Radio Propagation Models for DVB-H Networks

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Abstract— **This article studies the suitability of different UHF radio propagation models for the European mobile TV standard DVB-H (Digital Video Broadcast - Handhelds). Accurate signal propagation modelling is key for DVB-H network planning in order to minimize deployment costs. This article analyzes three propagation models: Okumura-Hata, Xia-Bertoni, and a model based on the Hata formulae adding a diffraction term calculated using the Deygout method. The performance of the models is evaluated with measurement campaigns from several scenarios with different conditions such as transmitter height, environment, and available geographical data.**

I. INTRODUCTION

DVB-H (Digital Video Broadcasting – Handheld) is the European mobile TV standard. It is based on the European standard for digital terrestrial television, DVB-T (Digital Video Broadcasting – Terrestrial), adding features in order to overcome its limitations for handheld mobile reception [1]. DVB-H is designed to operate in the UHF band, from 474 to 862 MHz, but upper frequencies usually cannot be used in order to avoid interference with GSM-900 transmissions. Commercial DVB-H services are currently on air in several European countries, such as Austria, Finland, Italy, Poland, Switzerland and the Netherlands. Moreover, DVB-H is also being deployed in some countries in South-East Asia and Africa.

One of the major concerns about the roll-out of DVB-H is the network infrastructure cost. DVB-H terminals suffer from much more severe propagation conditions than DVB-T. Not only in terms of increased path loss, but also because of signal fading effects as the result of multipath propagation and shadowing due to the mobility of the users.

As most digital TV sites cannot increase their transmission powers to avoid interference and due to electromagnetic exposure limits of the current international regulation, a considerably large number of new sites is required for the installation of additional DVB-H transmitters or repeaters (gap-fillers), complementing the existing broadcasting towers and forming very dense Single Frequency Networks (SFNs) [2]. This penalty is particularly evident for high area coverage targets (over 90% of service area locations), and implies very large investments in infrastructure. The reason is that it is especially costly to guarantee coverage to the last few per cent of the worst-served locations [3].

Since investment in new infrastructure is very costly, it is expected that existing broadcasting towers will be initially used to provide a basic DVB-H coverage, and additional transmitters or gap-fillers will be progressively deployed in critical areas (e.g., where indoor or vehicular reception is required), co-sited with cellular base stations if possible.

The network planning problem then consists in choosing, given a set of potential sites (mainly cellular sites, although the construction of new sites could be considered as well), the sites to be used with the type of emitter (transmitter or gap-filler) and its configuration, to provide a certain coverage level with the minimum deployment cost. Note that for a network planning exercise the target service area, the operating frequency and the transmission mode are given.

To perform planning exercises it is required to estimate the coverage level in the target service area of each of the different possible network configurations, as well as a detailed cost model with the cost information of using each of the transmitters and gap-fillers considered in each potential site. In order to compute accurately the area coverage in a DVB-H SFN, it is necessary an accurate prediction of the received power at each location from each transmission site in the network, and to determine how signals from the different sites contribute to the useful received signal or cause self-interference at each location.

This article analyses and compares the performance of several radio propagation models for DVB-H networks with field measurements campaigns in different scenarios that include high TV towers and low power transmitters in cellular sites. The goal of the paper is to define a methodology for DVB-H path loss calculations depending on parameters such as the deployment environment, transmitter height, and available geographical data for the predictions. The propagation models studied are the Xia-Bertoni propagation model, and a model that combines the Hata formulae with a diffraction term calculated using the Deygout method. These propagation models have been selected because they operate within the UHF band, and because they take into account terrain and building information to perform calculations in cities and urban areas.

This paper is structured as follows: Section II explains the propagation modelling process and describes the propagation models studied in this document. Section III describes the measurement campaigns used to calibrate, evaluate and compare the propagation models under study. Section IV shows the results of propagation model calibration and studies the application of each one to the environment and the transmission and reception conditions. Finally, Section V concludes the paper.

II. PROPAGATION MODELLING

Signal level prediction needs to take into account the reflection, diffraction and scattering propagation mechanisms suffered by the signal from the transmitter to the receiver. Propagation modelling depends on many parameters such as the environment, transmitter height, frequency, and available information about the deployment scenario.

When designing a DVB-H network, some considerations have to be taken before the selection of the suitable propagation model: the accuracy of calculations, the accuracy and resolution of the cartographical information available, the average distance between the transmitters and receivers, the deployment frequency and the size of the deployment area.

Generally speaking, propagation models can be classified into three types: deterministic, empirical, and physical-statistical models. Deterministic models calculate propagation losses mathematically using theoretical formulations. They require accurate information about the deployment scenario, not only about terrain and buildings, but also about reflection and diffraction coefficients of surfaces. For DVB-H deployments in large areas, this information will be difficult, even impossible, to obtain. Physical-statistical models combine deterministic models with statistics about the environment, in order to decrease the computational cost. Finally, empirical propagation models estimate the radio link using measurements.

This article studies the applicability for DVB-H radio propagation modelling of the Xia-Bertoni model [4] (physical-statistical model), and a model based on the Hata formulae [5] adding diffraction losses using the Deygout diffraction method [6] (empirical model and deterministic diffraction calculation). These propagation models have been selected because they can be used to estimate propagation losses in the UHF band and they don't need very accurate cartographical information to estimate diffraction losses. For this reason, both propagation models are suitable to perform predictions in large areas.

A. Xia-Bertoni Radio Propagation Model

Xia-Bertoni [4] is a physical-statistical propagation model that describes UHF signal propagation (operating frequency from 300 MHz to 3 GHz) in cities where the heights of transmitters are near the medium height of rooftops. It takes into account terrain and building profiles to estimate propagation losses. For each calculation point, Xia-Bertoni model adds a diffraction losses term that depends on the mean height of the buildings placed between the transmitter and the receiver.

For the Xia-Bertoni propagation model, the mathematical formulae that have to be adjusted are the following:

$$\begin{aligned} L(dB) = A + B\cdot\log(d) + C\cdot\log(f) + D\cdot\log(\alpha) + \\ + E\cdot\log(b) + F\cdot\log(r) + G\cdot\log(\beta) \end{aligned} \quad (1)$$

$$r = [(h_m)^2 + (w/2)^2]^{1/2} \quad (2)$$

Where d is the distance between the transmitter and the receiver in km, f is the operation frequency in MHz, b is the medium separation between buildings, h_m is the receiver height and w is the medium width of the streets.

B. Hata+Deygout Radio Propagation Model

Hata [5] is an empirical propagation model that takes the field strength information produced by Yoshihisa Okumura, developing a set of equations for path loss. The propagation model is suitable for frequencies from 150 to 1500 MHz, with base station heights from 30 to 200 m, and for distances between transmitter and receiver from 1 to 20 km. Okumura-Hata is a simple propagation model that does not require cartographical information to estimate propagation losses. For this reason, one of the limitations of the Hata model is that it does not take in consideration diffraction produced by obstacles placed in the propagation path between the transmitter and the receiver. To overcome this limitation, diffraction losses are calculated and added to losses estimated using the Hata propagation model. These diffraction losses are calculated using the Deygout [6] diffraction method. It considers that building effects can be approximated by multiple knife edges and estimate losses produced by the highest obstacles between the transmitter and the receiver.

When using Hata+Deygout model, the formulae to perform predictions is:

$$\begin{aligned} L(dB) = A_1 + B_1\cdot\log(d) + C_1\cdot\log(f) + D_1\cdot\log(h_b) + \\ + E_1\cdot Diffraction + F_1\cdot\log(d) + G_1\cdot\log(h_m) \end{aligned} \quad (3)$$

Being d the distance between the transmitter and the receiver in km, f the operation frequency in MHz, *Diffraction* the diffraction term calculated with the Deygout method and h_b and h_m the effective transmitter and receiver height in m respectively.

Consequently, the main difference between Xia-Bertoni and Hata+Deygout propagation model is that the first one makes an approximation of the building profile between the transmitter and the receiver whereas the second one takes into consideration the real building profile to make calculations.

C. Calibration Methodology

Using measurements calculated signal level can be compared and suitable propagation models for different reception conditions can be selected. Propagation model calibration is useful as well to mitigate the lack of precision of the available cartographical information. Calibration of propagation models consists of varying their characteristic parameters in order to minimize the difference between predictions and measurements. Propagation losses are calculated using formulations that model the different physical mechanisms suffered by the signal when propagating from transmitters to receivers. The contribution of the different propagation mechanisms is weighted depending on parameters such as the propagation environment or the transmitter height. Measurement campaign results are used to set the contribution of each term to the total losses.

The mathematic method used for the adjustment of the propagation models under study is the Least Mean Squares method. It tries to minimize the sum of the square of the differences between measurements and predictions [7]. Parameters to be optimized are A, B, C, D, E, F, and G for the Xia-Bertoni model and A_1, B_1, C_1, D_1, E_1, and F_1 for the Hata+Deygout propagation model.

Being y_i a collection of measurements and L_i the collection of predictions, the sum of the squares of the residuals is:

$$S = \sum_i (y_i - L_i)^2 \tag{4}$$

The LMS method tries to find coefficients that minimize S. These coefficients equal to zero the derivate of S respect each one. As a result, the equation system to solve is the following:

$$L_i = x \cdot a_i + y \cdot b_i + z \cdot c_i + ... \tag{5}$$

$$\frac{\partial S}{\partial x} = 2 \cdot \sum_i (y_i - L_i) \cdot \frac{\partial L_i}{\partial x} = 0 \tag{6}$$

$$\frac{\partial S}{\partial y} = 2 \cdot \sum_i (y_i - L_i) \cdot \frac{\partial L_i}{\partial y} = 0 \tag{7}$$

$$\frac{\partial S}{\partial z} = 2 \cdot \sum_i (y_i - L_i) \cdot \frac{\partial L_i}{\partial z} = 0 \tag{8}$$

III. MEASUREMENT CAMPAIGNS

When carrying out measurement campaign to calibrate propagation models, a significative number of samples have to be taken for each environment (dense urban, urban, suburban, rural etc.), because propagation conditions are different for each one. Measurement distribution is another important consideration. Measurement paths must be denser near the transmitter and sparser when they are far from the transmitter.

Before calibration, measurements are filtered in order to eliminate fast fading produced by multipath propagation. This filtering is usually performed using the Lee method. According to Lee, between 36 and 50 samples must be taken every 20-40 wavelengths [8]. Finally, calibration is recommended to be made using approximately 1/3 of measurements to adjust the parameters of propagation models and the other 2/3 to compare measurements and predictions in order to validate the calibration carried out.

In order to study and compare propagation models for DVB-H networks, five different scenarios have been analysed. Table 1 summarizes the characteristics of these scenarios. Reception is vehicular outdoor.

A. *Barcelona* (*Spain*)

The measurement campaign was performed by the company Abertis Telecom in November 2006 for the European WingTV project. The particularity of this campaign is that transmitter antenna is placed in a 320 high TV tower that is used to provide digital terrestrial TV services. Operation frequency was 482 MHz. The cartographic information available for this scenario is a digital terrain model map and a building map, both having a 5 m resolution.

B. *Gävle* (*Sweden*)

The campaign was performed by the companies Joanneum Research and ITV Arena. The city is characterized by an urban area at its center, surrounded by sub-urban zones with uniform buildings. The network frequency was 818 MHz and the height of the transmitter 25 m. For this deployment scenario terrain and building maps with 10 m resolution are available.

C. *Valencia* (*Spain*)

This measurement campaign was carried out by the iTEAM research institute inside the main campus of the Universidad Politécnica de Valencia. Measurements were taken using the iTEAM DVB-H test network. The test network has one transmitter placed inside the campus at 24 m height. The environment can be considered as suburban. Operation frequency was 594 MHz. The cartographic information available for this scenario is a digital terrain model map with 200 m resolution and a building map having a 1 m resolution.

D. *Bucaramanga* (*Colombia*)

The measurement campaign was performed by the RadioGIS research Group of the Universidad Industrial de Santander. The operation frequency was 880 MHz and the height of the transmitter is 40 m over terrain. The main feature of Bucaramanga is the hilly terrain profile, which has to be taken into account when modelling propagation mechanisms. Terrain and building information has 1 m resolution.

TABLE I
MEASUREMENT CAMPAIGN CHARACTERISTICS.

Measurement scenario	Operation frequency	Terrain/ Transmitter Height	Environment
Bucaramanga	880 MHz	940/40 m	Urban, hilly terrain profile
Barcelona	482 MHz	450/120 m	Urban
Gävle	818 MHz	19/25 m	Urban
Valencia	594 MHz	0/24 m	Suburban

IV. RESULTS AND DISCUSSIONS

Fig. 1 and Fig. 2 show the comparison between path loss measurements and predictions for the scenario of Barcelona. This scenario makes possible to observe propagation effects using high transmitters. Fig. 1 shows the results for the propagation models Okumura Hata and Hata+Deygout (calibrated with measurements), and Fig. 2 for the Xia-Bertoni propagation model with and without calibration. Results show that the Okumura-Hata propagation model obtains a good approximation of the mean level of the received signal (without calibration). A similar result is obtained with Xia-Bertoni propagation model. Predictions with Okumura-Hata and Xia-Bertoni do not model the received signal variability.

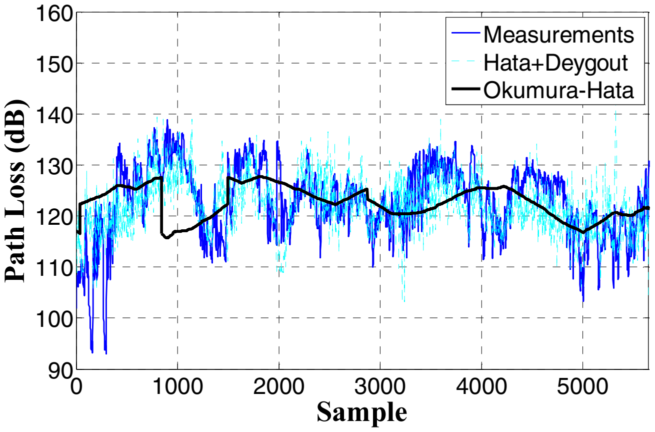

Fig. 1 Path loss comparison between measurements and predictions. Hata+Deygout and Okumura-Hata propagation models. Barcelona scenario.

TABLE II
STATISTICAL PARAMETERS OF THE ERROR BETWEEN MEASUREMENTS AND PREDICTIONS. BARCELONA SCENARIO.

Propagation Model	**Mean**	**Stantard Deviation**	**Correlation**
Okumura-Hata	0.6 dB	7 dB	0.48
Xia-Bertoni Non-calibrated	14 dB	10 dB	0.40
Xia-Bertoni Calibrated	0 dB	5.7 dB	0.48
Hata+Deygout	0 dB	5.1 dB	0.88

On the other hand, Hata+Deygout propagation model obtains the best approximation of the received signal level, but it needs to be adjusted using measurements in order to obtain reliable results. Table 2 shows the statistical parameters of the error between measurements and predictions for the studied propagation models in Barcelona. Correlation between measurements and predictions is calculated as well. It is observed that, the mean value and standard deviation are similar for Xia-Bertoni and Hata+Deygout propagation models, but correlation between predictions and measurements is higher for Hata+Deygout propagation model. For this reason, Hata+Deygout can be used if measurement campaign results and reliable and high resolution cartographical information are available.

Fig. 3 shows the results for the scenario of Gävle. In this scenario the height of the transmitter is comparable to buildings. Okumura-Hata propagation model obtains a good approximation of the mean value of the received signal, but it does not provide a good approximation of the signal variability. Adjusted Xia-Bertoni propagation model offers the best approximation of path losses. The same happens in Valencia scenario, where transmitter height is similar to buildings. Fig. 4 shows results in this scenario and Table 3 compares statistical parameters of the error between measurements and predictions for Valencia and Gävle.

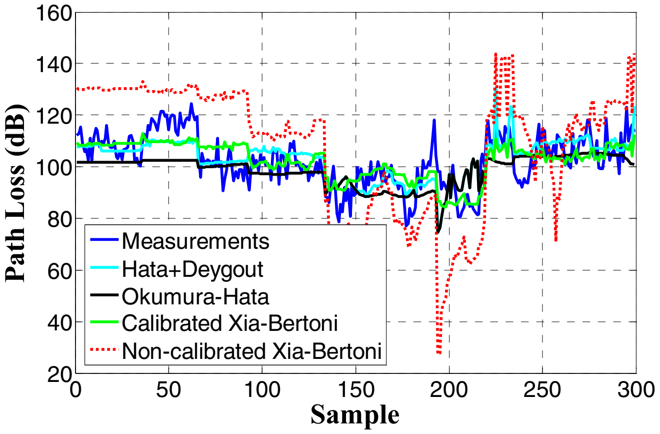

Fig. 2 Comparison between measurement points and predictions for Barcelona scenario. Xia-Bertoni propagation model.

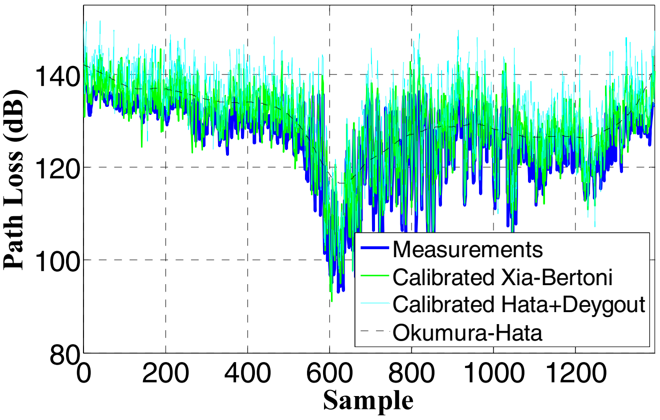

Fig. 3 Comparison between measurement points and predictions for Gävle scenario.

For high transmitters, as Xia-Bertoni propagation model calculates diffraction losses using mean building values, predictions will not follow the received signal variability. When transmitter is not so high, almost every building between the transmitter and the receiver will have an effect in the received signal. Xia-Bertoni will provide a best approximation of the received signal because it takes into account all the buildings placed between the transmitter and the receiver, whereas Hata+Deygout only takes into account the highest ones.

Finally, Fig. 5 presents results for the scenario of Bucaramanga. Bucaramanga is characterized by a very irregular terrain profile. Xia-Bertoni is the propagation model that obtains the best approximation to predictions. Hata+Deygout propagation model does not provide accuracy in predictions because diffraction modelling only uses building profile information, without taking into account the terrain profile, which has high influence in predictions for this scenario.

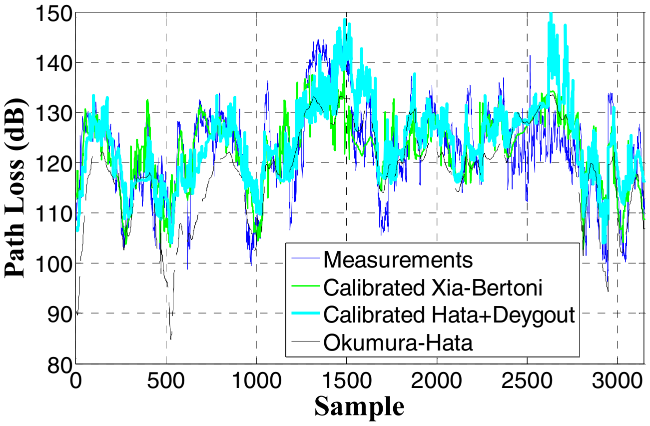

Fig. 4 Comparison between measurement points and predictions. Valencia scenario.

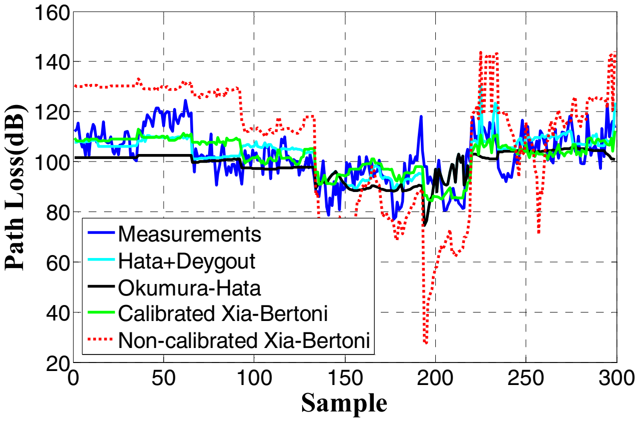

Fig. 5 Comparison between measurement points and predictions. Bucaramanga scenario.

TABLE III
STATISTICAL PARAMETERS OF THE ERROR BETWEEN MEASUREMENTS AND PREDICTIONS. GÄVLE AND VALENCIA SCENARIOS.

Propagation Model	**Mean**		**Standard Deviation**	
	Gävle	**Valencia**	**Gävle**	**Valencia**
Okumura-Hata	1 dB	4.3 dB	8 dB	7.5 dB
Xia-Bertoni Non-calibrated	40 dB	45 dB	20 dB	9.7 dB
Xia-Bertoni Calibrated	0.5	0 dB	5.3 dB	5.4 dB
Hata+Deygout	0.1 dB	-1 dB	6 dB	6.6 dB

Propagation Model	**Correlation**	
	Gävle	**Valencia**
Okumura-Hata	0.69	0.65
Xia-Bertoni Non-calibrated	0.40	0.50
Xia-Bertoni Calibrated	0.86	0.88
Hata+Deygout	0.73	0.70

V. CONCLUSIONS

In this paper, we have investigated the application of different physical-statistical UHF radio propagation models for DVB-H deployment. The performance of the propagation models has been analyzed using results from several measurement campaigns in scenarios with different characteristics: transmitter height, deployment frequency, environment, and terrain profile.

Results show that the election of the suitable propagation model has to be made taking into account the deployment scenario, the available cartographic information the transmitter height and the terrain profile of the deployment scenario. Another important conclusion is that measurements are necessary to adjust the characteristic parameters of propagation models.

The most appropriated propagation model depends strongly on the transmitter height. When the transmitter is high, the Okumura-Hata and Xia-Bertoni does not model signal fading. Hata+Deygout propagation model is suitable for this type of scenarios, but it has to be calibrated in order to be particularized to the deployment frequency and the environment. If transmitter height is comparable to buildings, calibrated Xia-Bertoni propagation model provide the better accuracy than Hata+Deygout propagation model.

Predictions are more reliable if terrain and building information is used to model diffraction, but if this information is not available, empirical propagation models offer a good approximation of the mean value of the received signal. Finally, for hilly terrain Xia-Bertoni propagation model is more suitable as it takes into account terrain and building profiles to estimate propagation losses.

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