On the coverage and cost of HPHT versus LPLT networks for rooftop, portable and mobile broadcast services delivery

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Abstract—The discussion around different network architectures, namely High Power/High Tower (HPHT) vs. Low Power/Low Tower (LPLT) for rooftop, mobile and portable indoor/outdoor digital terrestrial television service delivery. The analysis has been based on a practical network planning scenario. The results have been obtained with coverage simulations in the Basque Country, a region in northern Spain currently served with 64 transmitters of a traditional broadcast network. The results conclude that a LPLT network would require 3.3 more centers for providing the same coverage as the current HPHT network at a cost 3 times higher. Also, it has been observed that the current HPHT network fails to give portable and mobile coverage numbers close to real service targets in urban areas. In those cases, the approach with lower number of sites and cost is a mixed HPHT+LPLT network, where a set of LPLT transmitters complement the coverage provided by the HPHT network.


I. INTRODUCTION

T

HE nature of the best network infrastructure for providing terrestrial broadcast services is on the agenda of different technical groups within regulatory bodies and is being discussed worldwide [1][2]. The most appropriate standard is also a matter of analysis, with opposite views from the cellular [3][4][5] and traditional broadcast industries [6][7][8]. There are a wide range of factors that are fueling the discussions around this topic. In a moment where the broadcast UHF spectrum is under pressure for being partly (or completely) attributed to cellular broadband services [9][10][11], digital mobile broadcasting services, understood as a point to area service, are one of the key applications for the future of terrestrial broadcasting. Its roll-out involves significant network challenges if high percentage of the users is targeted at any time and any location [12][13].

Some studies have made attempts to compare the efficiency [14][15][16][17] and infrastructure requirements [18][19] of cellular networks versus traditional broadcast networks for this purpose[20][21]. Being portable and mobile TV services a potential key asset for the broadcasters of the future [22], it should not be forgotten that fixed reception will still be the main business and it will still be the reference service for a vast majority of broadcast content consumers [23][24]. This is especially true in countries where terrestrial is still the main means of television content delivery [25]. The feasibility of portable and mobile TV services has been studied after the standardization of DVB-H, mediaFlo and other early mobile broadcast standards [26][27]. Several proposals were made based on traditional broadcast networks. These studies analyzed the impact of increasing the ERP on the final coverage [28][29][30]. This technique is not appropriate for human exposure and power consumption reasons, especially in urban environments, not to mention that the coverage mismatch between indoor and outdoor coverage (20 to 40 dB) cannot be overcome by only by ERP corrections [18][30][31].

From a general standpoint there are two potential reference architectures for terrestrial broadcasting. The traditional broadcast network is mainly based on elevated transmitting sites that have effective radiated power (ERP) values in the range of dozens of kW. The typical elevation of transmitting antennas above the average height of the service area (h_{ ref }) is at least 150 m and quite commonly around 300 m. The range of heights and ERPs vary with the country, network operator and other factors, but the suggested values can be regarded as a reference. This network is usually named as High Power High Tower (HPHT) [2][16][17]. An alternative to this network is an infrastructure based on a network of transmitting sites at lower
heights, with shorter distance between transmitters and lower transmitter power. The $h_{eff}$ is lower than 40 m above average service area height and the transmitted ERP does not exceed a few kW. This network is regarded as Low Power Low Tower (LPLT)[2].

The objective of this paper is to provide objective comparison metrics for analyzing the potential advantages, disadvantages and associated cost of different network architectures: HPHT, LPLT and a mixture of HPHT/LPLT centers. The study will target three service types: fixed, portable (Class A and B for outdoor and indoor respectively) and mobile (Class C and D for in-vehicle handheld and vehicle built-in antenna respectively) reception and it will be based on a real planning exercise using existing HPHT and LPLT infrastructures [26]. The study is not tied to any specific standard (e-MBMS, DVB-T2 and DVB-T2 Lite). The work has assumed typical thresholds for fixed reception (C/N: 20dB) and portable/mobile reception (C/N: 6dB), and the network structure relies on those thresholds [6][7], ignoring the specific standard to deliver the contents. The comparison of efficiencies of different standards is out of the scope of this paper.

The main contribution of the paper is the provision of a realistic coverage analysis, network requirements and associated cost study of HPHT and LPLT structures following a clear and traceable methodology. In this sense, several studies have been published analyzing the advantages and disadvantages of delivering broadcast services with either HPHT or LPLT network architectures [16][33]. A major problem with these studies is their theoretical nature, based on lattice geometrical structures, not considering important aspects such as the impact of heterogeneous terrain and city structures. The study presented in this paper provides an analysis on a real case, using a large database of real HPHT and LPLT sites, for a planning exercise over a geographical area that exceeds 7000 sq km for a population coverage over 2 million citizens. The analysis includes a wide range of environments, terrains and population distribution. Moreover, the results of this study are not orthogonal to the information provided by the mentioned reports and provide a further analysis of practical implications and costs of HPHT and LPLT networks for fixed, portable and mobile television reception.

One of the conclusions where a consensus has been reached is the need for different network architectures for different services in different environments (urban, suburban and rural). The optimal network to provide high probability figures for fixed (97% of population), portable (90% of population) and mobile (90% of locations) receivers will not be the same in the three cases. This paper contributes with coverage comparisons of each service with different network structures in different scenarios.

The architecture of a broadcast network is a compromise between quality of service (in terms of coverage for each service) and associated cost. These two factors cannot be analyzed independently if the results of the analysis are to be applied to real network operation. The paper contributes providing reference ratios of number of transmitter sites, ERP and cost of different network architectures (HPHT, LPLT and mixed).

The paper is organized as follows. Next section describes the problem that this research is addressing as well as the methodology proposed to evaluate the different network options. Section III explains the simulation process, the planning parameters considered in the study as well as the cost model that will be used to compare the goodness of each network approach. Section IV contains the results of the study. Finally, Section VIII summarizes the major findings of the paper.

II. PROBLEM DESCRIPTION AND EVALUATION PROPOSAL

The analysis of the effectiveness of HPHT and LPLT approaches is resolved by evaluating the coverage and costs of each type of network on a real case that involves a large number of sites, a wide area (and served population) and enough diversity of reception scenarios to provide generic conclusions.

The exercise is carried over a geographical area currently served by 64 broadcast transmitting sites. As part of a real network, these broadcast transmitters have a wide range of effective heights and ERP values. The network structure is a classical hierarchical network, with several HPHT transmitters, and a few dozens of medium power and low power stations to provide a service to more than 97% of the population (fixed roof top antenna reception). For the sake of simplicity in explanations, this network will be referred as HPHT network.

A. Evaluation Procedure

The analysis will consist of several steps. The first one will be the evaluation of the potential of the existing HPHT network, currently designed for fixed reception, to provide portable outdoor (Class A), portable indoor (Class B) and mobile reception (Class C and D). The second step will be the planning of a new LPLT network using real sites (locations and heights) currently being operated by cellular mobile operators. The exercise will be repeated for fixed, portable and mobile broadcast services. A third step will consist of planning a hybrid network, composed by a subset of the HPHT network in conjunction with a subset of the LPLT sites, again for the three types of reception.

Each network solution will have associated a number of sites and overall cost, obtained with a cost model provided by the network operator company that includes all the items involved in real network deployment and operation. The conclusion of the study will be a comparison of coverage, complexity and cost of each solution.

B. Characteristics of the target service area

The study has been made analyzing the coverage in service areas of the region of the Basque Country (Spain), which has a total area of 7234 sq. km and a population of 2.19 million inhabitants (2012) distributed on 253 towns [27]. The population distribution is described in Fig. 1, representing towns with more than 1000 inhabitants.
The region is divided into three provinces, each of them with different geographical and demographical characteristics. The two provinces on the north are hilly with small valleys and irregular terrain, including coastal areas. The southern one has a wide plain with rolling terrain and mountains surrounding the plain by the south. These provinces represent different use cases for planning scenarios in real broadcast networks. Their capital cities and associated urban areas are marked as Urb.1, Urb.2 and Urb.3 and their major characteristics are summarized in Table I.

The first metropolitan area (Urb.1) comprises several cities over a continuous urban area with a total of 800,000 inhabitants. This area is surrounded by different mountains and hill ranges where various HPHT transmitters serving this area are installed. In this case, the transmitter sites are located at 400 m above the average service area height.

The second metropolitan area (Urb. 2) is a city on the coast, with irregular terrain and various hills that create coverage shadow areas for a single HPHT transmitter. Finally, the third area is a city on a plain, with regular design and wide avenues, located at more than 10 km from the nearest mountain, where the main HPHT transmitter serving the city is located.

There have been three candidate architectures, from a traditional HPHT network to a network exclusively based on LPLT centers. The third case stands in the middle, combining the HPHT with a selection of appropriate LPLT centers that complement the coverage of the traditional broadcast network for portable and mobile services.

III. SIMULATIONS

The procedure to evaluate each network configuration for each service target has based on optimizing each network model (HPHT, LPLT and Mixed) to achieve target coverage values.

The optimization of each network has been carried out using the same planning tools, network database elements, Digital Terrain Models (DTM) and digital map layers (i.e. building databases, population distribution, clutter, etc) used by network operators [28].

The coverage targets have been proposed by the network operator involved in this study and they are coherent with usual broadcast objectives. In fact, the coverage target for fixed reception has been raised to 97% of the population, in line with the fixed reception coverage of the current HPHT broadcast network.

The coverage in portable indoor scenarios has been set for 90% of population, whereas the outdoor portable and mobile coverage targets have been expressed in terms of outdoor location percentages (also 90% of locations). It should be noticed that population databases only match inhabitants to building areas and in consequence, rather than population, the target for any outdoor reception is a certain area probability.

Once the coverage was optimized for each network and service a cost model was used to compare the associated CAPEX/OPEX that each option would imply. Additionally, ratios of number of transmitter sites required by each solution with respect to the current 64 broadcast sites being operated in the region have also been used as one of the target comparison/evaluation criteria. Further details of the used databases, planning tools and cost model are given in the next subsections.

A. Databases

The coverage simulation procedure has based on three data
sets. The first involves the digital maps associated to the radio calculations and the population/coverage area statistics. The simulations are based on a DTM layer with 5 and 25 m resolution. This database is complemented with a vector layer of every building and associated population in major cities.

The second set of data is composed of the infrastructures of the broadcast network operator Abertis. This database comprises de the transmitter sites, antenna heights, current ERP values and antenna pattern of 64 transmitters. This network is composed of a few high power centers and a relatively dense set of medium and low power infrastructures.

The third set of data is a database with the location and height of every cellular communications site within the Basque Country [29]. This database is provided by the Spanish regulator and it has open access. The dataset is composed of nearly 1800 base stations. Before using this database for simulations, the authors checked individually with the position and height of each cellular site respect to the GIS used in this study in order to avoid misalignments among the different geo-referenced layers involved in the calculation process. While the position and candidate sites were restricted to the real sites, the ERP of each cellular site of the database was discarded. Finding optimal ERP values of the LPLT network for broadcasts services was one of the analysis targets.

B. Coverage Calculation Tools

The simulations were carried out using standard Radiocommunication planning tools, specifically the software package used by the network operator to carry out its current network planning [28]. Tables III and IV contain the link budget parameters have been based on the usual reference values. Reports on the same topic use similar references[31][33].

<table>
<thead>
<tr>
<th>Environment</th>
<th>Fixed Reception</th>
<th>Portable / Mobile</th>
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The field strength requirements for different reception modes provide a useful hint on the expected behavior of HPHT networks for indoor portable reception. There is a difference of 27.9 dB between the portable indoor and fixed reception thresholds (referenced to the rooftop antenna connection) that could be hardly compensated by increasing ERP.

### TABLE III

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Fixed reception infrastructure has been modeled under two assumptions. Whenever the building layer was available, the antenna height has been set to 4 meters above the roof top height. In reality, this value changes from building to building. The potential impact of incorrect assumption for this parameter was evaluated testing the coverage for 3, 5 and 10 m. above building height. The choice of 3 and 5 did not present significant differences in coverage whereas 10 m. provided rather optimistic results. The compromise value selected as the reference for this study was set to 4 m.

In the case of fixed reception the studies have been carried out twice. The first set of simulations uses building layer databases that are only available for main population centers in urban areas (Urb. 1, 2, 3 as described in Tables I and II). The second group of simulations is linked to rural areas, where the 3D building database is not available and thus some of the input data require different values for rural environments. Also, the
resolution calculation is slightly different in both cases: 5x5 m vs. 25x25 m. The propagation model for fixed rooftop reception coverage calculations is the ITU-R P.526 Recommendation [30].

The algorithm complements the free space loss with attenuation by diffraction considering different models for different profiles, depending upon the number of obstacles, their shape as well as the length of the transmitter – receiver path. In the case of portable and mobile coverage in urban areas the ITU-R P.1411 [31] was selected. This model differentiates LOS and NLOS paths, and includes reflections and diffractions including multi-screen attenuation, roof-to-street diffraction as well as possible tunneling propagation effects over the city building layer. This model is applicable whenever a 3D building database is available. In the studies included in this paper ITU-R P.1411 was applicable in service areas of Urb. 1, Urb. 2 and Urb. 3 where a 5x5 m building layer map was available.

The portable and mobile cases have been analyzed only in urban scenarios. Table III summarizes the planning values for rooftop fixed, portable (Class A, B) and mobile (Class C and D) services. The field strength planning value calculations have been based on two assumptions. First of all, the fixed reception will use current DVB-T planning values, assuming that the future transition to DVB-T2 will be based on similar C/Ns and thus with similar network architecture. The portable and mobile case has not assumed any specific signal or standard configuration and a reference minimum C/N of 6 dB has been supposed. This value is in line with potential implementations of mobile and portable services using either LTE eMBMS, DVB-T2 Lite or DVB-NGH [32].

C. Cost Model

The cost analysis associated to each center type involves either legacy Broadcast sites and new potential LPLT centers. This task has been performed using a detailed cost calculator. This tool includes CAPEX and OPEX costs using real data provided by the broadcast network operator involved in this study. These data can be grouped into several categories.

The first one comprises Broadcast RF equipment costs such as transmitter units, distribution lines, diplexers, antenna systems and similar modules. This part has been regarded as supply and installation goods part of the CAPEX investment and different redundancy options have been also considered. The model provides costs in this category for HPHT and LPLT sites, with HPHT options up to 1kW (transmitter power) and LPLT choices up to 100 W.

The OPEX costs include the transport subsystem operation (either microwave LOS links or fiber links) and it is a function of the required bitrate capacity and the link distance, which has been averaged depending upon the site location (rural/urban). Also, OPEX costs consider general maintenance as well as power supply costs that will be mainly depending upon the equipment output power. The model also takes into account equipment housing cost. In this case, the cost is a function of the type of site (HPHT and LPLT) as well as the place where the site is located (rural, town, medium size city and large city). Finally, the yearly cost of spectrum licenses, both for the broadcast UHF channel and microwave links (where applicable) has been added to the OPEX. The cost of each site thus depends upon the type of center (HPHT/LPLT), in terms of installation size, complexity and allocated ERP. Table V provides a comparison summary of the cost ratio (Cost\textsubscript{HPHT} / Cost\textsubscript{LPLT}).

<table>
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<tr>
<th>Cost Ratios between HPHT and LPLT Transmitters</th>
<th>LPLT</th>
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<tr>
<td>1W Gap filler</td>
<td>0.46</td>
</tr>
<tr>
<td>1W Transmitter</td>
<td>0.79</td>
</tr>
<tr>
<td>5W Gap filler</td>
<td>0.58</td>
</tr>
<tr>
<td>5W Transmitter</td>
<td>0.94</td>
</tr>
<tr>
<td>20W</td>
<td>1.43</td>
</tr>
<tr>
<td>100W</td>
<td>2.82</td>
</tr>
<tr>
<td>500W</td>
<td>4.46</td>
</tr>
<tr>
<td>1000W</td>
<td>5.54</td>
</tr>
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From Table V a comparison between the costs of HPHT and LPLT centers with equivalent ERPs can be made. Values show that LPLT centers involve higher costs than low power sites of the traditional broadcast network. The main difference in cost for the same power is due to housing costs and signal transport infrastructure in LPLT sites on urban environments. In the case of higher power values, which would be effectively the HPHT sites, the cost of traditional broadcast centers is much higher as previously expected.

The cost calculations have been carried out on a depreciation period of 10 years. The cost comparisons provided in the following sections are thus based on net present values associated to each network asset, considering investment, operation and maintenance over a period of 10 years.

IV. RESULTS

The results have been classified into two subsections. The first subsection provides the results, a comparison analysis and the conclusions on the coverage, associate network complexity (number of sites) and cost for fixed reception. In this first analysis, the coverage target is the current HPHT network coverage (97%), so the results apply to the LPLT network that would provide the same coverage. The number of sites and associate cost of this alternative is further developed.

The second subsection analyzes portable and mobile reception. As described in previous sections the coverage target is 90% of the population (portable indoor) and 90% of locations for portable outdoor and mobile modes. Two alternatives to the pure HPHT network are considered. The first one is a LPLT optimized for portable and mobile reception (reception Class A, B, C, D). The second choice is a Mixed HPHT/LPLT network, again with the LPLT sites optimized for portable and mobile reception.
A. HPHT versus LPLT for fixed reception

The original set of candidate locations for LPLT sites is the current cellular site database (1800 base stations), with a range of adjustable transmitter powers from 20 W down to 1 W. The transmitter antenna gain has been assumed constant (8 dBi) and the complete set of planning parameters can be found in Table IV. After site selection and power optimization an equivalent LPLT network would require 210 sites to provide the same population coverage percentage as the current 64 centers of the HPHT network for fixed reception over the entire region. This result is the outcome of simulations with a 25x25 m digital terrain model and the ITU-R P.526 model as described in Table IV (Section III.B). This gives a ratio of roughly 3.3 times more sites for the LPLT network.

The same analysis was repeated for urban environments, this time using the 5x5 m terrain grid map and a 3D building database. Variations of the number of sites needed to cover the three urban areas under study are shown in Table VI.

The distribution of the 210 sites into each ERP category and the associated environment is shown in Fig. 2. The distribution shows that the number of stations increases significantly in the case of small towns and rural environments, where HPHT broadcast infrastructures, mainly due to its heff advantage, show a clear gain in coverage with respect of LPLT stations.

The numbers show that in some cases, the number of LPLT stations that would be required to provide the same coverage to fixed receivers could be as high as 30 LPLT in the case of current broadcast sites significantly elevated over the service area.

This conclusion suggests a contradiction with numbers in Table VI, where the ratios between HPHT and LPLT are close to 3.3. The reason for the difference is the scope of each ratio. In Table VI, the ratio is referred to the whole network, which has been optimized to provide coverage to wide service areas (entire region in first place, and urban areas in the second). In consequence, provides the ratio for the entire network. Table VII illustrates a different idea, highlighting the number of LPLT transmitters to replace one HPHT site. This conclusion is relevant because it shows how different numbers are obtained if the HPHT vs. LPLT problem is analyzed from a theoretical point of view. In real networks, the number of total LPLT sites will be lower because some LPLT stations would be serving areas associated to more than one HPHT transmitter.

So far, the discussion is restricted to the number of LPLT sites (around 3 LPLT sites per each HPHT on average). If the network cost is brought into the picture, significant differences are found between both architectures. The result is that a cellular-type network needs 3.2 times more sites than a broadcast network whereas the cost of deploying and maintaining a LPLT network to provide fixed rooftop services is 3 times higher than the traditional broadcast network.

B. HPHT versus LPLT for mobile and portable reception

This subsection compares the requirements of HPHT, LPLT and Mixed HPHT/LPLT networks for delivering portable and mobile services. The simulations have been carried out over the service areas Urb.1, Urb. 2 and Urb. 3, using detailed building databases and appropriate propagation models for this type of environment (ITU-R P.1411). First, (study case 1, SC1) the coverage in urban areas using the current HPHT network infrastructure is analyzed. Study case 2 (SC2) is based on a new network, with LPLT sites. Next case, study case 3 (SC3) is a...
mixture of the previous solutions, where a mix between the current HPHT network complemented with LPLT sites is studied.

Regarding SC1, the portable indoor coverage numbers obtained with the existing HPHT network is on average a 40% of the population in urban areas. Only one of the towns under analysis provided figures close to 60%, whereas in some cases the achieved population coverage is lower than 10%. Fig. 3 illustrates coverage differences for each reception mode in some of the cities that compose Urb.1, 2 and 3 areas if a HPHT network is used. The mobile numbers are also below 60% (Class D) and never above 90% of locations (Class C).

These numbers confirm the concerns about the suitability of current network architectures for providing next generation mobile/portable services.

In SC2 and SC3, LPLT and HPHT/LPLT mixed networks were optimized and their associated cost was evaluated. Taking into account the field strength planning values in Table III, portable indoor is the most restrictive service, planning was made to achieve 90% of class B coverage. The number of sites needed for each case is shown in Table VIII. If compared with current HPHT site numbers in those areas there is a requirement of 4.45 LPLT sites per HPHT center. In some cases, where the HPHT site is kilometers away from the urban area (see Urb.3) its influence on the portable/mobile coverage is negligible and a full network of LPLT sites (44) is required in this city.

If a mixed approach between HPHT and LPLT would be taken, using 6 HPHT transmitters for portable/mobile coverage services, the cost is reduced on an 11% with respect to the LPLT only configuration. If the HPHT centers are not included in the cost calculations of the mixed mobile/portable network (they will be part of the fixed coverage anyway) the mixed network is 26% cheaper than a full LPLT one.

Combining the results obtained for the LPLT targeting fixed reception (Section VII.A) and the results for portable and mobile in urban environments (Section VII.B) the total number of sites would be 210 + 75 LPLT centers. This network would replace the existing 64 HPHT sites, providing similar coverage percentages for fixed reception and 90% of portable indoor/mobile in major urban areas of the region under study. The cost of this LPLT network would be 4.29 times the existing HPHT.

V. CONCLUSION

This paper has provides a comparison between HPHT and LPLT architectures based on studies carried out using service areas and network infrastructures in a region equivalent to 7000 sq. km and 2 million inhabitants. The analysis is based on coverage and associated cost of current broadcast infrastructures (considered HPHT) and existing cellular sites converted into Broadcast facilities (LPLT). There have been two main comparison metrics: the ratio between HPHT and LPLT sites to provide the same coverage under same reception conditions and the cost of each network approach.

The results show that the current HPHT network is the best option for fixed reception coverage. The current broadcast network needs 3.3 times less sites. Its cost remains 3 times lower than the cost of the equivalent LPLT network, while guaranteeing better coverage. Regarding mobile and portable services the current HPHT network is suitable to provide a base coverage (around 20-40%), especially outdoors, for mobile or portable services but it would be far not guaranty expected coverage targets (90%) no matter the case.

If we focus only in urban environments, LPLT only and HPHT+LPLT for mobile and portable reception require 7-8 times more sites than the number of existing HPHT centers. The best coverage results have been obtained the mixed HPHT+LPLT configuration with a cost that depending upon the assumptions it can be as much as 26% lower.

Considering a global network for both fixed, portable indoor and mobile coverage the LPLT network would require 210 centers for fixed reception plus 75 additional sites for providing 90% coverage to portable and mobile receivers. The cost of this network would be 4.29 times the current HPHT infrastructures.

Further work following this study will focus on the study of additional factors that will also have to be considered when defining the efficiency of different broadcast standards under different use cases and network conditions.

REFERENCES


