSIONS AND FUTURE PERSPECTIVES

The Project has demonstrated that a BNO's HPHT network can guarantee proper urban 5G Broadcast coverage for mobile reception, if complemented by seamless switching to broadband OTT service in some critical areas. However, crucial for wide adoption of 5G Broadcast is the availability of commercial user devices implementing specific tools, which are minimal, in addition to the standard 5G functionalities. Next step will be integration of 5G Broadcast services within broadcasters' service offering. This requires a common service layer, which can be enabled by the DVB-I specification [15],[16], as currently under consideration by a Joint Task Force formed by 5G-MAG and the DVB Project on DVB-I over 5G. Additionally, the system architecture here defined, while targeting different use cases, has a high degree of similarity with other activities taking place in various sectors of the broadcast domain, e.g., DVB-NIP (Native IP) [17], also considering redistribution of broadcast services to IP devices by means of a home or vehicular gateway and improving synergy with broadband delivery networks.

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