Propagation Model Calibration for DVB-SH in Terrestrial Single Frequency Networks

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Abstract—**This article studies terrestrial propagation model calibration for DVB-SH networks. DVB-SH is the European standard designed to transmit multimedia content to mobile terminals using a hybrid satellite/terrestrial infrastructure. One important particularity of DVB-SH is that it allows the implementation of Single Frequency Networks, where every transmitter emits the same signal at the same frequency. This article analyzes two propagation models suitable to perform propagation calculations in urban areas and S band: Xia-Bertoni, and a model based on the Hata formulae adding a diffraction term calculated using the Deygout method. Two different methodologies to calibrate propagation models using measurements from more than one transmitter in a SFN are studied and compared.**

I. INTRODUCTION

DVB-SH (Digital Video Broadcasting - Satellite Handheld) is the new European mobile broadcasting standard, designed to transmit multimedia content to mobile and handheld devices using a satellite along with a complementary ground component [1]. DVB-SH allows to efficiently providing mobile broadcasting services in all types of environment; using the satellite from its first day of service, and deploying progressively a terrestrial network by means of reutilizing existing cellular sites. The satellite ensures geographical global coverage. For example, a single geostationary satellite can provide coverage in Western Europe. Using a multi-beam configuration, regional content can be inserted. The terrestrial network provides coverage for situations in which signal reception is difficult, especially urban an indoor scenarios. DVB-SH is designed to use frequencies below 3 GHz, supporting the utilization of S-Band.

In April 2008, a dedicated geostationary satellite was launched in the USA. In Europe, the first DVB-SH satellite was launched in April 2009. Several field trials are currently taking place in many European countries [2], [3]. Commercial services are expected to start in late 2010.

For satellite DVB-SH transmissions , it is possible to choose between two modulations, OFDM (Orthogonal Frequency Division Multiplexing) and TDM (Time Division Multiplexing), but for terrestrial transmissions, only OFDM can be used. With OFDM transmission Single Frequency Networks that also include the satellite can be implemented. If satellite implements TDM modulation, amplifiers can work in the saturation zone and transmission power can be higher.

One of the most important advantages of OFDM is that it can cope with high levels of multipath propagation and makes possible the deployment of Single Frequency Networks (SFN), in which all transmitters send the same signal over the same frequency channel. Transmitters implement GPS receivers in order to guarantee signal synchronization. The signals coming from different transmitters of the SFN can be combined in a coherent way, or cause interferences, depending on the temporal difference between them. The aim of SFNs is not only the efficient utilization of the radio spectrum, but also the improvement of coverage when the signals are combined.

When designing a DVB-SH network, the received signal level has to be estimated. Propagation models perform predictions of the losses suffered by the signal in the propagation path between the transmitter and the receiver. In order to improve propagation models accuracy, their parameters can be calibrated using results from measurements campaigns. Calibration is normally made for only one active transmitter. When a SFN is already deployed, calibration of propagation models is needed to perform coverage calculations and allocate new sites. This article focuses on the study and validation of propagation models for the terrestrial component of DVB-SH. Calibration methods for S band radio propagation models in Single Frequency Networks are described. These methodologies have been validated with field measurements of one of the first DVB-SH technical pilots that took place in Barcelona (Spain), in December 2008. The trial was jointly performed by the Spanish project FURIA (Futura Red Integrada Audiovisual) and the European Celtic B21C (Broadcast for the 21st Century) project. The scenario was a Single Frequency Network formed by two terrestrial transmitters.

The rest of this paper is structured as follows: Section II describes terrestrial propagation modelling for urban environments in S band. Section III explains the radio propagation model calibration method for Single Frequency Networks. Section IV describes the measurement trial used to adjust and verify the propagation models studied in this work. Finally, Section V shows and discusses the results obtained after the calibration process.

II. TERRESTRIAL RADIO PROPAGATION MODELLING

Received signal level predictions are necessary to calculate the coverage provided in any wireless network. Propagation models perform predictions of the losses suffered by the signal between the transmitter and the receiver. Depending on the deployment frequency, different propagation models have to be applied. In this work, terrestrial propagation models under study work in S band, which is the operation frequency band in DVB-SH.

Propagation models can be classified into three types: deterministic, empirical and physical-statistical models. Deterministic models calculate propagation losses mathematically using theoretical formulations. For deployments in large urban areas, these propagation models are not feasible because they require accurate information about the deployment scenario, not only about terrain and buildings but also about reflection and diffraction coefficients of surfaces. Empirical propagation models calculate losses using only measurements. Empirical propagation models are not feasible because for each development scenario extensive measurement campaigns should be made in order to model the propagation. Finally, physical-statistical models combine deterministic models with statistics about the environment in order to decrease the computational cost. These propagation models are suitable for large area deployments but their characteristic parameters have to be adjusted using measurements in the deployment scenario [4]. Terrestrial propagation models studied are suitable to perform signal estimations in S band and urban environments, where diffraction effects have to be characterized: Xia-Bertoni propagation model [6] and a technique that combines the Hata formulae [7] with a method designed by Deygout [7] to model diffraction mechanisms.

Xia-Bertoni is a physical-statistical propagation model that describes signal propagation (operation frequency from 300MHz to 3GHz) 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. Equations for the calculation of propagation losses are the following:

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

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

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.

Hata is an empirical propagation model that takes the field strength information without taking into 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 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. Consequently, the main difference between Xia-Bertoni and this 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.

For Hata+Deygout propagation model, the formula to perform predictions is:

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

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 heights in meters.

In order to characterize the features of each environment, propagation models use approximations and suppositions to calculate the final losses. These simplifications cause error in simulation results. To minimize erroneous predictions, the selection of the suitable propagation model is very important as well as its calibration by means of measurement campaigns for each environment.

III. RADIO PROPAGATION MODEL CALIBRATION FOR SINGLE FREQUENCY NETWORKS

In SFNs, the received signal power is the combination of the power from each transmitter in the network. For this reason, the definition of the suitable propagation model becomes problematic when the SFN is operative and another transmitter has to be implemented. In SFNs, signals received within the OFDM symbol guard interval contribute to the useful signal, whereas signals with a time delay larger than the guard interval cause self-interference. Usually, a weighting function according to the signal delay is employed to determine the ratio between the useful and interfering contribution [9].

In this article two different calibration methods to adjust propagation models to measurements performed in SFNs are analysed. The aim is to obtain the suitable propagation model for each transmitter. Optimization algorithms under study are LMS (Leas Mean Squares) [11] and Simulated Annealing [10].

A. *Calibration Methods for Single Frequency Networks*

With the information of the received power at each measurement point, it is impossible to know the contribution from each antenna of the SFN, so the design of a specific method to SFN calibration has been considered. The calibration method has to obtain the best propagation model for each transmitter.

Optimization techniques try to find the characteristic parameter configuration that minimizes the error between measurements and predictions. 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. These parameters are different and have to be optimized for all the transmitters included in the SFN.

The most commonly used mathematic method for the adjustment of propagation models is the Least Mean Squares method. It tries to minimize the sum of the square of the differences between measurements and predictions. 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:

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

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

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

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

This method cannot be applied to calibrate SFNs because predicted losses in dB are considered as a linear combination of the parameters to optimize. When signal is received from more than one transmitter, the total signal is the linear sum of every contribution. Hence, the logarithmic prediction is not a linear combination of the parameters to optimize. Two different alternatives have been considered in this article. The first one consists on calibrating the propagation models considering that some measurements are received from only one transmitter. The second one studies the utilization of an optimization algorithm based on the Simulated Annealing technique.

1) *Calibration of each transmitter independently using LMS*: Fig. 1 shows the calibration method graphically. The first step is the classification of the available measurement routes depending on the distance from each transmitter. Points related to only one transmitter and those which benefit from the SFN gain are distinguished. The following step is to calibrate each isolated transmitter. Finally, all the individual calibrations are validated jointly making use of the measurements coming from the Single Frequency Network. The process repeats modifying the classification (varying the influence distances) until the difference between the simulated power and the measured power minimizes.

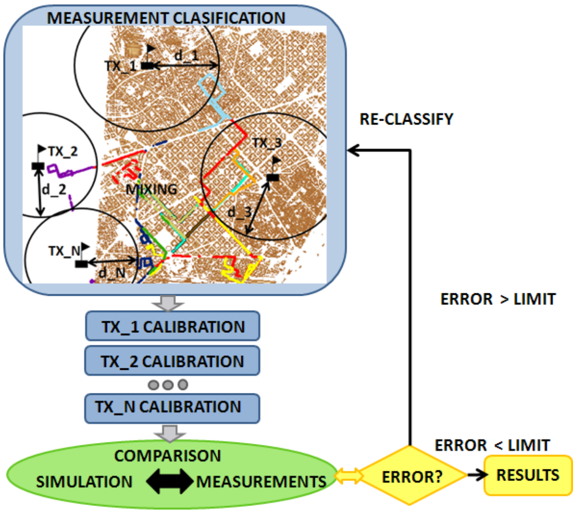

Fig. 1. SFN calibration methodology.

2) *Simulated Annealing:* Local search algorithms move across different solutions until the optimal one is reached or a stop criterion is satisfied. Simulated Annealing is an example of local search algorithms. The particularity of this algorithm is that it can move to a worse solution in order to avoid remaining in a local minimum. Each step of the SA algorithm replaces the current solution by an random nearby solution chosen with a probability that depends on the difference between the corresponding function values and on a global parameter, *T* (called temperature), that is gradually decreased during the process. The dependency is such that the current solution changes almost randomly when *T* is large, but increasingly downhill as *T* goes to zero. Fig. 2 shows the SA optimization method mechanism. Every state of the algorithm is defined by the characteristic parameters of the propagation model for every transmitter in the SFN. For Xia-Bertoni propagation model, the state obtained before *k* iterations, S^k, is defined as following, being *M* the total number of transmitters included in the SFN:

$$S_k = \left\{ [A^k_{tx1}, G^k_{tx1}], [A^k_{tx2}, G^k_{tx2}], \ldots, [A^k_{txM}, G^k_{txM}] \right\} \tag{9}$$

The parameter to minimize is the mean quadratic error between measurements and predictions. The mean quadratic error is defined as the square of the mean value of the difference between the quadratic value of measurements and predictions:

$$MCE = \sqrt{\frac{1}{N} \sum_N (y_i - L_i)^2} \tag{10}$$

Where *N* is the total number of measurements, y_i the collection of measurements and L_i the collection of predictions at the measurement points. This optimization parameter takes into account the minimization of both the mean value and the standard deviation of the error between measurements and predictions.

The next state is generated choosing randomly between two options:

- Random choice: One parameter for every transmitter under study is chosen randomly and its value is changed.
- Local search: One parameter for every transmitter under study is chosen and the next state is generated searching the value for this parameter that minimizes the mean quadratic error between measurements and predictions.

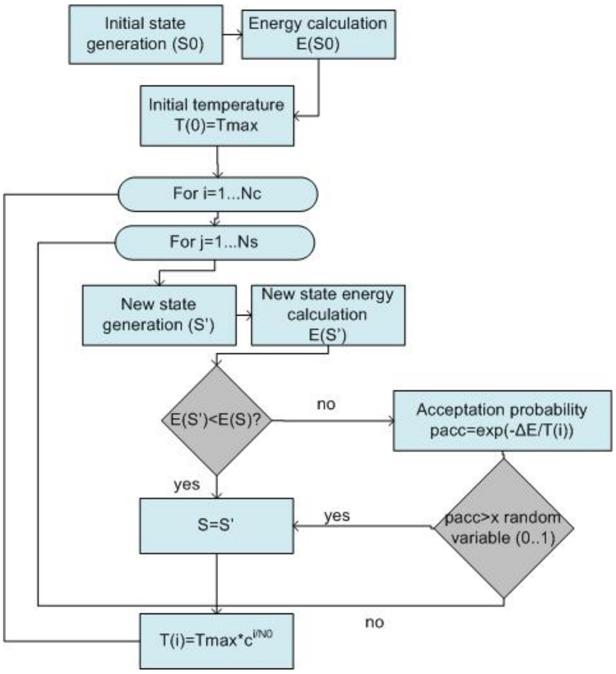

Fig. 2. Simulated Annealing process.

IV. MEASUREMENT SCENARIO

Measurement campaign was carried out in Barcelona in December 2008. The trial was performed using two transmitters emitting the same signal simultaneously, Peri-Pons transmitter and Urquinaona transmitter. Both transmitters were emitting a PIRE of 53.77 dBm. Antennas were omnidireccional and placed at a height of 78 and 57 m. Fig. 2 shows measurement paths and the deployment scenario under study. The transmission mode was FFT size 2K, Guard Interval (GI) 1/4, constellation QPSK, and turbo-code code rate 1/3. The measurement scenario is considered as urban. Operation frequency was 2177.5 MHz. Distance between transmitters is approximately 4 km. This value is lower than the maximum distance allowed by the transmission model to consider that signals coming from both transmitters contribute to the useful signal (12 km). Fig. 3 shows the measurement routes and the transmitter position. Measurements area was 20 km^2 approximately. Available cartographic information about this scenario are a Digital Terrain Model map and a buiding map, both having a 5 m resolution.

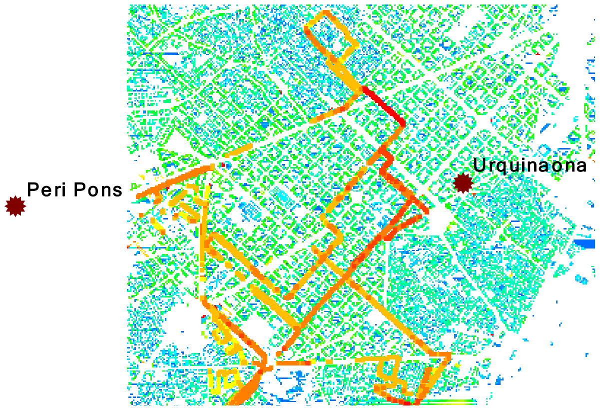

Fig. 3. Measurement scenario. Barcelona (Spain) city centre.

V. RESULTS AND DISCUSSIONS

In order to apply the optimization techniques to the propagation model calibration, configuration of the Simulated Annealing algorithm has to be studied to guarantee the convergence to the optimal solution. The number of iterations has been selected as the number of iterations that ensure that the mean quadratic error reaches a stable value. For the SA algorithm, convergence studies have been performed and the suitable values obtained are T_{max}=50, N_c=80, N_s=30, c=0.97, N_0=5. The total number of solutions evaluated is 2400. A total of 5 different random seeds have been executed.

Table 1 shows the statistical parameters of the error between measurements and predictions for the propagation models studied in this article calibrated using the LMS method and the SA method. It is observed that SA method obtains better results than LMS method. The reason for the better performance of Simulated Annealing is that, for every measurement point, the received signal comes from both transmitters and the contribution to the total signal depends on the distance to each transmitter. That dependency is already modelled in the propagation formulae. For this reason, modelling the signal as the sum of the contributions from each transmitter provides better results than modelling some points as receiving signal from one independent transmitter.

Fig. 4 and Fig 5 compare measurements and predictions for adjusted Hata+Deygout and Xia-Bertoni propagation models, respectively. Figures show that adjusted Xia-Bertoni propagation only obtains a good approximation of the mean received signal level, whereas Hata+Deygout propagation model calculates received signal variations. For this reason, correlation between measurements and predictions (Table 1) is higher for Hata+Deygout than for Xia-Bertoni propagation model. The reason is that Xia-Bertoni propagation model calculates diffraction losses using mean building values whereas Deygout takes into account the highest buildings to perform calculations. As transmitters are high compared to buildings, the modelled diffraction will be more accurate if it takes into account the highest buildings than their mean height value.

TABLE I

STATISTICAL PARAMETERS OF THE ERROR BETWEEN PREDICTIONS AND MEASUREMENTS FOR EACH CALIBRATION METHOD.

	LMS method		**SA**	
	Xia-Bertoni	Hata-Deygout	Xia-Bertoni	Hata-Deygout
Mean	-0.2 dB	-0.7 dB	0 dB	0 dB
Standard deviation	5.7 dB	7.4 dB	2.39 dB	6.16 dB
Correlation factor	0.3	0.68	0.39	0.75

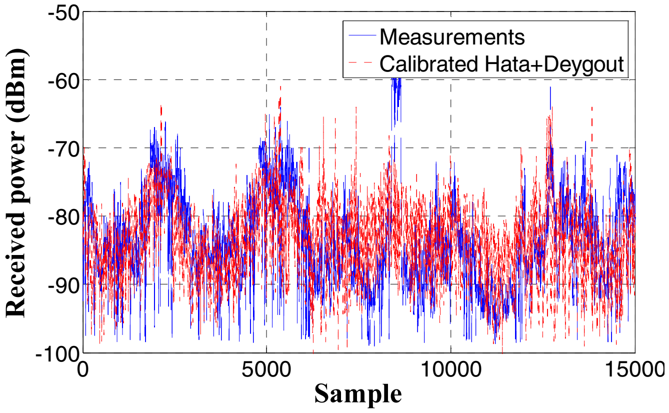

Fig. 4. Measurements and predictions with calibrated Hata+Deygout propagation model.

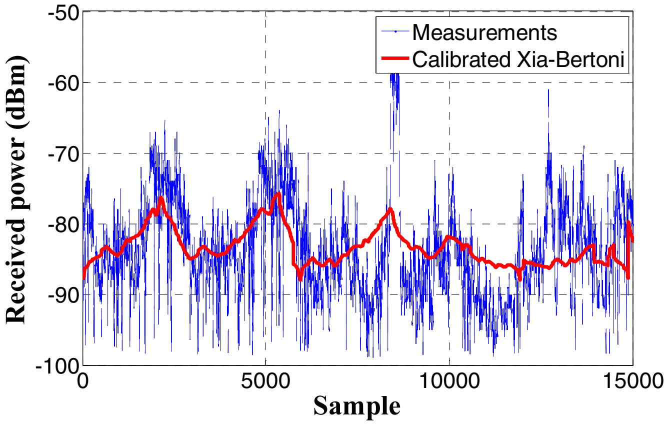

Fig. 5. Measurements and predictions with calibrated Xia-Bertoni propagation model.

VI. CONCLUSIONS

We have investigated the calibration of propagation models in terrestrial DVB-SH Single Frequency Networks. In SFNs received signal comes from more than one transmitter. Some traditional calibration methods such as the Least Mean Square algorithm cannot be applied in SFNs and other methodologies have to be applied in order to find the propagation models that minimize the error between predictions and measurements. Two different propagation models have been studied and compared: Xia-Bertoni and Hata with a diffraction term calculated using the Deygout method. Their characteristic parameters have been calculated by means of two optimization techniques. The first one considers that, when distance to the transmitter is lower that certain value, received signal comes from this transmitter independently. Propagation model parameters and influence distance are adjusted and verified using the measurements considered to be received from every transmitter of the SFN. The second calibration method is based on Simulated Annealing. Results show that Simulated Annealing obtains a better adjustment because at every measurement point received signal comes from both transmitters. Using optimization algorithms, propagation models can be adjusted and the error between measurements and predictions is minimized. Results show that Hata+Deygout propagation model obtains a better approximation to the received signal level, and that the Xia-Bertoni propagation model only makes predictions of the mean signal level value.

Future work consists on studying the results of the next DVB-SH measurements campaign that will take place in Barcelona in February 2010. This trial will study the satellite component jointly with the terrestrial network. Results will allow the calibration of satellite propagation models and the combinations of satellite/terrestrial signals.

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