International Broadcasting Convention 2017 (IBC2017)

14-18 September 2017

Long-term perspectives of TV convergence towards 5G: mobile and fixed applications

IET Journals
The Institution of Engineering and Technology

ISSN 2515-236X
doi: 10.1049/oap-ibc.2017.0470
www.ietdl.org

A. De Vita[1], R. Gaffoglio[2], V. Mignone[1], Alberto Morello[1] ✉

[1]Rai – Radiotelevisione Italiana, Italy
[2]Dip. di Fisica, Università degli Studi di Torino, Italy
✉ *E-mail: alberto.morello@rai.it*

Abstract: The third generation partnership project (3GPP) has defined in Release 14 the new evolved version of Multimedia Broadcast Multicast Service system, whose characteristics are well aligned to the technical requirements coming from the broadcast sector for TV services. This paves the way to allow broadcasters and content aggregators to deliver mobile TV content over cooperative broadcast high power high tower and mobile low power low tower network infrastructures, using a converging broadcast 3GPP technology. In a longer term perspective, in the 2020 decade, might this full-IP convergent technology become a candidate successor of DVB-T2 (ATSC or ISDB-T) also for digital terrestrial television home services? Is there a technical and business case for converging fixed and mobile TV on the same networks and technologies? The study investigates the performance of 3GPP Release 14 in theoretical, regular networks and in a real area around Turin (Italy), trying to give a technical background to answer the above strategic questions.

1 Introduction

In recent years, the mobile communication sector has been undergoing an impressive growth in data traffic, due to the increasing demand for high quality and bandwidth-hungry mobile multimedia services, a significant portion of which is identifiable with high quality video clips, while live broadcast television distribution still remains limited, because of the monthly data caps in the billing profiles. Consequently, mobile operators are continuously making their networks more efficient by investing in new generations of mobile technology (3G, 4G, and 5G in the near future) and in denser networks.

Mobile networks are primarily conceived for two-way and one-to-one services (i.e. unicast); they can deliver video services, as short-form clips, generally with limited quality of service (QoS), on a best effort basis. However, the unicast approach for live events (requiring a multiplication of the same TV content for each connected user) seriously puts under strain mobile networks, especially during peak traffic periods.

3G and 4G standards have been extended by a multicast specification (MBMS, Multimedia Broadcast Multicast Service; eMBMS, evolved version of MBMS), able to deliver the same TV content to an unlimited number of users, without duplication of the same video bit-stream as it happens for unicast, thus using the lowest amount of spectral resources. The use case considered by mobile network operators was the provision of live video events (sport, concerts) to multiple viewers in a specific area, temporarily allocating part of the cellular mobile network capacity to this multicast service, while another part of the capacity is allocated to unicast broadband multimedia. This use-case will be named in the following as ‘event-TV’.

The recent third generation partnership project (3GPP) Release 14 [1] defines a new eMBMS system with characteristics well aligned to the technical and functional requirements coming from the broadcast sector to deliver regular ‘mobile-TV’ services, characterised by high quality HD video content at guaranteed QoS (without buffering time), covering permanently wide territories (countries, regions). Terrestrial networks generally consist of high power high tower (HPHT) networks for traditional TV and Radio broadcast services and cellular low power low tower (LPLT) networks for mobile telephony and broadband multimedia communications. The HPHT scenario is based on a limited number of high-power transmitters with large antenna heights and effective isotropic radiated power (EIRP) values in the range of some kW to many tens of kW. Even using a few transmitters, this type of network allows the coverage of large service areas, and linear TV content is easily delivered to a mass audience in a roof-top reception scenario. Conversely, the LPLT architecture is characterised by a dense network of transmitters, with rather low power levels and antenna heights, which are optimised for wireless unicast communication for handheld user devices and are better suited for indoor coverage even in urban areas. For ‘mobile-TV’, Release 14 can support the implementation of cooperative HPHT and LPLT network infrastructures, offering a significant implementation cost reduction, as better explained in the following.

The last hypothetical use case which Release 14 could enable is broadcasting of high quality TV content to domestic TV receivers connected to roof-top directive antennas, as a replacement of current broadcast services (the DVB, ATSC, ISDB-T, families of technology). This use case is named in the following as ‘fixed-TV’.

In which spectrum bands could the above-mentioned video services (i.e. event-TV, mobile-TV and fixed-TV) be allocated? Considering the international spectrum allocation regulations, in Europe the 700 MHz band will be cleared from digital terrestrial television (DTT) services around 2020–2022 and reallocated to broadband mobile services. 3GPP Release 14 video streaming services may be delivered in this newly allocated band or higher mobile frequency bands, with standard mobile channel raster (e.g. 5 or 10 MHz 4G/5G channels for up-link and for down-link in frequency division duplexing). However, such channels, being typically bi-directional, are more suitable for ‘event-TV’ services, with dynamic multicast/unicast capacity allocation in mobile LPLT networks, rather than for regular country-wide mobile-TV services (down-link only). A stand-alone mobile-TV service could instead use the supplemental down link gap, 738–758 MHz, to be allocated in Europe on a country-by-country basis. Instead, ultra-high frequency (UHF) broadcast spectrum below 700 MHz (8 MHz channel raster) will remain reserved to broadcast DTT services (down-link only) at least until 2030. According to the technology neutrality principle established by the EU rules, both DVB-T/T2 or stand-alone 3GPP Release 14 down-link might be adopted in this band (the 3GPP solution would need (5 + 3) MHz channel aggregation to fully exploit the 8 MHz bandwidth). Nevertheless, national normatives could be more restrictive and impose a specific technology, to avoid technology proliferation and to ensure the universal access to media services. Thus such UHF frequency bands below 700 MHz could be considered as future candidates for 3GPP *mobile-TV* and *fixed-TV* services.

The study analyses 3GPP Release 14 main technical features and investigates its performance in theoretical, regular networks and in a real example scenario of the area around Turin (Italy), in UHF bands (700 MHz or sub-700 MHz). Both mobile-TV and fixed-TV scenarios are considered. The study concentrates on outdoor reception: a recent report indicates that on-line video consumption at home, although predominantly (70%) over outdoor consumption, mainly uses fixed-broadband and WIFI connections [2].

2 New features in eMBMS Release 14

With Release 14, the following important features are introduced in the eMBMS standard to cope with broadcast requirements:

- Free-to-air and receive-only mode, i.e. free-to-air reception without SIM card and without contractual obligation with a network operator.
- The possibility to dedicate 100% of the available radio resources to broadcast (standalone mode), thus overcoming the limit of 60% specified in previous eMBMS releases.
- The definition of a longer cyclic prefix (CP) of 200 μs to cover an inter-site distance (ISD) of up to about 60 km in a single frequency network (SFN) scenario.

The maximum allowed spectrum efficiency is 4.9 bit/s/Hz (with 256-quadrature amplitude modulation (QAM), not including guard bands).

3 Simulation results for an ideal network

The first part of the present study focuses on ideal cases, providing an overview of the different situations that could be encountered in real networks (parameter values are representative of typical cases in Italy). The simulation framework is described in Annex.

For mobile-TV services, the target area coverage percentage is 98%, for an outage probability in the small areas of 2%, while for Fixed-TV services the target area coverage percentage is 95%, for an outage probability in the small areas of 5%; both situations are indicated in the following as ‘good quality’ coverage. To evaluate the achievable spectrum efficiency for mobile-TV and fixed-TV services, a nation-wide SFN approach is considered. Should frequency reuse-1 be adopted (mobile systems usually have reuse-1), negative effects of co-channel interferences at the country border (due to the different transmitted content in neighbouring countries) have to be taken into account. Such effects are more relevant for HPHT solutions than for LPLT, due to the larger affected area.

3.1 Mobile reception

With the main goal to evaluate the physical layer parameters of 3GPP Release 14 for delivering mobile-TV services, three different transmitter configurations were simulated: HPHT only, LPLT only and co-operative HPHT/LPLT. The required signal to interference plus noise ratio (SINR) is set to 10 dB for a spectral efficiency of about 2.5 bit/s/Hz (average number, assuming 3.5 dB Rayleigh fading and implementation margin over Shannon limit), allowing for the delivery of 10–15 HD programmes (high efficiency video coding) in an 8–10 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 (i.e. DVB-T2/lite and 3GPP Release 14).

The coverage performance generally depends on the transmitter power and height, the system CP for SFN operation (limited to 200 μs in Release 14), the size of the coverage area and ISD and the environment type (rural, suburban or dense urban). The SFN behaviour goes from a noise limited scenario, where an increase of EIRP corresponds to a proportional SINR increase (this is typically the case for reduced transmitter height and power and large ISD), to an interference (the interference comes from signal components from distant transmitters, with a propagation delay>CP) limited scenario, where an EIRP increase does not produce significant SINR increase (saturation effect for very large transmitter EIRP or reduced ISD).

For a HPHT network, Fig. 1*a* shows the minimum required EIRP to achieve SINR = 10 dB in 98% of the coverage area with 2% outage probability, for two transmitter antenna heights H_{TX}, i.e. green curves – $H_{TX} = 500$ m (e.g. transmitter on a mountain) and blue curves – $H_{TX} = 200$ m (e.g. transmitter on a tower). The suburban area propagation model is assumed and two CP values are considered: 200 μs, as introduced by Release 14, in comparison with 300 μs, to assess the benefit that a further increase of the CP could provide (DVB-T2 offers several CPs, up to 448 μs for 16k-orthogonal frequency-division multiplexing; this mode copes with a moderate vehicular speed). Dotted lines refer to SFN networks; as a reference, the continuous lines refer to a single transmitter, representing an ideal interference-free multi-frequency network (MFN) network (i.e. a very large frequency reuse factor).

The SFN power gain versus MFN is clearly visible (dotted versus continuous lines of the same colour) when the CP is sufficiently high with respect to the ISD, and can be as high as 10 dB for small ISDs, while it reduces for larger ISDs, when the CP is not sufficient to cope

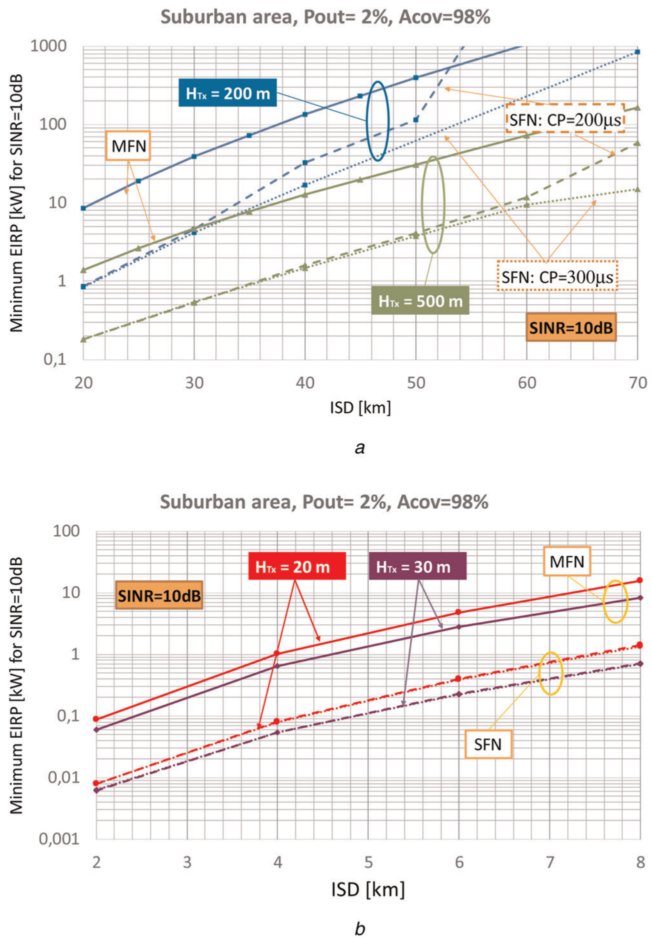

Fig. 1 *Suburban coverage: minimum transmitter EIRP required to achieve a SINR threshold of 10 dB as a function of the ISD for different network configurations (MFN, SFN), transmitter heights (H_{Tx}) and CPs*
(a) HPHT network, ***(b)*** LPLT network

with adjacent transmitters. A good-quality coverage can be guaranteed with an ISD of 60 km and 12 kW EIRP for $H_{TX} = 500$ m; in the case of $H_{TX} = 200$ m a higher EIRP is necessary, and the effect of the shorter CP is more clearly visible. The required EIRP is about 100 kW for an ISD is about 50 km and CP = 200 µs.

Fig. 1*b* shows the simulation results for a LPLT network. The good-quality coverage could be guaranteed by the LPLT network (red curves – $H_{Tx} = 20$ m) with an ISD of 4 km using 100 W EIRP, or ISD = 6 km using 500 W EIRP (applicable to urban cells not affected by strong electromagnetic load restrictions). To compare the HPHT and LPLT networks, the ratio between the HPHT and LPLT transmitter coverage areas (indicated as CR_{HL}) was evaluated. In the examined cases, CR_{HL} is about 225 or 150, for a HPHT transmitter height of 500 or 200 m, respectively, and 100 W LPLT transmitters. In the case of 500 W LPLT transmitters, CR_{HL} reduces to 100 or 70, respectively. Focusing on the Italian territory, the coverage of 170,000 km^2 of flat suburban/rural areas by HPHT sites would theoretically require <100 broadcast towers (60 for $H_{TX} = 500$ m or 87 for $H_{TX} = 200$ m), instead of about 6000 or 13,500 LPLT mobile towers, depending on their transmitted EIRP.

When considering the urban areas, for the HPHT network the maximum ISD reduces to about 45 km, for the same good quality coverage and for 12 kW EIRP ($H_{TX} = 500$ m), while for an ISD of 60 km urban areas at a distance from the transmitter >15 km cannot be covered by the HPHT network alone, and LPLT network cooperation is required. In a real network, there is an option to install new HPHT transmitters just outside towns, or exploiting the synergy with existing LPLT networks. Fig. 2 shows the HPHT (left) and cooperative (right) network coverage in urban areas. In the example case, the HPHT network adopts an ISD of 60 km with an EIRP of 12 kW ($H_{TX} = 500$ m), thus targeting the full suburban coverage of the territory as shown in Fig. 1*a*; LPLT transmitters have been inserted from a distance of 15–30 km from the HPHT transmitter, to complete urban coverage. The LPLT transmitters' ISD is 2.5–4 km for an EIRP of 100–500 W (good outdoor urban coverage).

Again, taking the example of Italy, without the HPHT network, the coverage of 32,000 km^2 of dense urban areas would ideally require a number of mobile sites in the order of 2500 or 6500, depending on the allowed EIRP, while the cooperation of HPHT would save 25% of such urban installations thus significantly reducing urban LPLT network costs and electromagnetic impact. A random allocation of HPHT transmitters with respect to urban areas is assumed; nevertheless, in several cases, the HPHT television transmitters are located near important urban areas, thus the LPLT required installations could be even smaller.

3.2 Fixed reception

To assess the potential of 3GPP Release 14 for fixed reception and directive roof-top antenna, in comparison with DVB-T2, the investigation considers a target SINR of 19 dB, corresponding to DVB-T2 256-QAM with low density parity check coding rate 2/3, having a spectral efficiency of 5.3 bit/s/Hz (excluding guard bands, CP and pilot overhead).

For HPHT networks, Fig. 3 shows the minimum transmitter EIRP required to get the target SINR of 19 dB for a good quality suburban coverage (representing also dense-urban coverage for roof-top reception), as a function of ISD for different transmitter antenna heights (blue curves for $H_{TX} = 200$ m and green curves for $H_{TX} = 500$ m). As in the 'Mobile Reception' section, two CP values are considered: 200 µs, as offered by 3GPP Release 14, in comparison with 300 µs. As a reference, the continuous lines refer to a single transmitter, representing an ideal interference-free MFN network (i.e. very large frequency reuse factor).

Comparing Figs. 1*a* and 3, the huge EIRP difference required by mobile and fixed roof-top antenna reception is evident, due to the difference in receiving antenna gain and height: for an ISD = 50 km mobile-TV requires about 18–20 dB more EIRP than fixed-TV in a suburban area, already taking into account the different SINR targets (10 dB for mobile-TV, 19 dB for fixed-TV),

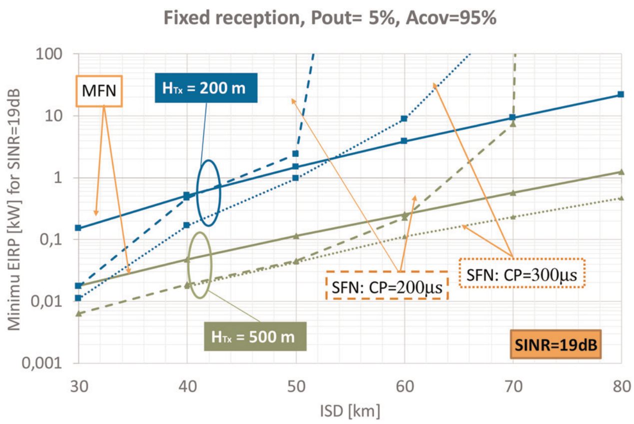

Fig. 3 *Minimum transmitter EIRP required to achieve the SINR threshold of 19 dB in 95% of the coverage area with 5% outage probability as a function of the ISD for different network configurations (MFN, SFN), transmitter heights (H_{Tx}) and CPs*

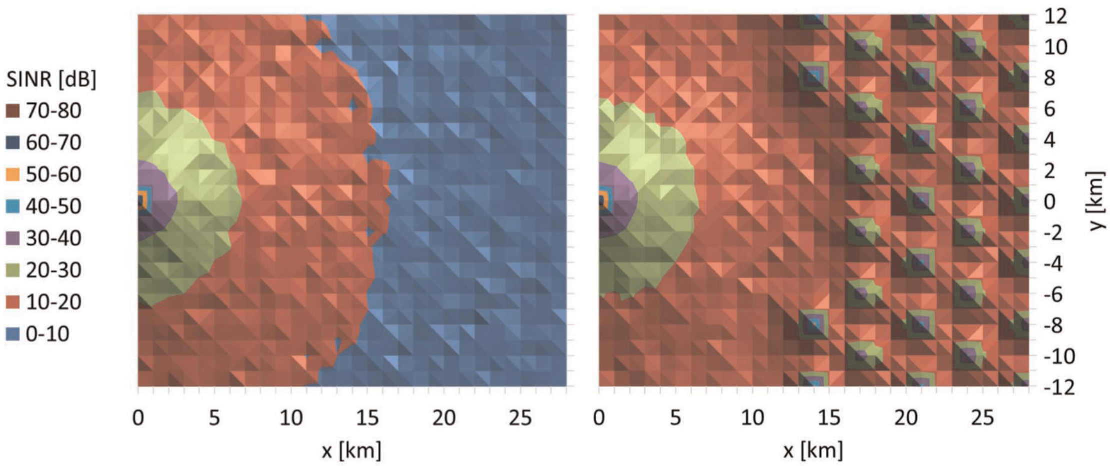

Fig. 2 *SINR @98% versus distance from the HPHT transmitter in the urban coverage area for the HPHT only (left) and hybrid HPHT/LPLT (right) scenario versus the distance from the nearest HPHT transmitter, located in (0,0) (uneven LPLT peaks are due to sampling)*

but neither considering urban mobile reception nor indoor reception, which would further enlarge the difference.

Also in the case of fixed roof-top reception the SFN gain versus MFN is clearly visible (dotted lines versus continuous lines of the same colour) when the CP is sufficiently high with respect to the ISD. In the simulations, to maximise network gain, the receiving antenna was pointed to the transmitter generating the strongest signal, instead of to the nearest one. However, in this case, the gain is not as high as with an omnidirectional receiving antenna, because the directive antenna attenuates the useful contributions from the surrounding transmitters: it can be as high as 4 dB for small ISDs, where the CP keeps the network self-interference low, and reduces to 0 dB or becomes negative for larger ISDs. For CP = 200 µs, there is a sharp limit in the maximum ISD, in the order of 50 km for transmitter heights of 200 m: thus for flat countries, which cannot exploit mountains and hills to locate transmitters, 3GPP Release 14 cannot support large ISDs. 3GPP is currently considering the possibility of introducing new larger CP values in future releases of the standard, to cope with larger ISD. Values aligned with those offered by DVB-T2 should be considered.

4 Simulation results for the metropolitan area of TURIN

Tests in the real environment have been carried out for mobile reception in the metropolitan area of Turin. The EMLAB® software allowed radio-electric evaluations to be made, taking into account the terrain profile and the alternation of rural/suburban and urban environments.

The coverage provided by the HPHT network for 95% of locations was evaluated, for a SINR target of about 10 dB, with the same receiving system parameters used in the simulations of the theoretical model. The coverage results are reported in Fig. 4 for an area of about 40 km around the city of Turin, including other small urban areas. The map clearly shows that urban areas far from the main transmitter (in the present case, Torino Eremo) cannot be covered with good quality by the HPHT network only (other poorly served areas are hilly or mountainous). Hence LPLT transmitters are necessary to serve the small urban areas highlighted with red circles. To be noted that the simulation only considers HPHT transmitters covering the represented area; far HPHT transmitters (outside the examined area) may cause severe interference for which a larger CP could be required.

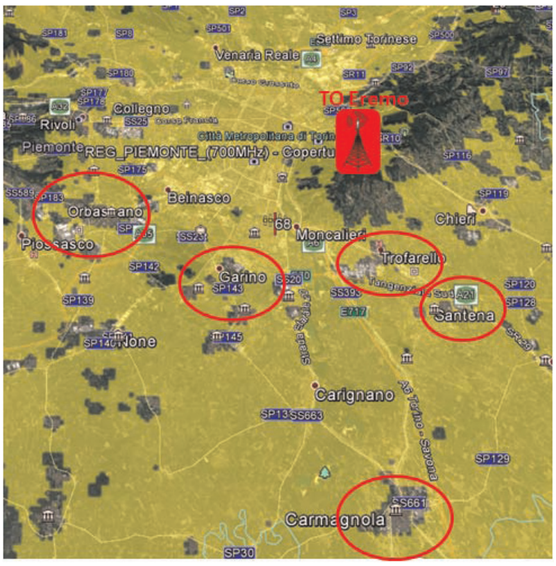

Fig. 4 *Mobile TV coverage results relative to the area around Turin (Italy)*

5 Conclusions

This exercise indicates that 3GPP Release 14 offers an important instrument for the successful deployment of TV services in the UHF band after 2020: at the physical layer it performs similarly as DVB-T2 (both are based on OFDM and state-of-the-art forward error correction (FEC) schemes) for moderate ISD, and it is expected that next releases of the standard may introduce even larger CP (up to 500 µs) for larger ISDs.

The 3GPP technology offers mobile solutions both for the event-TV use-case (e.g. local distribution of live concerts and sports events for a limited period of time) and for a more ambitious case of a nation-wide, regular mobile-TV service. In the latter case the new features introduced in Release 14 allow for a low cost SFN network implementation based on: (i) a HPHT network (typically, co-sited with a conventional broadcast network), with an ISD in the order of 50–60 km, covering rural and suburban areas, and urban areas in the vicinity (10–15 km) of transmitters; (ii) a complementary LPLT network covering urban areas located farther from the HPHT transmitters (not all mobile sites should be used, since the required ISD would be of about 2.5–4 km). Compared with a pure country-wide cellular LPLT network, this combined HPHT/LPLT network configuration would require a much smaller number of transmitters to cover the same area (the multiplication factor is between 70 and 225, depending on the LPLT maximum EIRP and HPHT antenna heights). The great advantage of this solution, with respect to a pure broadcast system (i.e. T2-Lite or DVB-NGH), is the widespread availability of 3GPP technologies in mobile devices. It remains to be demonstrated that overcoming this blocking factor is sufficient to re-launch the business case of mobile-TV.

More complex is the analysis on a possible role of 3GPP Release 14 (or future 5G/6G solutions) to provide fixed-TV services during or after the 2020-2030 decade. From a purely technical and economic analysis, merging fixed-TV and mobile-TV services on the same network is objectionable in terms of power and spectrum optimisation. As demonstrated in this study and as widely accepted in the technical community, the reception conditions (defined by the available SINR) for fixed roof-top antennas and for mobile receivers differ by three or more orders of magnitude (even disregarding indoor reception); for example the study shows that urban coverage needs a cooperative LPLT network only for mobile-TV, not for fixed-TV. Thus, the achievable spectrum efficiencies are very different (around 2.5 bit/s/Hz for mobile-TV, 5 bit/s/Hz for fixed-TV); well matching the different TV content quality requirements (5′–12′ portable screens require significantly lower video bit-rates than 40′–60′ fixed-TV screens). All these factors indicate that, although the broadcast HPHT network infrastructures, originally designed for fixed-TV, may be very useful to implement low-cost 3GPP mobile-TV, these services will not converge into a single emitted signal.

A question remains: is there any additional technical or economic driver to converge fixed-TV to the 3GPP technology, or will the current 3GPP/DVB duality continue? A wide range of commercial elements will influence such future evolution, given that the technical performance of 3GPP may catch DVB in future 5G releases. Will 3GPP Release 14 be massively implemented in next generation portable devices, and will they cover also sub-700 MHz bands and 8 MHz channels? What economies of scale could be gained by using 3GPP technologies also in TV receivers? What barriers would the migration from DVB to 3GPP technology face because of the population of legacy TV receivers in service? How will broadcast and mobile network companies evolve in the future? Unless a significant ecosystem change takes place, few elements seem to drive the convergence so far.

6 AnneX - the simulation framework

The SFN structure considered in the coverage evaluations is the hexagonal transmitter lattice of Fig. 5, where *N* HPHT transmitters

IBC, Open Access Proc. J., 2017, pp. 1–5

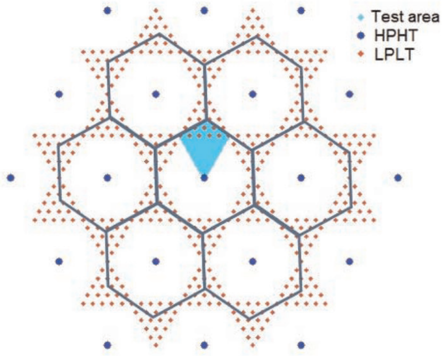

Fig. 5 *Cooperative HPHT/LPLT transmitter configuration*

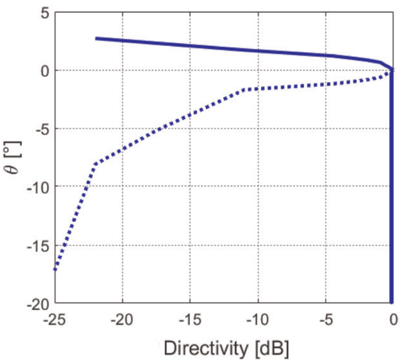

Fig. 6 *Transmitter antenna directivity in the vertical plane (for tilt = 0°)*

(*N* being the minimum number of elements for the network to be considered as ideally infinite) are regularly arranged according to a specified ISD. The simulation model allows adding LPLT transmitters (red dots in the figure) at the border of the HPHT transmitter coverage area if required to reach the target QoS.

The MATLAB® programs implemented carry out Monte Carlo simulations to calculate the SINR for each receiving point of the area under test, considering as interferers all signals having a delay above the CP duration, assuming the equalisation interval, as defined in [3, clause 3.5], being equal to the CP. Depending on the channel estimation method, it could be as large as the symbol duration. So results in the study could be considered as a worst case.

The propagation model is the one defined in Recommendation ITU-R P.1546-5 [4], which reports the curves of the field strength exceeded at 50% of the locations within any small area of ~500 m × 500 m and for 50%, 10 and 1% of the time, as a function of the distance from the transmitter, for an EIRP of 1 kW. To guarantee the service coverage at the 99% of the time, as suggested by international recommendations and planning studies [3], the useful signals are considered at 50% of the time, while the interfering ones at 1%.

The statistical variations of the field strength in the small areas are assumed to be log-normally distributed with a standard deviation $\sigma = 5.5$ dB. The target percentage of locations in the small area for good quality reception is set for a fixed roof-top reception at 95% and for a mobile reception at 98%.

Different EIRP and heights for the HPHT and LPLT transmitters have been considered. Transmitter antennas are omnidirectional in the horizontal plane, while in the vertical plane a directivity pattern is considered (see Fig. 6), to reduce network self-interference, as typically done by real antennas: precisely, the maximum of 0 dB is set at 0°, −3 dB at 1°, then the attenuation increases linearly to −22 dB at 3° (for simplicity, constant EIRP has been considered for negative angles, without affecting the simulation results, since the critical areas are on the border of the transmitter coverage). In addition, the antenna directivity is tilted downwards in order to place the −3 dB attenuation at the border of the service area.

The mobile receiving terminal is a handheld device typically considered at a height of 1.5 m with a single antenna with a gain of −3.5 dBi, taken from the typical value considered in the literature [3] and assuming the presence of headphones extension. In the fixed roof-top scenario, the receiver is located at 10 m above ground level with a 9.15 dB gain (value taken from [3] considering 4 dB cable losses) directional antenna, whose directivity pattern is defined in [5]: 0 dB in the range ±20°, falling linearly from 0 dB at ±20° to −16 dB at ±60°.

The real coverage of the Italian territory has been calculated using the software module EMLAB® by Aldena assessing the radio-electric coverage using a detailed digital terrain model and Recommendation ITU-R P.1812-4 [6] propagation model.

7 References

1 3GPP TR 38.913 V0.4.0 (2016-06): '3rd generation partnership project; technical specification group radio access network; study on scenarios and requirements for next generation access technologies', (Release 14)

2 OFCOM Digital Day: 'https://www.ofcom.org.uk/research-and-data/multi-sector-research/digital-day' 2016

3 Report ITU-R BT.2254-2: 'Frequency and network planning aspects of DVB-T2', Geneva, 2014

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

5 Recommendation ITU-R BT.419-3: 'Directivity and polarization discrimination of antennas in the reception of television broadcasting', Geneva, 1992

6 Recommendation ITU-R P.1812-4: 'A path-specific propagation prediction method for point-to-area terrestrial services in the VHF and UHF bands', Geneva, 2015