NETWORK PLANNING FOR DELIVERING DIGITAL TELEVISION TO MOBILE AND PORTABLE DEVICES: A HYBRID BROADCAST AND CELLULAR APPROACH

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Abstract

This paper describes a methodology for planning digital television services for mobile terminals. The work is based on planning scenarios for DVB-H systems, but the basics of the methodology and most of the results can be easily extrapolated to other systems such as MediaFLO. The paper provides a methodology that allows a gradual deployment of digital terrestrial television networks to mobile receivers as a function of the macro-scale coverage goal. Specifically, the model tries to reduce the initial cost of the network deployment in an urban environment, taking advantage of the use of two different network infrastructures: the DTV broadcast network and the 2G/GSM or 3G/UMTS cellular network infrastructure. Both networks have different characteristics which can be used in a cooperative way in order to improve the coverage vs. cost ratio. The paper presents the procedure to achieve coverage at high percentage of locations starting with the infrastructure installed at the broadcast network sites at urban environment.

Keywords

Digital Television, Mobile Services, DVB-H, Network Planning, Coverage Estimation

INTRODUCTION

Mobile digital television services are nowadays one of the most interesting questions for broadcasters and content providers.

There are several technical possibilities for delivering this type of services. Among them, the use of 3G cellular networks, such as UMTS/HSDPA [23], is one of the worth mentioning. Nevertheless, the massive access of users to the mobile television (“mobile TV”) services by the cellular networks would imply the demand of an excessive amount of resources. Nowadays, the scale of the cellular networks that would be necessary for providing this service makes this solution unfeasible at a reasonable cost.

A more feasible choice can be based on the use of the existing broadcasting networks [9], where the necessary resources, and therefore, the budget, are not so directly dependent on the number of users. The standard DVB-T [1], successfully used for digital television broadcasting services in many countries, has proved the capacity of providing services for mobile reception to certain extent, especially when reception diversity is included [10]. However, this standard has shown some limitations. The main objections lie, first, in the excessive power consumption of the batteries employed in today’s terminals and second, the limited robustness in indoor or mobile reception for receivers without reception diversity. It should be also mentioned the low efficiency of current antennas on handheld devices.

The DVB-H standard [2]-[4], [8] was defined as an enhanced system in order to overcome these difficulties. This system takes advantage of the strengths of DVB-T and improves the weak points related to the mobile TV services. For this purpose, new technical features were included in the standard, mainly in the link layer, such as:

“Time Slicing” – Mechanism for time division multiplexed transmission of the programs that compose the DVB-H multiplex. Unlike DVB-T, where all the programs are transmitted in parallel sharing the channel throughput, in DVB-H each program is transmitted in periodic short bursts at a high throughput. Using this procedure, the receiver operates only during the burst intervals, which allows a significant power saving (up to a 90% in comparison with DVB-T), and therefore, an appropriated use of the battery.

“MPE-FEC (MultiProtocol Encapsulation-Forward Error Correction)” – Algorithms that enable the error correction in the receiver, caused by channel impairments. These algorithms allow a better service quality both in mobile

reception and in reception conditions with high level of impulsive noise (a usual situation in urban environment).

The physical layer in DVB-H is similar to DVB-T, except for some differences in the signaling process, the use of an additional interlace and the introduction of the 4k mode. This mode is configured with intermediate values with respect to 2k and 8k modes, in order to achieve a trade off between the maximum distance between adjacent transmitters in Single Frequency Networks (twice as long with respect to 2k mode), and the maximum reception speed (twice as fast with respect to 8k mode). This configuration allows a greater flexibility in the DVB-H networks design, and makes possible the broadcasting of services at a higher speed or at higher frequencies (L-Band).

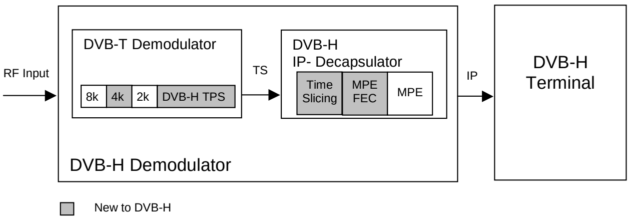

Fig. 1. DVB-H receiver architecture.

The standardization of the DVB-H system started in 2002 with the definition of the commercial requirements. In 2003, the DVB Project (www.dvb.org) appealed for the development of technological proposals that laid the foundations of the standard DVB-H, published in 2004 [2]. In March 2008, the European Union endorsed DVB-H as the recommended standard for the mobile TV service in Europe. Nowadays, the mobile TV service based on DVB-H is available in some countries. There are more than 50 experimental transmissions, and the commercial launch has been announced planned for 2008 in several places of the world [14].

In this paper the methodology and the architecture for a gradual and economical deployment of a DVB-H network are proposed. Both conditions are considered as key factors by the broadcasters and the service providers.

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The studies about the design of this kind of networks are scarce. The most significant work was carried out by D. Gómez Barquero [5]-[7], where a DVB-H network architecture for urban environments that uses the existing DTV broadcasting and the mobile telephone infrastructure is presented. This work proposes a network planning methodology based on a multipurpose genetic algorithm, which optimizes the cost vs. coverage ratio. The mentioned authors assume that the cost vs. coverage ratio can be optimized depending on a quite wide range of possible transmitter power levels.

The above-mentioned method has an important drawback in its implementation for DVB-H. Following a cellular network planning approach: the range of transmitted power levels that can be installed on reality is actually very small. Moreover, the maximum transmitter power is limited by several factors. First, there are maximum values established by European (and worldwide) regulations regarding human exposure to electromagnetic fields. Second, transmitting antennas in urban environments are usually located at heights that are not significantly different than the average roof level. In this case the propagation is determined by diffraction and scattering on the urban morphology, and consequently, there are many situations in which an increase in the transmitted power entails a very limited increase in the coverage area. For these reasons, the transmitted power in the cellular infrastructure is not considered as a variable value in the proposed methodology. The planning methodology proposed in this paper tries to obtain accurate results which ensure the maximum correlation between predicted and empirical values when the system becomes operational. In this way, the procedure focused both on the link budget and on the propagation methods.

The paper is structured in nine sections. The first part describes a general approach to DVB-H and defines the context of the study. Next, the objectives of the paper and coverage definitions are outlined. In the fourth section, the design possibilities of the network architecture for providing DVB-H services are discussed, and a stand-alone DVB-H network is proposed as the best solution for urban environments. In the fifth and sixth sections, the link budget and the more suitable propagation methods for the design of this kind of networks are explained. Next, a design methodology based on the cellular network planning is proposed, and a case study for medium size city is then solved. Finally, the conclusions of the study are summarized.

OBJECTIVES

The main goal of this study consists of developing a planning methodology for DVB-H networks in urban reception environments, based on the collaborative use of DTV broadcasting and 3G cellular network infrastructure (Transmitter sites). The methodology must allow a gradual and cost-effective deployment. The planning procedure tries to adapt regular mobile telephony network planning to the specific characteristics of the DVB-H networks and services.

The main goal of the study can be divided into the following partial objectives:

- Analyze the possible network architectures, and determine the most efficient solutions.

- Evaluate the advantages and drawbacks of the coverage estimation algorithms when they are applied to the DVB-H networks planning.
- Specify the steps of the planning methodology of DVB-H systems in urban environments.
- Determine the more suitable values for the parameters of the DVB-H network configuration, as a function of the coverage criteria.
- Define the best radio configuration for DVB-H sites related to the transmitter site, such as frequency, transmitter power and antenna configuration.

COVERAGE SPECIFICATION

The nature of the DVB-H services allows a great diversity of transmission modes. Nevertheless, for planning purposes, they can be simplified to the following cases [3]:

***Portable reception* –** The receiver stays fixed or moving at a very low speed (walking). It is usually considered that the portable receiver is not moved during reception [3]. The portable reception occurs mainly in urban areas. There are two types of portable reception:

- Class A: Outdoor reception, when the receiver is located at no less than 1.5 meters above ground level.
- Class B: Ground floor indoor reception where the receiver is located at no less than 1.5 meters above floor level, with a window in an external wall.

Mobile reception – The receiver is moved at medium to high speed (no walking speed). There are two kinds of mobile reception:

- Class C: Outdoor reception, when the receiver is located at no less than 1.5 meters above ground level (for instance, antenna integrated in a car).
- Class D: The receiver is located inside a vehicle (bus or train), at no less than 1.5 meters above ground level.

This study applies the definition of coverage described in the DVB-H implementation guide [3]. According to this specification, the coverage area is composed of 100m x 100m cells, named “small area”. A small area is composed of 0.5m x 0.5m areas, designated as “receiving location”. A receiving location is regarded as covered if the required C/N and C/I values are achieved for the 99% of the time. The coverage of a small area is classified as:

Good – If at least 95 % of receiving locations at the edge of the area are covered for portable reception and 99 % of receiving locations within it are covered for mobile reception.
Acceptable - If at least 70 % of locations at the edge of the area are covered for portable reception and 90 % of receiving locations within it are covered for mobile reception.

In order to characterize the quality of the mobile reception, where the time variation is significant, the standard DVB-H includes a degradation criterion named MFER5 [5], [11]-[13]. This criterion means that a 5% of the total number of frames is erroneous (after MPE-FEC correction). The criterion MFER5 is used to mark the degradation point of the DVB-H service.

The threshold values for “good coverage” and “acceptable coverage” considered in this study are those proposed by the DVB-H implementation guide [3] for each kind of service. These threshold values are based on the MFER5 criterion, although this criterion could be revised in the future after the analysis of a considerable number of results from field trials.

NETWORK ARCHITECTURES

The DVB-H standard considers the use of different network configurations, as it can be seen in Fig. 2 and Fig. 3. It is possible to use the DVB-T infrastructure for broadcasting both DVB-T and DVB-H services. For this purpose, two possibilities are viable. In the first one, DVB-H services share the multiplex with the DVB-T services. In the second one, DVB-T hierarchical modulation can be used for transmitting in parallel the DVB-H services (in a high priority stream, with a more robust modulation and a lower throughput) and the DVB-T services (in a lower priority stream and a higher throughput).

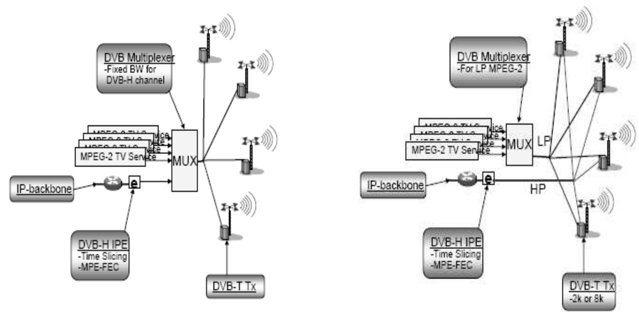


Fig. 2. Network architecture for the transmission of DVB-H services based on the use of the DVB-T network, sharing the multiplex or using a hierarchical modulation. ***Figure as appears in DVB-H standard [3].***

Both solutions allow a fast introduction of DVB-H services. In any case there are several limitations:

- DVB-H high coverage percentages can not be achieved in urban areas where building and vehicle indoor coverage is a requirement. DVB-T networks are traditionally designed for fixed coverage with roof antennas.
- DVB-H can use the same frequency band as DVB-T (UHF Band 470-862 MHz) but in order to guarantee the coexistence with GSM-900 services, the useful

band is reduced until 700 MHz. Therefore, it could be necessary a frequency re-planning for DVB-T networks when DVB-H services are added to the existing DVB-T services.

For these reasons, it is more convenient an independent DVB-H network design, much denser than in DVB-T. The density correlates with indoor signal level distribution requirements.

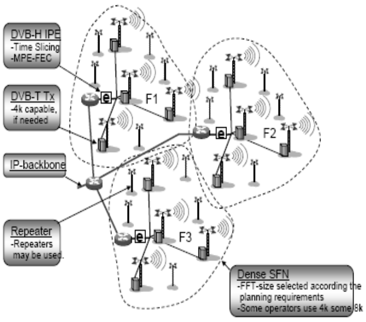


Fig. 3 Independent DVB-H network architecture. ***Figures as appears in DVB-H standard [3].***

In order to save cost and time in DVB-H network deployment, it will be interesting to start using DVB-T existing infrastructure for DVB-H transmitter installation. Usually, DVB-T sites are located at high spots and a first coverage layer can be achieved from them. This primary coverage can be completed with sites that today are used by cellular networks. These networks are usually very dense in urban areas in order to supply 3G services (300-500 m coverage radius in an urban area), with less dominant sites (height not much higher than building roofs), and can supply a continuous coverage layer. This mixed solutions has been already suggested in the literature [5]-[7].

PROPAGATION PREDICTION TOOLS

Digital Terrestrial Television services to mobile receivers and cellular communications share various characteristics: mobility, indoor coverage requirement, a significant variability of the received levels. The methodology presented in this paper proposes that the DVB-H network shares some of the transmitter sites belonging to the 2G and 3G networks. Considering the similarities between both services and networks, and taking into account that they will also share part of the network infrastructures (sites), the propagation prediction tools used for cellular services might be good candidates for estimating the mobile digital terrestrial television coverage. This approximation should not be considered obvious. The cellular services operate at different frequencies and it should not be forgotten that DVB-H is a broadcast service.

The coverage simulations presented in this paper were performed using a customized network planning suite. This tool has been widely for planning 2G (GSM) and 3G (UMTS) services. This suite includes a wide range of propagation prediction tools of various types: empirical, semiempirical and deterministic. In the following section, the convenience of each propagation prediction model for planning DVB-H services in urban environment is discussed with an emphasis on identifying both advantages and disadvantages of each algorithm.

Empirical Models. Okumura-Hata

Those models are based on a plane earth propagation model that is modified by means of empirical correction factors. The correction factors are obtained from measurement data. One of the most representative empirical models is the Okumura-Hata formula [15]. This algorithm was modified with extensions provided by the COST231 [16] research action. The computational resources and complexity of this model are very low. At the same time, the performance is acceptable for predicting coverage in rural and semiurban environments. The algorithm requires digital terrain and clutter databases. The performance of Okumura-Hata is always dependent on the adjustment of the correction factors with real measurements inside area under study. Typical values of the standard deviation of the error are in the range of 10 to 14 dB. This method is useful to plan wide areas (national coverage) in order to obtain a first approximation of the coverage percentages; in any case, Okumura-Hata is not algorithm adequate for planning urban environments. The buildings and other structures in a city are not considered in the calculation process, leading to unacceptable error values.

Semi-empirical Models. Walfish-Ikegami and Xia-Bertoni

The semiempirical models can be considered as an evolution of the empirical models. They provide a better estimation of the propagation losses in urban and suburban environments by considering the additional losses due to diffraction and reflection. Those effects are caused by the group of buildings and urban structures in the transmitter-receiver path. The loss is divided into two components. The first one is associated to diffraction and reflection on the roof of the building along the propagation path (multiscreen diffraction loss) and the second one is associated to the scattering and reflection in the vicinity of the receiver (roof-top-to-street diffraction and scatter loss). The latter is calculated based on the median height of the buildings and the median width of the streets in the study area. Representatives of this type of models are COST-231 Walfish-Ikegami [17], [18] and Xia-Bertoni [19].

The semiempirical models have a moderate complexity and require moderate calculation resources. Their results are good in suburban environments and acceptable in urban environments, provided a previous adjustment of the model constants based on field measurements in the area under study. The standard deviation of the error associated to the semiempirical models is close to 8dB. The disadvantage of these methods is the requirement for building geometry databases (3D cartography). The tools used by telecommunication operators provide default parameters that try to overcome the lack of building databases, but in this case the prediction error increases significantly. The semiempirical models where discarded for obtaining the final results of this paper, mainly due to the fact that they have not been developed for the UHF band below 700 MHz. Another disadvantage for using the semiempirical methods for planning DVB-H services is the typical effective height of the transmitter sites used for broadcast services; usually well above the roofs and out of the range of heights allowed by the model. It should be also taken into account that for those sites close to the mean height of the building roofs, the above mentioned 8 dB increases significantly.

Deterministic Models. Vertical Plane Ray Tracing.

The models based on ray tracing techniques use an approximation of the Maxwell equations. They use a combination of geometric optics and diffraction theory. These methods consider that the propagation can be modelled by a set of signal “rays” that are originated at the transmitter with a certain angular resolution on the horizontal plane (between 1º and 5º). Each one of the launched rays interacts with the terrain and obstacles causing diffraction or reflection. A reflection originates a single ray but diffraction generates again a set of rays that propagate in every direction. In any case, a reflected or diffracted ray can suffer again successive reflections or diffractions. Among all the rays originated only a limited number reaches the receiver. The field strength at the receiver input is calculated as the vector combination of all these rays.

The ray tracing techniques can be applied following a three dimensional model of the propagation path or using two planes where calculations are carried out independently for each plane, horizontal and vertical (2D+2D models). When the transmitter effective height is above the mean building roof heights, it is usual to carry out the calculations associated to the vertical path, disregarding the horizontal plane calculations. In this case the algorithms consider the direct ray (in LOS cases), the ray reflected on the ground, and the rays diffracted on the building roofs. The methodology proposed in this paper considers a mixture of broadcast and cellular transmitting sites, which in both cases are above the roof top of the buildings and then use the vertical plane ray tracing model is proposed. [21]

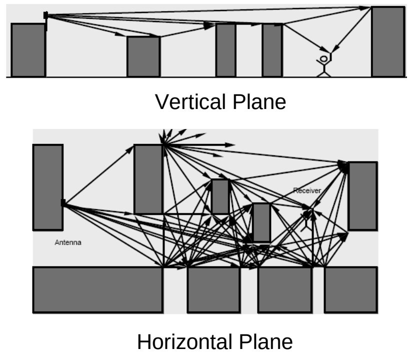


Fig. 4 Geometry of the ray tracing model 2D+2D.

Most of the ray tracing algorithms are quite complex and require a big amount of calculation resources. On the other hand, these methods provide the best accuracy in urban environments even in the case where calibration with measurements is not possible. If the models are calibrated with measurements, the standard deviation of the prediction error can be as low as 5 dB. These advantages made the authors select this type of models as the best candidates for the present study. In the same way as the semiempirical models, the ray tracing algorithms require digital terrain and building databases. These databases were included in the tool used to carry out the present work.

LINK BUDGET

This section describes the calculation of the link budget for different DVB-H reception scenarios. The discussion of the methodology of the link budget is a previous requirement for planning the DVB-H network and is associated to the discussion of suitable service thresholds. The link budgets have been calculated at two frequencies: 500 and 700 MHz, which in many countries are close to the limits of the frequencies assigned to DVB-H services. The most significant difference between both frequencies is on the efficiency of the receiving antennas inside the DVB-H receiver. The antenna gain reference values have been extracted from the DVB-H implementation guidelines report [3], publicly available from the European Telecommunication Standards Institute (ETSI). The differences in the antenna gain produce more restrictive thresholds in the 500 MHz band for both “good” and “acceptable” coverage (70% and 90% of the locations respectively as defined by the ETSI). On the other hand, the propagation losses are higher for the 700 MHz band. This fact compensates the antenna efficiency differences leading to similar coverage distances.

In any case, if an optimum frequency band was selected, the lower frequencies would be probably more appropriate in order to avoid any interference between GSM-900 and DVB-H chipset modules (especially on the tuning stages) for receivers that have both services integrated in the same device (probably a majority of the future receivers in the market).

The DVB-H parameter combination considered for this study was presented in a previous section:

- Channel bandwidth BW=8 MHz
- Transmission mode: 8K, GI=1/4
- Subcarrier modulation: QPSK, Code Rate 2/3
- Additional protection rate: MPE-FEC 3/4

The C/N threshold values have been obtained from the DVB-H implementation guidelines [3]. The building penetration losses and inside vehicles have been considered 11 and 7 dB respectively with a standard deviation of 6 dB [3]. The transmitting antenna gain has been set to 8 dB, which is a typical value for horizontally omnidirectional antennas in the UHF band.

It is important to stress that the link budget calculations proposed in this paper, take into account the effect of the prediction error standard deviation (5dB for ray tracing techniques) by means of a lognormal margin. This is a common practice when planning mobile services, but has not been widely applied when planning digital broadcast systems.

Assuming that the spatial variation of the received field strength level and the prediction error follow a lognormal function and considering that both phenomena are independent variables (which might not be true for all cases) the overall deviation is can be calculated by means of a quadratic sum as shown in Table 1. The calculations in Table 1 are intended for good coverage.

	Class A	Class B	Class C	Class D
Good coverage target L2%	95%	95%	99%	99%
K(L2%)	1,64	1,64	2,33	2,33
Outdoor deviation (dB)	5,5	5,5	5,5	5,5
Indoor deviation (dB)	0	6	0	0
Predicction error deviation (dB)	5	5	5	5
Total deviation (dB)	7,4	9,6	7,4	7,4
Good coverage target - Lognormal margin (dB)	**12,2**	**15,7**	**17,3**	**17,3**

Table 1. Lognormal margin calculation for "good coverage" scenarios"

Table 2 shows a link budget example for a DVB-H service at 500 MHz, broadcasted using 50 W from a transmitting site that belongs to the 3G network.

The link budget allows designing efficiently the planning margins and at the same time, using the Okumura-Hata model, provides a quick approximation of the coverage radius. In this case, the use of DVB-H services inside vehicles has not been considered as relevant in the first phase of system deployment, and the emphasis has been put on class B reception (portable indoor). This approach suggests a coverage radius of 2 km, for DVB-H services broadcasted from traditional DTV sites (1 Kw) and a radius of 0.5 km for transmitters installed on 3G cellular sites (50 W). This first result suggests a dense network for delivering DVB-H services in urban environments for indoor portable reception. The density of transmitters will be similar to the one required by the 3G services.

Variable	Units	Class A	Class B	Clase C	Class D
f	MHz	500	500	500	500
20log(f)	dB	54,0	54,0	54,0	54,0
PTx	dBm	47	47	47	47
GTx	dBi	8	8	8	8
LTx	dB	3	3	3	3
PIRE	dBm	52	52	52	52
Ga	dBi	-12	-12	-2	-12
Lgsm	dB	1	1	0	1
LRx	dB	0	0	0	0
KToB	dBm	-105,2	-105,2	-105,2	-105,2
F	dB	6	6	6	6
C/N	dB	6,3	9	15,5	15,5
Pinmin	dBm	-92,9	-90,2	-83,7	-83,7
Lb/Lv	dB	0	11	0	7
Pmmn	dB	0	0	0	0
Gdiv	dB	5	5	5	5
Cl1	dB	3,9	5	9,5	9,5
Cl2	dB	12,2	15,7	17,3	17,3
Acceptable coverage thresholds					
Pmin1	dBm	**-81**	**-66,2**	**-77,2**	**-59,2**
Emin1	dBu	**50,2**	**65,0**	**54,0**	**72,0**
Lp1	dB	133	118,2	129,2	111,2
R	Km	2,8	1,1	2,2	0,7
Good coverage thresholds					
Pmin2	dBm	**-72,7**	**-55,5**	**-69,4**	**-51,4**
Emin2	dBu	**58,5**	**75,7**	**61,8**	**79,8**
Lp2	dB	124,7	107,5	121,4	103,4
R	m	1,6	0,5	1,3	0,4

Table 2. Link Budget for a 3G site f = 500 MHz

PLANNING METHODOLOGY

The methodology proposed in this paper for planning DVB-H services is based on a shared use of transmitter sites that belong to 2G and 3G networks. The coverage target will be urban environments and the planning procedures will be based on the network design for cellular communications, modified when necessary to account for DVB-H service peculiarities. Figure 5 summarizes the network planning process flow

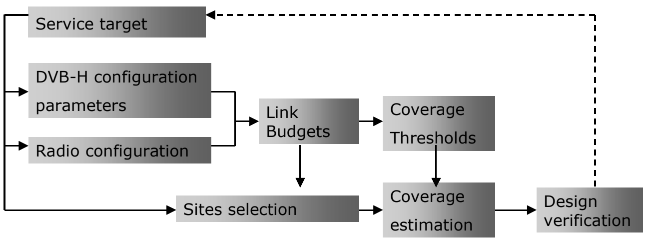


Fig.5 Urban DVB-H network design methodology scheme based on DTV/3G mixed solution

Service specification

The starting point of the planning process consists of setting the DTV service targets (coverage and service specifications). The most relevant aspects that should be specified at this stage of the planning process are the following:

- *Coverage target* – The minimum percentages for "acceptable" and "good" coverage have to be specified within the study area for each one of the service types: portable outdoor, portable indoor, mobile inside vehicles and mobile (A,B,C, and D) The network design can be carried out following an scalable model, where an initial deployment with a minimum investment is made. This initial deployment will require coverage targets not very ambitious, especially for Class B indoor portable reception which will be the most demanding scenario in terms of network infrastructures, and later on as the service penetration increases, increase the density of the network with more infrastructures that provide higher coverage percentages.
- *Mobility* – In the case of considering mobile reception with a vehicular built-in receiver or a portable receiver inside a vehicle (for example inside a bus) it is required to specify the maximum speed for which the services should be available. The speed and associated Doppler effect will have to be considered when selecting a DVB-H mode, that will affect directly to the maximum transmitter distance in Single Frequency Networks.
- *Capacity* – The throughput required for delivering a certain number of services will be dependent on the DVB-H parameter combination as a compromise between signal robustness and bit rate. Specifically the critical parameters will be the modulation scheme, guard interval and data redundancy.

DVB-H parameter choice

Once the service targets have been set, the next step will be the specification of the DVB-H parameter choice based upon the mentioned specifications. In the case of the work presented in this paper the combination is one of the choices that will be most likely selected for deploying the first DVB-H networks, according to the compromise between robustness and throughput [4]. Table 3 summarizes the parameter set.

Parameters	DVB-H
Channel Bandwidth	5,6,7,8 MHz
FFT Mode	8k,4k,2k
Guard Interval	224, 112, 56 ,28, 14, 7 us
Modulation	QPSK, 16QAM, 64QAM
Proteccion Mecanism	Convolution Code + RS FEC + MPE-FEC
Inner code rate	1/2, 2/3, 3/4, 5/6, 7/8
MPE-FEC code rate	1/2, 2/3, 3/4, 5/6, 7/8 (optional)
Virtual Time Interleaving	2KiDi8K, 4KiDi8K (optional)
Theoric Bit Rate (Mbits/s)	4,98 - 31,67 (@8MHz)

Table 3. Key DVB-H configuration parameters

- *Bandwidth*– The bandwidth will be most likely specified by the Digital Television plan of the country where the service is being deployed. In the case of Spain, the channel width is 8 MHz.
- *Operation Mode* – The choice of the operation mode is a compromise between the maximum distance of the transmitters within a SFN and the maximum speed of the receiver. In an urban environment of a medium size city the SFN distance will not be a restriction. Also, within the city, high vehicle speeds should not be a requirement. Consequently the mode 8K has been selected as it behaves better in the presence of impulsive noise.
- *Modulation and Channel Coding.* – The use of higher order modulation schemes (16-QAM y 64-QAM) provides a higher multiplex capacity, but it also requires better C/N ratios at the input of the receiver. At the initial stages of the DVB-H services introduction, it is considered adequate to use QPSK. The channel coding is suggested to be set to CR=1/2, MPE-FEC=3/4, which provides, as explained in [4], a balance between capacity and robustness.

Network RF Parameter Configuration

Usually, in the planning process of cellular services, and as a previous step before the calculation of link budgets, the radiofrequency parameters of the transmitters are specified. This configuration refers mainly to the type of radiating system (antenna and feeding network) and the output power of the transmitters that will be used. As a preliminary approach, the radiating systems will be supposed omnidirectional in the horizontal plane for all the transmitters of the DVB-H network, (existing DTV sites and new candidates from the 2G and 3G networks). The transmitter power will be different depending on the type of site.

Existing DTV sites are usually located at a dominant hill or tower. Usually, those locations are furnished with electric mains infrastructure capable of delivering several dozens of KW/h. The rooms where the transmitting equipment is installed has a system to maintain constant temperature and humidity. Those sites are prepared for installation of transmitters in the range of dozens of KW. On the other hand, the sites used for cellular networks, especially in urban environments, are located mostly on top of a building roof, or mounted on a 20-30 m. high tower, over the building roof heights. The maximum transmitted power from the cellular sites is usually controlled by the regulator in order to avoid human exposure to high power radiations. This regulation is different from country to country, but most of them work in the same range of radiated power. In the case of Spain, the radiation limits are set by the act RD 1066/01 [22]. It should be also considered that the infrastructure available at these sites in urban environments, from the electrical lines and temperature regulating systems, does not allow the installation of high

power transmitters. Moreover, the cellular transmitter sites are not usually dominant locations over the building and terrain heights, so the use of high power transmitters does not correlate with wider coverages because urban obstacles cannot be overcome just by increasing the output transmitted power.
Having analyzed all the factors relevant to the network RF configuration, the transmitter power that will be considered for those DVB-H sites collocated with 2G-3G systems will be in the range of dozens of Watts, which, at the same time is the typical 3G output power in urban environments.

Site Selection and Design Check

After the DVB-H parameters and the Radio Frequency parameters of the network have been specified, the link budget can be calculated and the number of sites required to provide a coverage area according to the initial target. As described in previous section, the DVB-H network will be composed by two types of sites: a few (in many cases less than two) sites that are being used by current DTV services, usually with effective heights well above the users' building roofs, and the sites that are currently being used by cellular operators, located on top of the roofs of the buildings inside the city. In this process, if there are only one or two DTV transmitting sites, the adequate selection of the transmitter sites of the cellular network that will be also selected as DVB-H transmitter sites will be one of the key aspects for achieving the coverage target. There are heuristic tools in order to choose the best configuration of transmitting sites inside the target coverage area [24], but in most cases, the process is carried out by an engineer based on coverage simulations that optimize the network structure after successive iterations. The final step will consist on a coverage simulation considering both the DTV and the subset of 2G-3G sites that will also broadcast DVB-H services.

AN STUDY CASE: PLANNING FOR A MEDIUM SIZED CITY IN SPAIN

The methodology proposed in the previous sections has been applied to carry out the DVB-H services planning for a medium sized city in southern Spain. The target coverage is an area of approximately 22.5 squares Km (8.7 square miles). These dimensions of the coverage area are small enough to avoid any restrictions with respect to the maximum transmitter distance for implementing a SFN. Also, being an urban environment, the requirements for mobile receivers (maximum speed with correct reception) will not also be a limiting factor.

The current DTV services to fixed receivers (DVB-T) are broadcasted from a transmitting site outside the city on top on a hill and an antenna tower 50 m. high. The broadcast antennas are approximately 100 m above the city building roofs. Following the methodology proposed in this paper this infrastructure will be used to provide the basic DVB-H coverage that will be complemented with lower power sites inside the city (actually 3G sites). The 3G network has 35 sites uniformly spread over the city.

The DVB-H parameters choice for this planning exercise has been the same as the combination recommended in previous sections: Channel bandwidth 8MHz, transmission mode 8K, Guard Interval 1/4, carrier modulation QPSK, code rate 2/3 and MPE-FEC coding 3/4. The available bit rate associated to these parameters is 4.98 Mbps, which allows broadcasting 12 programs at 384 Kbps (CIF picture format).

RF Configuration and link budget

The output power for the DVB-H transmitter located on the DTV tower will be 1Kw (60 dBm) and 50 W (47 dBm) for the transmitters to be installed in sites belonging to the 3G network. As far as the transmitting antennas is concerned, as a first approximation, an omnidirectional system on the horizontal plane will be used. This radiating system has a main lobe which beamwith in the vertical plane (3dB) is 11º and a downtilt of 5º. Those values are usual for achieving coverage radius in the range of 0.5 to 2 km for each site.

The network design will be carried out for two frequencies 500 MHz (TV Band IV-UHF) y 700 MHz (TV Band V-UHF). This frequency choice tries to take into account the variations due to frequency in the range of the frequency band candidates to be used in the DVB-H networks that will be deployed in the near future (between 470 and 700 MHz). The planning thresholds for both frequencies can be calculated as explained in previous sections from the link budgets. Results are shown in Table 4 and Table 5 for each one of the possible coverage definitions (A, B, C, D) given by the ETSI (outdoor portable, indoor portable, in vehicle and mobile).

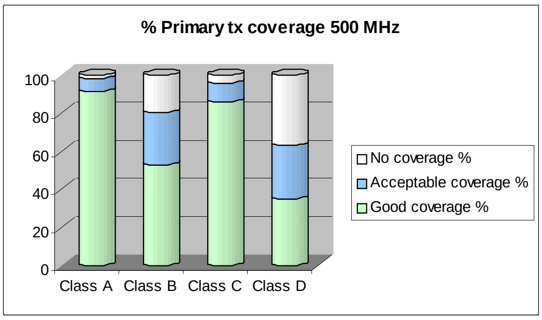
IV Band (500MHz)	Class A	Class B	Class C	Class D
Good coverage	<68 dBm	<51 dBm	<64 dBm	<47 dBm
Acceptable coverage	69-76 dBm	52-61 dBm	64-72 dBm	48-54 dBm
No coverage	>77 dBm	>62 dBm	>73 dBm	>55dBm

Table 4. Coverage Thresholds f = 500 MHz

V Band (700MHz)	Class A	Class B	Class C	Class D
Good coverage	<73 dBm	<56 dBm	<65 dBm	<52 dBm
Acceptable coverage	74-81 dBm	57-66 dBm	66-73 dBm	53-59 dBm
No coverage	>82 dBm	>67 dBm	>74 dBm	>60dBm

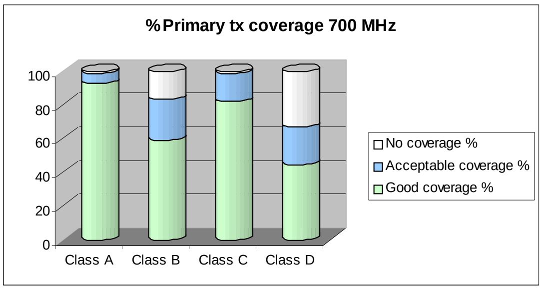
Table 5. Coverage Thresholds f = 700 MHz

The coverage provided from the DTV site with 1kW has been the first step in the process. The coverage location percentages are shown in Figure 6 and Figure 7 for 500 MHz and 700 MHz respectively. The coverage has been specified according to the usual "acceptable" and "good" grades (70 and 95% of the locations).



	Class A	Class B	Class C	Class D
Good coverage %	91,6	53,1	86,3	35,2
Acceptable coverage %	6,9	27,8	9,9	28
No coverage %	1,5	19,1	3,8	36,8

Fig. 6. Good and Acceptable percentages as a function of the DVB-H service class. DTV transmitter site only, f = 500 MHz



	Class A	Class B	Class C	Class D
Good coverage %	93,1	59,3	82	44,8
Acceptable coverage %	5,8	24,4	16,9	22,5
No coverage %	1,1	16,3	1,1	32,7

Fig. 7. Good and Acceptable percentages as a function of the DVB-H service class. DTV transmitter site only, f = 700 MHz

The simulations show a negligible influence associated to the frequency choice. The coverage results obtained for both frequencies are similar because the antenna efficiency in the 700 MHz band is compensated by the higher free space transmission loss. It should be also noted that the percentage of locations where the Class B services would be available with "good" grade is too low.

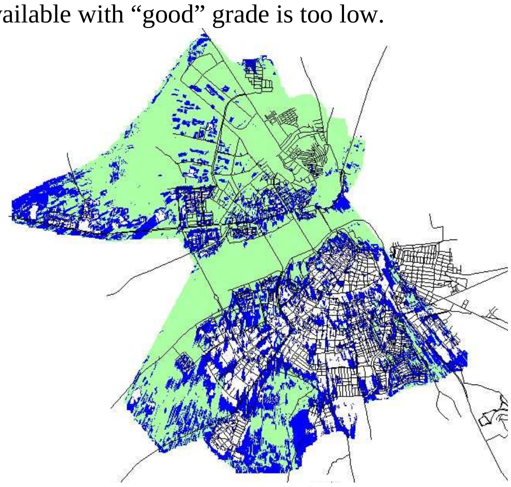
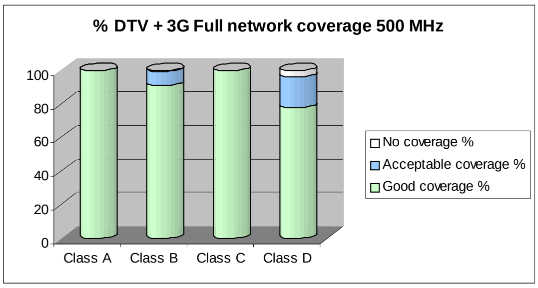


Fig. 8 Coverage map showing "acceptable" coverage areas (blue) and "good" coverage areas (green) for Class B services if only the DTV site is used. (f = 500MHz)

Figure 9 shows the coverage results if the main DTV site is complemented with transmitters installed at every one of the 35 3G sites inside the city. The simulation in Figure 9 corresponds to 500 MHz.



	Class A	Class B	Class C	Class D
Good coverage %	99,9	91	99,7	77,7
Acceptable coverage %	0,1	8,5	0,2	18,2
No coverage %	0	0,5	0,1	4,1

Fig. 9. Good and Acceptable coverage levels as a function of the service type (Class A, B,C,D) if the DTV Site and the whole set of 3G sites (35 sites) are used to install DVB-H transmitters (within the city F = 500 MHz

As shown by results from previous paragraphs, if a Class B indoor coverage percentage for more than 90% of the locations, the density of the network would be similar to the one associated to 3G networks. In fact, if all the existing 3G transmitters for the city example in this paper, the coverage achieved is close to the 100% for outdoor reception (Class A) and a 90% for indoor (Class B).

Considering that the use of the whole set of 3G sites for installing DVB-H transmitters is the final stage of the network deployment process, different simulations have been carried out in order to establish the relationship between intermediate number of 3G sites and the coverage achieved. In this exercise, the network planner should optimize the subset of sites that provides the maximum coverage percentages.

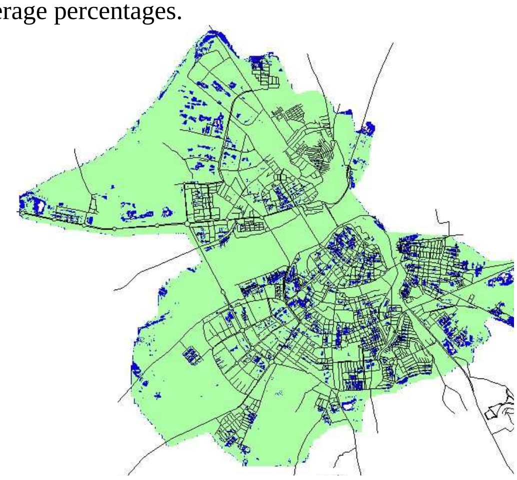


Fig. 10 Acceptable (blue) and Good (green) coverage for Class B services using the DTV site plus the whole set of 3G sites (35 sites) f = 500MHz

Figure 11 shows the different values of coverage percentages for each service class as a function of increasing number of 3G sites for installing DVB-H transmitters. Bar groups on figure 11 contain results for 9, 18, 27 and 35 3G sites.

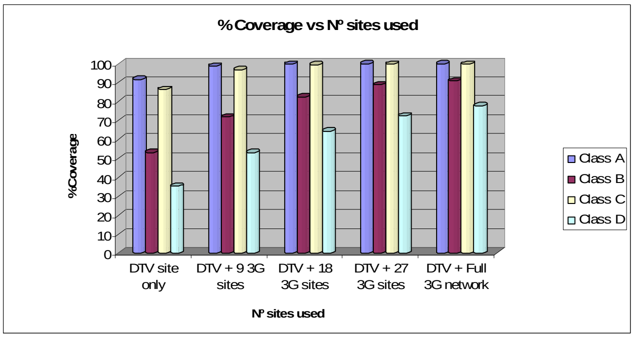


Fig. 11. Good coverage percentage by service class as function of the number of 3G sites used.

The results for Class B, show that the coverage increases significantly if the number of 3G sites used to complement the initial coverage of the DTV DVB-H transmitter standalone. The threshold for obtaining a DVB-H Class B coverage is 18 sites (equivalent to half of the 3G network density). If the number is increased, first to 27 and later to 35, the tendency of the coverage enhancement is less significant.

These results can be very useful for the initial deployment stages of the DVB-H network, because the broadcaster can set an initial coverage target with a relaxed coverage target below 80% of the locations and progressively, as the number of viewers (subscribers) increases, new sites can be included. As stated before, the final density of the network will be close to the one associated to 3G networks in urban environments, if coverage targets higher than 90% of the locations are the objective.

CONCLUSIONS AND FUTURE LINES

The results obtained in the previous sections have shown the feasibility of the idea proposed by previous planning exercises in [5]-[7]. This paper has provided an estimation of the cost (in terms of the number of transmitter sites) versus the coverage achieved, proposing also a planning methodology that allows the broadcaster to deploy DVB-H services gradually. In a first stage, percentages below 80% of the locations will be covered, and this figure will be gradually increased by increasing the density of transmitting sites.

Special emphasis has been made on the link budget calculations including the uncertainty of the prediction method itself into the link budget calculation.

In the case of urban environments, ray tracing methods are recommended, provided a 3D digital model of the city under study is available. More specifically, the results in this paper have been obtained with a ray tracing method in the vertical plane. As part of the future work, DVB-H measurements are needed in order to optimize the prediction algorithms.

Other aspects, not usually considered by studies for coverage planning, such as EM human exposure radiation level restrictions and transmitter installation infrastructure restrictions (cooling and power mains installation) have also been considered in this paper.

Also, it should be taken into account that due to the high number of transmitters required for high coverage percentages, there will be some areas of the network where the number of signals present at the receiver antenna will be high. This situation might be a problem at certain spots of the coverage area, due to the degradation suffered by the minimum C/N values associated to a dense SFN. A specific study for quantifying the degradation as a function of received echoes (within and outside the guard interval) is also a future study area of the authors of this paper.

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