MOBILE AND BROADCAST NETWORKS COOPERATION FOR HIGH QUALITY MOBILE VIDEO: A WIN-WIN APPROACH

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ABSTRACT

The article investigates the coverage achievable by three different network configurations for delivering high quality multicast video services to mobiles: conventional broadcast High Power High Tower (HPHT), mobile cellular Low Power Low Tower (LPLT), and mixed structures. Different spectrum efficiencies, transmitter distance and power, and receiver characteristics are considered, representing a range of possible network scenarios.

The study actually models generic radio interfaces with particular characteristics. Nevertheless, the choice of the parameters reflects configurations in use in 4G or currently under discussion for 5G, preferred over similar/better performing DVB T2Lite or NGH (Next Generation Handheld) broadcast technologies, to facilitate the user terminal implementation (smartphones and tablets).

The results clearly indicate that the best solution in terms of Capex/ Opex for running the network is represented by the cooperative approach where most of the rural/suburban coverage is provided by the HPHT network and the LPLT cellular networks are used to complete the coverage, especially in densely populated urban areas. This allows avoiding the installation and operation of thousands of LPLT transmitters, with a very significant reduction of the corresponding network costs.

INTRODUCTION

The mobile communications sector is characterized by an exponentially increasing traffic demand for high quality mobile multimedia services, a significant portion of which identifiable with linear Television (TV) and scheduled broadcast (point-to-multipoint) distribution.

Current 3G and 4G mobile networks can deliver video services, but were primarily designed for two-way and one-to-one services, in the form of on-demand videoclips (e.g., YouTube), generally with limited quality of service (QoS), on a best effort basis. Using the current unicast approach, video streaming represents a serious challenge for mobile operators, that will face the risk of overloading their very expensive frequency resources.

While 3G and 4G standards have been extended by a broadcast specification (MBMS, Multimedia Broadcast Multicast Service), that allows for the delivery of content to an arbitrary number of mobile viewers in a typical cell, the use case is not fully compliant with the requirements of TV Media Companies, that need to deliver “live high quality video content” (High Definition, HD) at guaranteed QoS (without buffering time) to millions of viewers at affordable price. A big challenge is the requirement to deliver linear video content to a large number of viewers simultaneously (in the same cell or across many cells). This is being considered in the framework of the 5G initiatives, where a heated debate is running about the choice of the best network infrastructure for providing digital mobile/portable IP-multicasting services, based on an evolution of the 4G e-MBMS protocol.

In recent years, an evolution of the LTE-A (4G) technology, called LTE-A+, has been proposed by Technische Universitat Braunschweig to allow for the implementation of the “Tower Overlay” concept, Ilsen et al (1). This consists of transmitting broadcast services to mobiles from a traditional broadcast infrastructure, based on large cells, representing a more efficient delivery solution to cope with a high number of users consuming simultaneously the same service within a given coverage area. LTE-A+ proposes additional features to the LTE standard, like longer cyclic prefixes (CP), that are necessary to support the HPHT broadcast environment. This paves the way to cooperation between the cellular and broadcasting networks, in order to reach all mobile devices without the need to add a specific broadcast receiver in the devices.

To verify the proposed approach in the field, Rai CRIT launched in 2015 an experimental trial in the Aosta Valley. During this trial, two data streams, DVB-T2 and LTE-A+, shared the same UHF channel in time-division: the first one conveyed conventional HDTV programs to domestic DVB-T2 receivers, and the second one conveyed a flow intended for LTE-A+ devices.

Meanwhile, a simulation study was started to understand the strengths and the weaknesses of the different network structures. The goal was finding the best solution for delivering high quality video to mobiles at limited network costs and affordable price for the customers.

This article describes the above mentioned simulation analysis of the performance achievable by three different network infrastructures: (i) conventional broadcast HPHT, (ii) mobile cellular LPLT, and (iii) mixed network structures. A wide range of spectrum efficiencies, transmitter distances and powers, as well as receiver characteristics have been considered, to represent different possible scenarios for the delivery of multicast 5G video services to portable/mobile terminals.

4G AND FUTURE 5G TECHNOLOGIES FOR HIGH QUALITY VIDEO

The adoption of Long Term Evolution (LTE) and its further evolution LTE-Advanced (LTE-A) has enabled mobile network operators (MNOs) to use a portion of their network capacity for broadcast popular content or data. LTE and LTE-A are worldwide recognized Fourth-Generation (4G) cellular technologies supporting the broadcast transmissions by means of the evolved Multimedia Broadcast Multicast Services (eMBMS) standard, which is commercially known as LTE Broadcast, Roesller (2). They can use the same broadcast stream to serve multiple - theoretically unlimited - users within a single cell with the same video or data service, instead of needing multiple unicast delivery to every user individually. However, 4G eMBMS only supports a mixed carrier mode, where broadcast and unicast data share the carrier capacity. In particular, up to 60 percent of the total LTE resources can be allocated for eMBMS.

In DVB-T/T2 systems, OFDM symbols are characterized by long CP lengths to counter artificial echoes from far emitters operating in SFN (Single Frequency Network). The maximum CP length for an 8 MHz channel is 224 μs for DVB-T (8k mode), corresponding to 67 km propagation path difference, and could be up to 532 μs for DVB-T2 (16k and 32k modes); the values reduce to 179,2 and 425,6 μs, respectively, for a 10 MHz channel, keeping the same number of subcarriers. The cyclic prefix lengths adopted by LTE systems, based on OFDM, as specified in (3), are considerably shorter because of the more limited typical cell size. In order to allow for the use of eMBMS with a SFN approach, longer prefix lengths have been introduced as an option in the LTE-A standard, with a maximum value of 33.3 μs, corresponding to 10 km propagation path difference. Therefore, 4G multicast solutions are only suitable for dense cellular networks.

Although MNOs are currently investing in 4G network deployments, the mobile industry is already working on the definition of the future 5G mobile communication system. Following the current requirements and expectations from both users and operators, it is likely that future 5G wireless networks will also include the efficient provision of massive mobile multimedia services through one or several broadcast transmission modes.

As a matter of fact, 3GPP has just started several new Study Items for 5G, the next generation of mobile networks. The new systems will be characterized by significant enhancement in terms of bit rate, reliability, latency, number of connected users and devices, and coverage. To achieve these challenging enhancements, the system will exploit new radio access techniques (among them, improved modulation and coding schemes, massive MIMO, 3D beamforming, non-orthogonal multiple access), very high bandwidths (up to 100 MHz), small cell structures (pico and femto cells), and new network architectures (software defined networking, virtualization).

At physical layer, new modulation formats are under study to provide improvements in terms of performance and reliability. As an example, innovative multicarrier systems like filtered OFDM, Faster than Nyquist/Time Frequency packed signalling, and single carrier modulations are currently being studied. These techniques may require a rather shorter cyclic prefix to counter natural or artificial echoes: this property, by increasing the Inter Symbol Interference (ISI) Free Interval (IFI) may have beneficial impact on HPHT and hybrid network performance.

Furthermore, a number of items, highly relevant for broadcast services, are currently discussed within 3GPP. They include:

- Standalone eMBMS network and flexible use of capacity, in order to allow for 100% allocation to the broadcast mode, for eMBMS-only networks without unicast services;
- Free-to-air and receive-only mode i.e. free-to-air reception without SIM Card and contractual obligation with a network operator;
- eMBMS-Sharing, allowing for the combination of the networks of two eMBMS operators into a single SFN.

THE BROADCAST AND MOBILE NETWORK SCENARIOS AND MODELS

From a general standpoint, there are two potential reference architectures for terrestrial broadcasting. The traditional broadcast HPHT networks are based on elevated transmitting sites, usually sparsely distributed across the service area, with effective radiated power (EIRP) values in the range of some kW. By this topology, relatively few transmitters can cover large service areas, and linear TV content is easily delivered to a mass audience. Oppositely, for mobile broadband communications, cellular LPLT networks are used. They are based on a denser network of transmitting sites, with antennas located at lower heights, lower transmitter power, and mainly employed to provide bi-directional (unicast) data traffic.

The present study concentrated on an ideal case, representative of the Italian scenario[1], characterized by flat areas surrounded by hills and mountains. HPHT transmitters are situated on top of hills at a height of 600 m a.g.l. and an EIRP of 3 kW. For the LPLT network, two different EIRP levels have been considered, namely 150 W and 800 W, to represent respectively the case when the electromagnetic load of the cell cannot be increased and a more typical case commonly employed by MNOs (20 W power amplifier per sector). The low towers height is in both cases 20 m. The receiving terminal is a handheld device with single antenna (no MIMO) plus headphones extension, having a gain of -3.5 dBi, typically considered at a height of 1.5 m.

The study was then extended to a "*flatland*" scenario, typical of continental Europe. In this scenario, HPHT transmitters are located in a flat area, possibly in the center of the city, at 200 m a.g.l. (above ground level) having an EIRP of about 80 kW (4). The EIRP level considered for the LPLT network is 1 kW. The low towers height is 30 m a.g.l. The receiving terminal is a handheld device with single antenna (no MIMO) having a gain of -7.35 dBi and a height of 1.5 m (5).

The system parameters are summarized in Table 1.

Table 1. Deployment parameters for the different scenarios

Scenario	Network type	EIRP [W]	Tx height [m]	Rx height [m]	Rx gain [dBi]
Italian	HPHT	3000	600	1.5	-3.5
	LPLT (1)	150	20		
	LPLT (2)	800	20		
Flatland	HPHT	80000	200		-7.35
	LPLT	1000	30		

ITU-R P.1546-5 Propagation Model (6) in urban and suburban environment has been used, which is suitable for both HPHT and LPLT network propagation, as well as portable/mobile reception. The study was concentrated on outdoor reception, leaving the investigation of the indoor case to a second phase.

[1] The Italian territory is 302.000 km^2 wide, with 170.000 km^2 rural/suburban areas, 100.000 km^2 mountainous territory and 32.000 km^2 dense urban areas, Annuario Italiano (8).

COVERAGE SIMULATION TOOL

The evaluation of HPHT, LPLT and hybrid HPHT/LPLT networks performance has been carried out by means of a simulation program based on Matlab® software (7). Such tool defines an - ideally infinite - hexagonal grid, bounded to a finite region due to computational limitations. Transmitters are placed along three non - adjacent vertices of the hexagons, both in HPHT and LPLT scenarios as depicted in Figure 1.

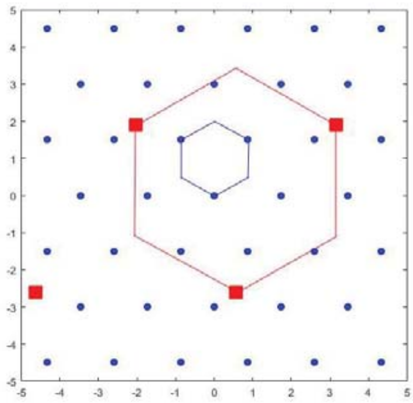

Figure 1 – HPHT (■) and LPLT (●) transmitter hexagonal pattern

Using the parameters defined in the previous section, the simulation tool evaluates the Signal to Interference plus Noise Ratio (SINR) in each point of the simulation grid. In particular, it performs a Monte Carlo analysis, taking into account the statistical variations of the signal due to the fading that characterizes the channel model. By considering an appropriate SINR threshold (example: 10 dB, corresponding to about 2.5 bit/s/Hz capacity, assuming 3.5 dB Rayleigh fading and implementation margin over Shannon limit) and two target Reception Location Probabilities (RLP) for error free reception, i.e. 98%, identified as good reception quality, and 95%, acceptable reception condition, the program evaluates the SINR and maps to a scale of three colours the values corresponding to the case of good quality (RLP>98%, green squares), acceptable quality (95%<RLP<98%, yellow circles) and not served areas (RLP <95%, red crosses).

COVERAGE RESULTS

The main goal of the study was the evaluation of the impact of the physical layer parameters (e.g. Modulation and Coding scheme, Echo Resilience-Guard Interval) in an ideal regular network for delivering multicast high-quality video services. Three different transmitter configurations were simulated: HPHT network only, LPLT network only and co-operative HPHT/LPLT configurations. To compare the HPHT and LPLT networks, the coverage ratio of the HPHT network versus the LPLT network (CR_{HL}) was considered, defined as the ratio between the HPHT transmitter coverage area and the LPLT transmitter one, for a given reception quality. Different spectrum efficiencies, transmitter distances, output power values, and receiver characteristics were considered, for a 10 MHz channel with 700 MHz carrier frequency.

Figure 2 shows the suburban coverage for HPHT and LPLT networks, in the *Italian* case study. The Inter Site Distance (ISD) is set to the maximum value to guarantee at least 95% location probability in the coverage area. The ISI free interval is 500 µs, a value defined to remove the interference limitations and concentrate the analysis on the noise limitations. The required SINR is set to 10 dB for a spectral efficiency of 2.5 bit/s/Hz, allowing for the delivery of 16 HD programs (HEVC) in a 10 MHz frequency slot. These values do not represent specific systems, but may be considered as representative for a generic state-of-the-art mobile radio interface.

As can be seen from Figure 2 (a), an HPHT ISD of 40 km allows to achieve a good quality reception over 46% of the service area, still acceptable over 54% of the area. The same coverage could be guaranteed by the LPLT network with an ISD of 3.5 km using 150 W EIRP, or 5.5 km if the cell Electromagnetic load limitations allow for the increase of the LPLT EIRP up to 800 W. This results in a CR_{HL} of about 130, when using 150W EIRP, with the HPHT network guaranteeing low-cost, full outdoor coverage of rural/suburban areas. Focusing on the Italian territory, the coverage of 170.000 km^2 of flat Suburban/Rural areas by HPHT sites would theoretically require about 123 broadcast towers, instead of 16.000 mobile towers. If the cell Electromagnetic load allows the LPLT EIRP to be increased to 800 W, the coverage ratio becomes 53, and the number of required LPLT stations to cover rural suburban areas reduces to 6500.

Assuming a SINR of 7dB, the achievable HPHT ISD could be increased up to 48 km, guaranteeing good coverage in 53% of the area and acceptable in 47%. For the LPLT network, the ISD is 4 km for 150 W EIRP, and 6 km for 800 W EIRP. This leads to a CR_{HL} of 144 and 64, respectively for 150W and 800 W EIRP.

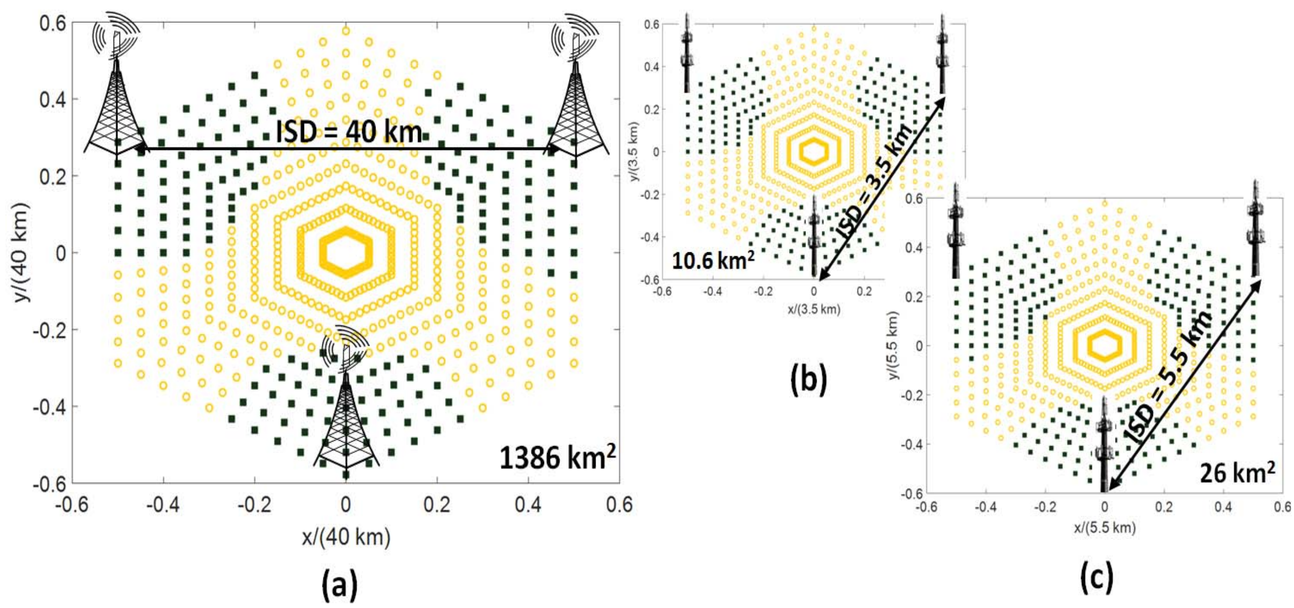

Figure 2 – Coverage results for the outdoor suburban case: SINR threshold 10dB, ISI Free interval 500µs – *Italian* case: a) HPHT, b) LPLT (150W), c) LPLT (800W).

The analysis for the dense urban environment is shown in Figure 3. An ISD of 40 km for the HPHT network only guarantees about 16% good coverage and 15% acceptable coverage. The HPHT network could be considered for covering urban areas at distance from the transmitter less than 12 km. For the urban areas located in the remaining 69%, the LPLT co-operation is required, with ISD of about 2 km in the case of 150 W transmitter EIRP and 3.5 km when the transmitter EIRP is of 800 W. Taking again the example of Italy, without the HPHT network, the coverage of 32,000 km^2 of dense urban areas would ideally require about 9400 mobile sites, reducible to 3000 if the LPLT EIRP can be increased to 800W. If the HPHT transmitters are located near important urban areas, possibly the network co-operation would allow avoiding the installation of a significant percentage of LPLT cells in urban areas, thus significantly reducing network costs and electromagnetic impact.

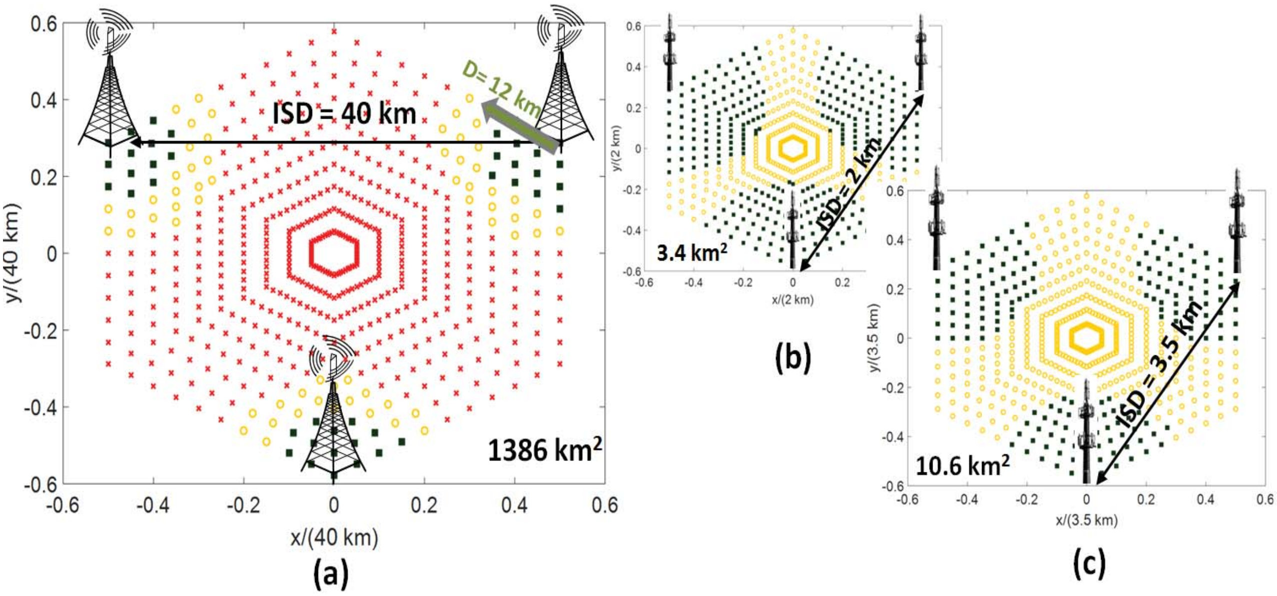

Figure 3 –Coverage results for the outdoor dense urban case: SINR threshold 10dB, ISI Free Interval 500µs – *Italian* case: a) HPHT, b) LPLT (150W), c) LPLT (800W).

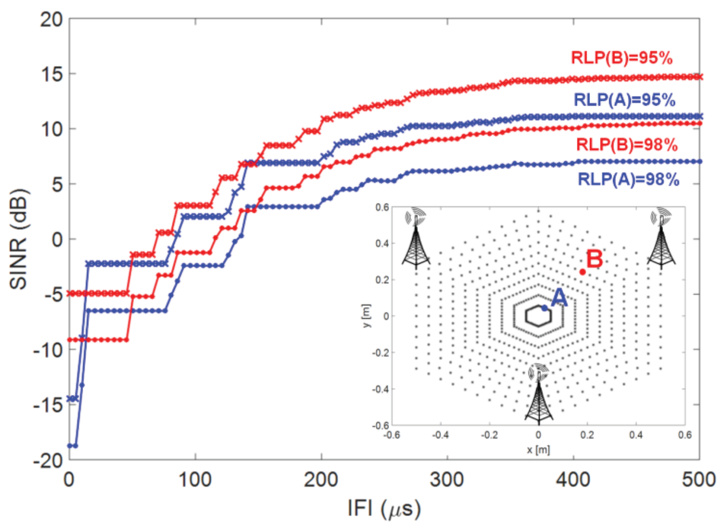

Figure 4 – SINR *vs* ISI Free Interval at location A and B, assuming RLP=95% and 98% - Outdoor suburban

Finally, the impact of the interference free interval (i.e. guard interval) on the coverage results of the HPHT network has been considered, taking into account that the implementation of echo resilience by means of long guard intervals may require long symbols, thus reducing the maximum mobile terminal speed. Figure 4 shows the behaviour of the SINR *vs* ISI free interval for two receiving points inside the hexagonal grid. The ISD is 40 km; point (A) is at the border of the cell (distance from the transmitters 23 km), and point (B) approximately at 10 km distance from one transmitter.

As an example, simulations have been performed for the case of ISI free interval equal to 250 µs. Results show that for a SINR threshold value of 10 dB, considering a suburban environment, HPHT ISD reduces to 35 km, obtaining good coverage in 40% of the area and acceptable in 60%. For the LPLT network, the ISD is 3 km for 150 W EIRP, and 5 km for 800 W EIRP. The coverage ratio CR_{HL} becomes 136 for 150 W EIRP and 49 for 800 W. Alternatively, to keep the ISD at 40 km, the SINR threshold should be set to 8 dB, allowing to get a good coverage in 44% of the service area, becoming acceptable for the 56%. The same coverage could be achieved by the LPLT network with an ISD of 3.8 km using

150 W EIRP, or 6 km for 800 W EIRP. The coverage of urban areas by HPHT network is guaranteed for distances from the transmitter less than 8 km, while the co-operation by LPLT cells is required in the farther urban areas.

Simulations carried out for the *flatland* case provided results very similar to the *Italian* case, when considering LPLT transmitter EIRP of 800 W. As an example, the suburban environment requires an HPHT ISD of 40 km, or LPLT ISD of 5 km, which results in a CR_{HL} of 64. So the same consideration of the *Italian* case could be applied to the general *flatland* case.

Table 2 summarises the coverage results for the different scenarios.

Table 2. Coverage results

Scenario	Network type	Environment	SNR [dB]	IFI [μs]	ISD [km]	Tx coverage area [km^2]	% area @98% RLP	% area @95% RLP	CR_{HL}
Italian	HPHT	Suburban	10	500	40	1386	46	54	
	LPLT(1)				3.5	10.6	43	57	130
	LPLT(2)				5.5	26	50	50	53
Italian	HPHT	Suburban	7	500	48	1995	53	47	
	LPLT				4	14	53	47	144
	LPLT				6	31	66	34	64
Italian	HPHT	Dense Urban	10	500	40	1386	16	15	
	LPLT(1)				2	3.5	63	37	
	LPLT(2)				3.5	10.6	45	55	
Italian	HPHT	Suburban	10	250	35	1061	40	60	
	LPLT(1)				3	7.8	64	36	136
	LPLT(2)				5	21.7	61	39	49
Italian	HPHT	Suburban	8	250	40	1386	44	56	
	LPLT(1)				3.8	12.5	51	49	111
	LPLT(2)				6	31.2	53	47	44
Flatland	HPHT	Suburban	10	500	40	1386	54	46	
	LPLT				5	21.7	52	48	64

CONCLUDING REMARKS

TV Media Companies would be interested to deliver in the coming years “live high quality video content” (HD, guaranteed QoS, no buffering time) to millions of mobile viewers at affordable price. The minimum TV service offering could be of 10-15 HDTV programs (HEVC, 1.5 Mbit/s per HD video). Such services could be delivered in Europe in the 700 MHz frequency band (a portions of which is for down-link use only), which will be transferred from broadcasting to mobile services in 2020-2022. LTE-A eMBMS and cellular networks (LPLT) already allow for a good coverage, but the cost for an extensive territory coverage would be very high, due to the huge number of transmitting sites. Unfortunately, this 4G solution is not applicable to HPHT networks, because the cyclic prefix/guard interval is too small to prevent SFN self-interference by far transmitters.

5G technologies, introducing larger ISI free Intervals, could offer an opportunity for HDTV mobile multicast at reasonable costs, using a combined HPHT and LPLT network. The HPHT network, with an ISD in the order of 35-40 km, would cover rural and suburban areas, and urban areas in the vicinity of the transmitter (in the order of 8-12 km). The LPLT networks (ISD of 2-3 Km) would cover urban areas, which are located farther from the HPHT transmitters. This combined network configuration would require a much smaller number of transmitters to cover the same area (the multiplication factor is between 50 and 130, depending on the LPLT maximum EIRP).

Neglecting the real-estate, tower, and primary distribution costs, and assuming a HPHT equipment cost 5-10 times higher than that of LPLT, the coverage of the Italian territory by means of a co-operative HPHT-LPLT network would dramatically reduce network costs by a factor of 3-4 times, with respect to a pure LPLT network. Therefore, the cooperative network approach represents the best opportunity to broadcast for High Quality TV contents to mobile devices for all the actors of the value chain: media companies, broadcast and mobile operators and the end users.

REFERENCES

1. Ilsen S., Rother D., Juretzek F., Bretillon P., Seccia J., Ripamonti S., “Tower Overlay over LTE-Advanced+ (TOoL+) – Field Trial Results”, IEEE 2015 ICCE-Berlin conference

2. Roesller A., “evolved MBMS broadcast and multicast in LTE”, Rohde & Schward webinar, August 2011.

3. 3GPP TS 36.211 V13.1.0 (2016-03). “3rd Generation Partnership Project; Technical Specification Group Radio Access Network; Evolved Universal Terrestrial Radio Access (E-UTRA); Physical channels and modulation (Release 13). March 2016.

4. Report ITU-R BT.2254-2, Frequency and network planning aspects of DVB-T2, ITU-R, Geneva, 2012

5. TC-SPG 20156 EBU Technical Report: "Simulation parameters for theoretical LTE eMBMS network studies"

6. Recommendation ITU-R P.1546-5; Method for point-to-area predictions for terrestrial services in the frequency range 30 MHz to 3000 MHz, ITU-R, Geneva, 2013

7. MATLAB. Natick, Massachusetts: The MathWorks Inc., 2015.

8. ANNUARIO STATISTICO ITALIANO 2014; http://www.comuniverso.it

ACKNOWLEDGEMENTS

The authors would like to thank Bruno Sacco of Rai-CRIT, Andrea Cagliero and Rossella Gaffoglio of Università di Torino, for the fruitful discussions on the context and results analysis and for their advice and suggestions for system modelling and software development.