



## LONG TERM PERSPECTIVES OF TV CONVERGENCE TOWARDS 5G: MOBILE AND FIXED APPLICATIONS

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### ABSTRACT

3GPP has defined in Release 14 the new eMBMS system, whose characteristics are well aligned to the technical requirements coming from the broadcast sector for TV services. This paves the way to allowing 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 (or 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 paper 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.

### INTRODUCTION

In recent years, the mobile communications 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, and eMBMS, the evolved version), 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 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 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 characterized 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 – 22 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 <sup>(1)</sup>. 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) <sup>(2)</sup>. Instead, 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

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<sup>1</sup> e.g. 5 or 10 MHz 4G/5G channels for up-link and for down-link in Frequency Division Duplexing (FDD)

<sup>2</sup> A stand-alone *mobile-TV* service could instead use the Supplemental Down Link (SDL) gap, 738 - 758 MHz, to be allocated in Europe on a country-by-country basis.



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 paper 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].

### **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  $\mu$ s, to cover Inter Site Distances (ISD) 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-QAM, not including guard bands).

### **SIMULATION RESULTS FOR AN IDEAL NETWORK**

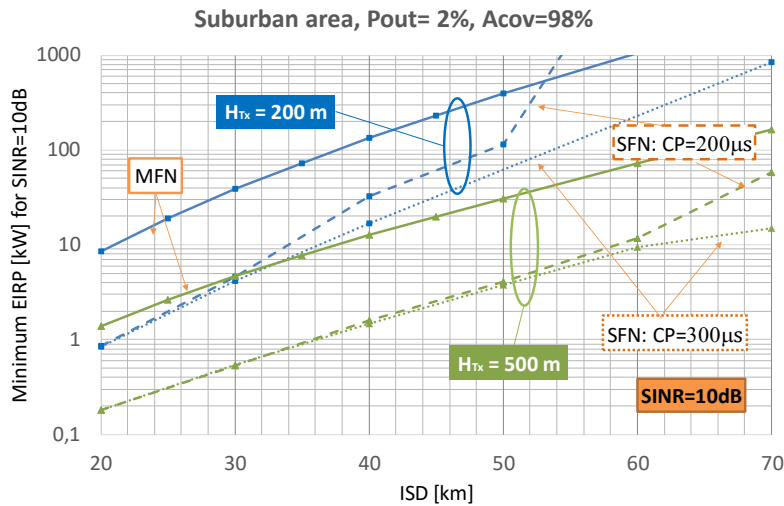
The first part of the present study focuses on ideal cases, providing an overview of the different situations that could be encountered in real networks (parameter values are representative of typical cases in Italy). The simulation framework is described in Annex.

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.

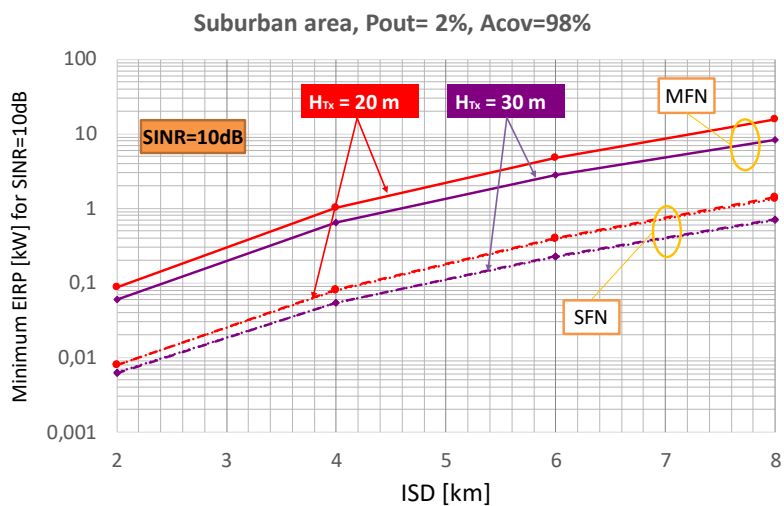
#### **Mobile reception**

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<sup>3</sup>, allowing for the delivery of 10 - 15 HD programmes (HEVC) in a 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).



(a) HPHT network



(b) LPLT network

Figure 1 - Suburban coverage: minimum transmitter EIRP required to achieve a SINR threshold of 10 dB as a function of the intersite distance ISD for different network configurations (MFN, SFN), transmitter heights ( $H_{TX}$ ) and cyclic prefixes (CP). (a) HPHT network (b) LPLT network

The coverage performance generally depends on the transmitter power and height, the system cyclic prefix for SFN operation (limited to 200  $\mu$ s in Release 14), the size of the coverage area and intersite distance 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 intersite distance), to an interference<sup>(4)</sup> limited scenario, where an EIRP increase does not produce significant SINR increase (saturation effect for very large transmitter EIRP or reduced intersite distance).

For a HPHT network, Figure 1a 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

<sup>3</sup> Average number, assuming 3.5 dB Rayleigh fading and implementation margin over Shannon limit.

<sup>4</sup> The interference comes from signal components from distant transmitters, with a propagation delay > CP

area propagation model is assumed and two CP values are considered: 200  $\mu\text{s}$ , as introduced by Release 14, in comparison with 300  $\mu\text{s}$  <sup>(5)</sup>, to assess the benefit that a further increase of the CP could provide. 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. very large frequency reuse factor).

The SFN power gain vs MFN is clearly visible (dotted versus continuous lines of the same colour) when the cyclic prefix 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 with adjacent transmitters. A *good-quality* coverage can be guaranteed with an ISD of 60 km and 12 kW EIRP for  $H_{\text{TX}} = 500$  m; in the case of  $H_{\text{TX}} = 200$  m a higher EIRP is necessary, and the effect of the shorter CP is more clearly visible. The required EIRP is of about 100 kW for an ISD of about 50 km and CP=200  $\mu\text{s}$ .

Figure 1b shows the simulation results for a LPLT network. The *good-quality* coverage could be guaranteed by the LPLT network (red curves -  $H_{\text{TX}} = 20$  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  $CR_{\text{HL}}$ ) was evaluated. In the examined cases,  $CR_{\text{HL}}$  is about 225 or 150, for a HPHT transmitter height of 500 m or 200 m, respectively, and 100 W LPLT transmitters. In the case of 500 W LPLT transmitters,  $CR_{\text{HL}}$  reduces to 100 or 70, respectively. Focusing on the Italian territory, the coverage of 170000  $\text{km}^2$  of flat suburban/rural areas by HPHT sites would theoretically require less than 100 broadcast towers (60 for  $H_{\text{TX}} = 500$  m or 87 for  $H_{\text{TX}} = 200$  m), instead of about 6000 or 13500 LPLT mobile towers, depending on their transmitted EIRP.

When considering the urban areas, for the HPHT network the maximum ISD reduces to

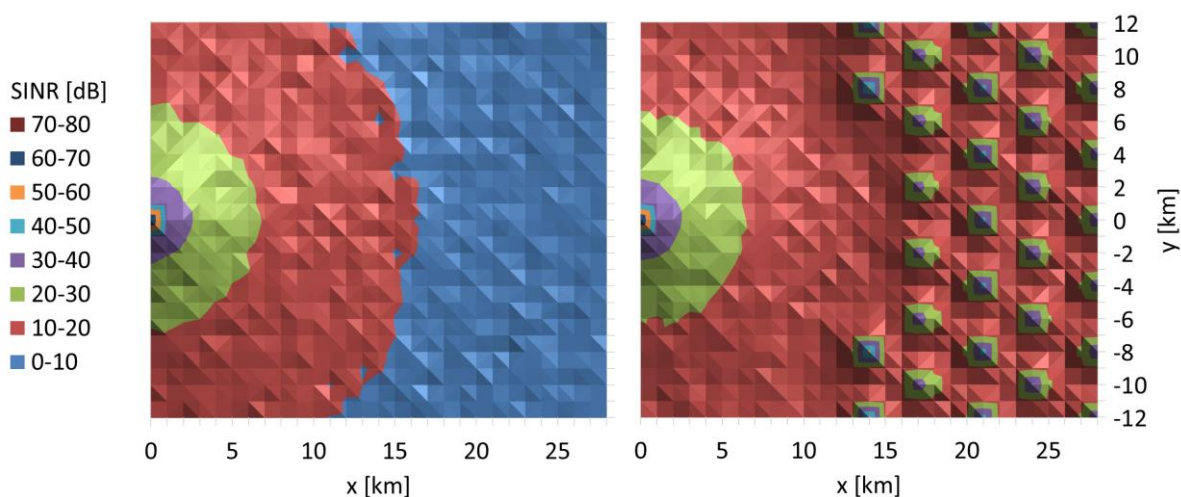


Figure 2 –SINR @98% vs distance from the HPHT transmitter in the urban coverage area for the HPHT only (left) and hybrid HPHT/LPLT (right) scenario vs the distance from the nearest HPHT transmitter, located in (0,0) (uneven LPLT peaks are due to sampling).

<sup>5</sup> DVB-T2 offers several CPs, up to 448  $\mu\text{s}$  for 16k-OFDM (this mode copes with moderate vehicular speed).

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 larger than 15 km cannot be covered by the HPHT network alone, and LPLT network cooperation is required <sup>(6)</sup>. Figure 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 Figure 1a; LPLT transmitters have been inserted from a distance of 15 km to 30 km from the HPHT transmitter, to complete urban coverage. The LPLT transmitters ISD is 2.5 to 4 km for an EIRP of 100 to 500 W (*good outdoor urban coverage*).

Again, taking the example of Italy, without the HPHT network, the coverage of 32000 km<sup>2</sup> 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 <sup>(7)</sup>, thus significantly reducing urban LPLT network costs and electromagnetic impact.

### Fixed reception

In order to assess the potential of 3GPP Release 14 for fixed reception and directive roof-top antenna, in comparison to DVB-T2, the investigation considers a target SINR of 19 dB, corresponding to DVB-T2 256-QAM with LDPC (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, Figure 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  $\mu$ s, as offered by 3GPP Release 14, in comparison

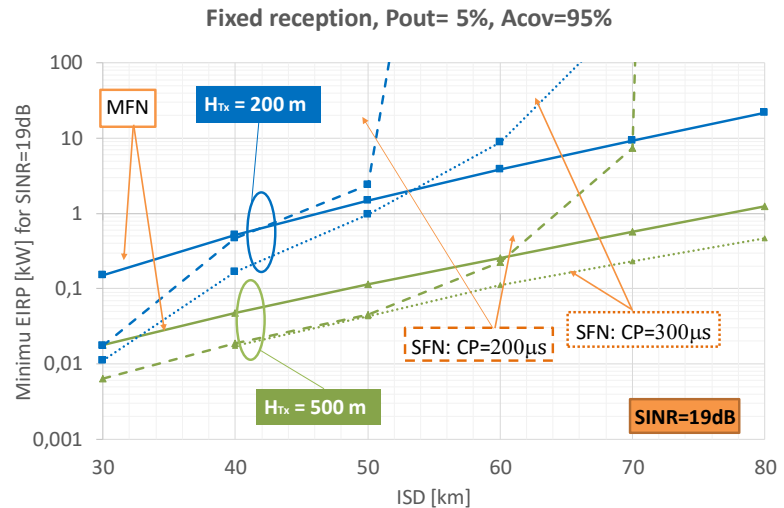


Figure 3 - Minimum transmitter EIRP required to achieve the SINR threshold of 19 dB in 95% of the coverage area with 5% outage probability as a function of the Intersite distance (ISD) for different network configurations (MFN, SFN), transmitter heights ( $H_{TX}$ ) and cyclic prefixes (CP).

<sup>6</sup> In a real network, there is the option to install new HPHT transmitters just outside towns, or exploiting the synergy with existing LPLT networks

<sup>7</sup> 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

with 300  $\mu$ s. 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 Figures 1a 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), 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 cyclic prefix CP is sufficiently high with respect to the ISD <sup>(8)</sup>. However, in this case the gain is not as high as with omnidirectional receiving antenna, because the directive antenna attenuates the useful contributions from surrounding transmitters: it can be as high as 4 dB for small ISDs, where the cyclic prefix keeps the network self-interference low, and reduces to 0 dB or becomes negative for larger ISDs. For CP = 200  $\mu$ s, 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 cyclic prefix values in future releases of the standard, to cope with larger intersite distances. Values aligned with those offered by DVB-T2 should be considered.

## 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<sup>®</sup> software allowed radioelectric 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 Figure 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

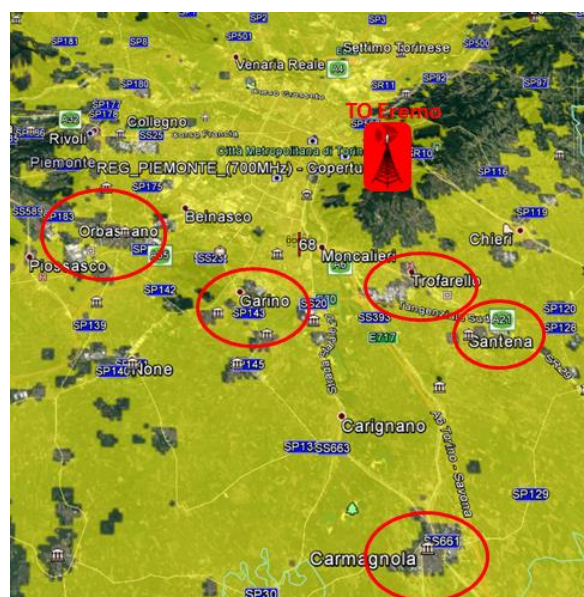


Figure 4 - Mobile TV coverage results relative to the area around Turin (Italy)

<sup>8</sup> 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.



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 cyclic prefix could be required.

## 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 FEC schemes) for moderate Inter-Site-Distances, and it is expected that next releases of the standard may introduce even larger cyclic prefix (up to 500  $\mu$ s) 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 inter-site distance 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 inter-site distance would be of about 2.5 to 4 km). Compared to 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 systems (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 relaunch 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 - 30 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.

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## ANNEX - THE SIMULATION FRAMEWORK

The SFN structure considered in the coverage evaluations is the hexagonal transmitter lattice of Figure 5, where N HPHT transmitters (N being the minimum number of elements for the network to be considered as ideally infinite) are regularly arranged according to a specified Inter-Site Distance. 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<sup>®</sup> programs implemented carry out Monte Carlo simulations to calculate the Signal to Interference plus Noise Ratio for each receiving point of the area under test, considering as interferers all signals having a delay above the CP duration<sup>9</sup>.

The propagation model is the one defined in Recommendation ITU-R P.1546-5 [3], which

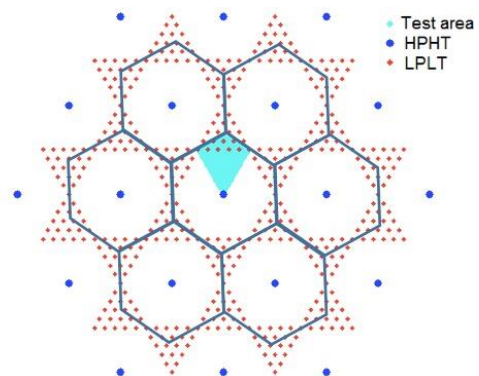


Figure 5 - Cooperative HPHT/LPLT transmitter configuration

<sup>9</sup> Assuming the equalisation interval, as defined in [4], being equal to the cyclic prefix. Depending on the channel estimation method, it could be as large as the symbol duration. So results in the paper could be considered as a worst case.

reports the curves of the field strength exceeded at 50% of the locations within any small area of approximately 500 m by 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 [4], 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 fixed roof-top reception at 95% and for 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 Figure 6), to reduce network self-interference, as typically done by real antennas: precisely, the maximum of 0 dB is set at  $0^\circ$ , -3 dB at  $1^\circ$ , then the attenuation increases linearly to -22 dB at  $3^\circ$  (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.

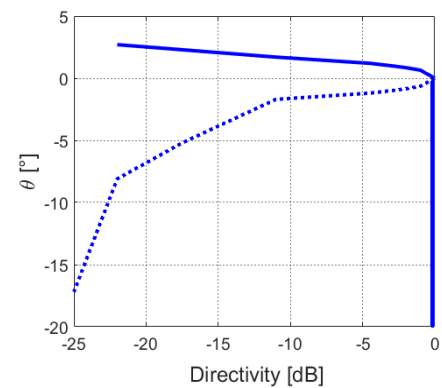


Figure 6 – Transmitter antenna directivity in the vertical plane (for tilt= $0^\circ$ )

The mobile receiving terminal is a handheld device typically considered at a height of 1.5 m with single antenna with a gain of -3.5 dBi, taken from the typical value considered in the literature [4] and assuming the presence of headphones extension. In the fixed roof-top scenario, the receiver is located at 10 m a.g.l. with a 9.15 dB gain<sup>10</sup> directional antenna, whose directivity pattern is defined in [5]: 0 dB in the range  $\pm 20^\circ$ , falling linearly from 0 dB at  $\pm 20^\circ$  to -16 dB at  $\pm 60^\circ$ .

Real coverage of the Italian territory has been calculated using the software module EMLAB<sup>®</sup> by Aldena assessing the radio-electric coverage using a detailed DTM (Digital Terrain Model) and Recommendation ITU-R P.1812-4 [6] propagation model.

<sup>10</sup> Value taken from [4] considering 4 dB cable losses.