Characterization of the wideband wireless channel in the context of DVB systems

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Abstract—Recent radio systems (3G, DVB-T/H) present a wideband bandwidth possibly enlarging the capacity of the networks. The systems are interference-limited and thus an accurate radio network planning requires a refined characterization of the interference levels. A French research project called Semafor has been set up to investigate this characterization by means of two tools. First a hardware equipment is able to detect low interference levels by making use of antenna arrays and powerful algorithms. Second a coverage simulation tool is used. It is based on a propagation model able to estimate accurately large range echoes. System parameters like the interference level and SINR for DVB are simulated and validated by extensive measurement campaigns realized in the project with sophisticated testbeds.

Ray-tracing; wideband measurements; DVB

I. INTRODUCTION

The radio network planning of wideband wireless systems does require prediction of the received power level by electromagnetic wave propagation prediction models. Furthermore the simulation of the reception quality may be greatly improved by taking also into account characteristics of the predicted wideband channel like the delay and angle dispersions. The simulation of diversity or MIMO performances clearly takes benefit from space-time predictions. But the same already applies when simulating simple transmit receive systems.

In particular, in WCDMA networks presenting a 5MHz bandwidth, the intra-cell and extra-cell interference levels depend on the impulse response of channels from the base stations to the mobile station. The loss of orthogonality between the spreading codes, which is related to the intra-cell interference, is due to the delay dispersion in the propagation channel. The larger is the delay dispersion, the higher is the interference. Besides, in the 8MHz-bandwidth DVB-T/H networks, the delayed echoes of the propagation channel cause inter-symbol interferences when they arrive outside the FFT window of the demodulator. The length of the DVB symbols is increased by the guard interval to mitigate the effect of most of the delayed echoes. However distant interactions can generate excess delays greater than the guard interval, thus generating interference, especially around high transmitters overhanging wide areas as met in a DVB network.

Then the prediction of the power delay profile or channel impulse response can be exploited to estimate the site-specific interference level in wideband systems such as WCDMA and DVB. The paper mainly focuses on DVB aspects, but most of the work about interferences applies to WCDMA. Assessing efficiently the multipath and the long delays can significantly improve the radio coverage and thus the radio network planning of such wideband systems.

Following a FP6 IST European project (Antium) where a measurement equipment was developed, a French research project named Semafor has been initiated and aims at providing a unique (all systems in one) metrology platform that could be embedded in a light vehicle or portable by a human. All physical parameters of various waveforms (2G, 3G, Wimax, DVB) impacting the capacity and the quality of the networks are studied in a context of Radio Network Planning. Furthermore solutions to locate the transmitters (possible jammers) in a dense environment (Urban Area) are investigated. Convergence scenarios are studied and the main project results are validated by real field measurements. Two objectives of this project are discussed in this paper and consist in accurately measuring and finely predicting the interferences in various kinds of networks (UMTS, Wimax, DVB-T/H). On one hand, a demonstrator developed by a partner is able to decode all kinds of waveform, to measure the low-level interferences, to detect and to locate the sources. On the other hand, an urban propagation model predicts the wideband channel characteristics that are provided to algorithms estimating the interference level or SINR (Signal-to-interference-plus-noise-ratio).

The propagation model used in this study is a ray-tracing model that predicts 3D contributions in any kind of urban configuration. This model complements the 3D urban model described in [1], as further contributions were added: rays interacting with distant obstacles in line-of-sight from the base-station but not obligatory from the user terminal. Ray-tracing models are today the best solution to estimate the site-specific space-time characteristics of the narrowband or wideband urban propagation channel, which is essential for the simulation of the performance of new radio systems [2]. Many works in the last decade present comparisons to wideband channel characteristics, such as the power delay profile, the delay spread or the angular spread [3]-[4]. Comparisons
between wideband measurements and predictions of the 3D urban model are presented as well in this paper, for high transmitters and long propagation ranges.

Section II of the paper presents results from the experimental characterization of the wideband propagation channel realized in the PLASMA DVB experimental platform in the city of Metz. The measurements are used for the tuning of the propagation model and for the evaluation of prediction performance: prediction of received power and prediction of the power delay profile. Section III describes the algorithms used to simulate the interference level and the SINR in DVB networks. Simulation results are proposed. Finally, section IV draws some conclusions.

II. EXPERIMENTAL CHARACTERIZATION OF THE PROPAGATION CHANNEL

Partners of the Semafor project realized various measurements in two different networks (an UMTS network in Paris and a DVB-H network in Metz) in order to evaluate the performance of the metrology platform as well as to investigate the narrowband and wideband characteristics of the propagation channel. This section reports two of the measurement campaigns that were carried out in the DVB-H network for characterizing the propagation channel around high-macrocell urban transmitters. Both campaigns take place within the PLASMA DVB experimental platform of TDF composed of three SFN transmitters around the city of Metz emitting on channel 50 (central frequency: 706MHz). The testbed is presented in Fig. 1. The transmitters Scy-Chazelles and Saint-Julien are located on the top of hills overhanging the city, thus providing a large coverage. The EIRP of all transmitters is 1kW. The antennas are vertically-polarized panel antennas with 60° half-power beam-width in the horizontal plane and 30° in the vertical plane.

A. Power level measurements

The first measurement campaign consists in collecting the power received in the streets when transmitter C2R or Scy-Chazelles is switched on. Actually the same measurement drive-test is realised twice for each transmitter. In the first trial, the transmitted signal is a continuous wave (CW) generated by the R&S SMH at frequency 706MHz. The receiver system measures the power received within a narrow bandwidth, i.e. approximately 8MHz. The acquisition time is 1ms. The receiving antenna is a vertical quarter-wavelength antenna positioned above a metallic plate that is fixed on the top of the vehicle. The total power provided to the transmitter antennas is monitored during all the measurement campaign to control the stability of the transmission. We observed, in particular, that the short-time variations of the power from the transmitted DVB and CW signals are lower than 0.1dB.

The CW drive-test permits to characterize the propagation loss and small-scale variations for one particular sub-carrier, whereas the DVB drive-test permits to characterize the propagation loss and small-scale variations for the total signal power. Besides, all these measurements are used to evaluate the performance of the propagation model tuning. Indeed propagation models are generally tuned from CW measurements, in order to benefit from a large signal dynamic and to avoid co-channel interference, although the aim of the tuned model is to predict the received power of wideband signals (UMTS, DVB). In our study, the propagation model to be tuned is intended to compute urban coverage maps with 5m-wide pixels. Therefore measurements are averaged over 5m-wide intervals to provide consistent comparison and error statistics.

The 5m-wide intervals where at least 5% of the raw measurements are under the bottom threshold (noise floor plus 3dB) are filtered out, thus most of the noise impact is removed. A similar rule applies for the top threshold of the receiver. The average number of measurements per interval is 540. Averaged powers from CW measurements are quoted CW-AP. Averaged powers from DVB measurements are quoted DVB-AP.

The difference DVB-AP minus CW-AP is calculated on the intervals where both values are valid. When the averaged powers are calculated from powers expressed in Watts, the mean difference is 0.77dB (from 6000 intervals around C2R and 7000 intervals around Scy-Chazelles). The mean difference is quite constant whatever the transmitter are, the reception area or the received power level. The standard deviation, which is quite constant whatever the transmitter are, the reception area or the received power level. The standard deviation, which is strongly impacted from various sources of mismatches between CW and DVB measurements (e.g. errors in the GPS locations, changes in the vehicle traffic, inaccuracy in the measure level, etc), is 3.49dB. This value is small enough to validate the consistency of the study showing that DVB-AP and CW-AP differs mainly from a small offset. One conclusion is that tuning a propagation model from averaged CW measurements may be convenient even for predicting wideband signals.

Remark that the value of the mean difference between DVB-AP and CW-AP depends on the way the average is performed. Computing the average from powers expressed in dBm gives a mean difference equal to 1.95dB. Computing the median power instead of the average gives a mean difference equal to 1.35dB.

Figure 1. PLASMA DVB experimental platform.
Besides, we determine statistics of the power variations around averaged powers CW-AP and DVB-AP. The power variations are calculated over each valid 5m-wide interval. Fig. 2 shows the cumulative distribution functions. The standard deviation of CW power variations around CW-AP is 4.6dB, although the standard deviation of DVB power variations around DVB-AP is about 2.3dB.

B. Performance of the propagation model tuning

The tuning consists in adjusting some parameters of the propagation model such that the error between measurements and predictions is minimised. The tuning of the 3D urban model done with CW-AP measurements gives parameters very similar to the ones from DVB-AP measurements, except the offset parameter varying from about 1dB. Therefore the usual process that consists in tuning propagation models from CW measurements can be used advantageously to predict coverage of wide-band signal networks. The tuning needs only to be corrected by a small offset that depends on the signal bandwidth and the measurement post-processing (averaging interval and power unity).

The error standard deviation of the 3D urban model tuned from DVB-AP measurements (averaged from powers in dBm) is 6.2dB. The mean error is 0.0dB. The error distribution is illustrated in Figure 3.

Predictions of this tuned 3D urban model are compared as well to the raw (or non-averaged) measurements. All measurements contained within the same 5m-wide interval are compared to the same predicted average power. This comparison gives an error standard deviation equal to 6.7dB and a mean error equal to 0.0dB. The error distribution, presented in Figure 3, gives the value of the margin that must be added to predicted powers in order to assess the power level exceeded in x% of the time. The error distribution can be roughly approximated by a log-normal law.

C. Wideband channel characteristics

In the second measurement campaign, the reception equipment is the demonstrator developed in the frame of the IST project ANTIIUM and the French research project SEMAFOR. The demonstrator shown in Figure 5, including an array antenna, is able to acquire different kinds of waveforms, i.e. WCDMA (UMTS-FDD and UMTS-TDD) and OFDM (DVB-T/H and WiMax), and to realize off-line processing in order to detect and to identify interfering signals and transmitters [5]. The calculation of the impulse response is an essential part in the interference analysis process. The capacity of the demonstrator to measure impulse responses with large power dynamics is used here to characterize the wideband propagation channel around urban macrocell transmitters and to evaluate the predictions of the 3D urban model.

The antenna array of the demonstrator is composed of five antennas positioned on a metallic plate fixed on the roof of the vehicle. The output from each antenna is processed independently, thus providing five different acquisitions of the impulse response. Measurements are realized in 51 locations in the center of Metz, as illustrated in Figure 4. The acquisition at each of these locations lasts 600ms, while the vehicle is moving. An impulse response is processed and stored every 4ms for each antenna output. The sampling period of the impulse responses is 109ns. Measurements presented in this paper were realized when the transmitter Scy-Chazelles is switched on. This configuration provides a large variety of impulse responses, which turned out to be challenging for the interpretation and the evaluation of the propagation model.

Acquisitions of the impulse response are processed to get one averaged Power Delay Profile (PDP) per location, i.e. averaged over the five outputs and over the whole acquisition time. The difference between the peak power in the PDP and the noise floor is in the range from 44dB to 56dB. Excess-delays up to 11μs are observed for significant contributions (power relative to the peak is greater than –15dB), which means that strong far interactions (excess propagation path greater than 3.3km) occur in this environment. Fig. 5 shows the delay-spread measured at each location. The delay-spread is calculated only from the samples with power relative to the peak greater than – 42dB. It varies strongly from one location to the other. In particular, we observe very large delay-spreads in two different areas: from location 25 to location 29, where the receiver is in a valley; from location 33 to location 39, where the receiver is in the dense urban center. The total received power in these areas is lower than total received powers collected elsewhere. The direct path is strongly attenuated either by a hill or by the downtown buildings. Thus the relative powers of contributions coming from distant interactions become significant and increase the spread of the delays.

Figure 2. Cumulative distribution function of the power variations around AP.

Figure 3. Cumulative distribution function of the prediction error when compared to DVB averaged measurements or DVB raw measurements.
For the simulation purpose, different receiver points are created along 30-meter-long paths parallel to the street and centered on each measurement location. Predictions are realized at all these points with up to 4 reflections and 1 diffraction allowed for each single ray. Delay-spreads are computed following the same rule as for measurements. One averaged delay-spread is calculated for each location, as shown in Figure 5. The prediction is able to find the main variations of the measured delay-spreads, except in two areas. First, the prediction is pessimistic in locations from index 1 to 5. The reason is certainly that these locations are at the boundary of the high-resolution geo map data representing the city. Therefore strong interactions with buildings beyond this boundary cannot be simulated. Second, the prediction is pessimistic in locations from index 33 to 39, actually in the dense urban part of Metz. As illustrated in Figure 6 at location 36, the ray-tracing simulates only few contributions from distant interactions. The reason is that most of this kind of contributions is strongly attenuated by the dense urban area. We assume that the measured delayed contributions are generated from a distant interaction and then from canyoning in the urban centre, which is not yet simulated.

Finally, the ray-paths predicted at locations 26 are shown in Figure 6 to illustrate what happens in locations from index 25 to 30; a great number of rays with large delays are generated by reflections/diffractions on the buildings located on the hills surrounding the receiver. Both the measure and the prediction give high delay-spreads in these locations.

The predicted and measured delay-spreads are very sensitive to the power of the main contributions of the PDP (especially the direct-path). Consequently, an error in the prediction of one of these powers misleads significantly the prediction delay-spread. Then estimating accurately the delay-spread at a precise location seems tricky. However, as shown in this paper, the ray-tracing can assess the main tendencies of the delay-spread. It is able to detect the areas where the risk for large inter-symbol interferences is important. The radio network planning might use advantageously this ability. And in some circumstances, when transmitters are on air, the prediction of possible interferences might be checked by a metrology equipment.

III. SYSTEM PARAMETERS PREDICTION

A. Prediction of the DVB SINR

The prediction of the total received power is the basic propagation result for the simulation of the DVB network coverage. The received SINR is calculated from the total received power, provided that the excess delay of the multi-paths coming from the same transmitter is considered as negligible compared to the guard interval. Besides wideband channel predictions can be used to simulate system parameters that are related to the delay or angle dispersions: inter-symbol-interferences, receiver SINR threshold (system simulations show significant variations of the SINR threshold depending on the characteristics of the channel impulse response) or performance of a MIMO system.

We present in this section the impact of the wideband channel prediction on the calculation of the inter-symbol-interference and SINR level in an environment with high delay dispersion. The propagation model predicts the power delay profile at a given receiver, composed of multiple contributions coming from on-channel transmitters located or not in the same SFN cell (Single Frequency Network). The total useful signal $U$ and the total interfering signal $I$ are calculated by the addition of these multiple contributions:

$$ U = \sum_{m=1}^{M^*} \sum_{i=1}^{N(m)} w_i \cdot P_{m,i}, $$

$$ I = \sum_{m=1}^{M^*} \sum_{i=1}^{N(m)} \left(1 - w_i\right) \cdot P_{m,i} + \sum_{m=M^*+1}^{M} \sum_{i=1}^{N(m)} P_{m,i} $$

Where $U$ is the total power of the useful signal; $I$ is the total power of the interfering signal; $M$ is the total number of
transmitters; $M'$ is the number of transmitters from the same SFN network, i.e. the $m^{th}$ transmitter belongs to this SFN network if $m \leq M'$; $P_{m,i}$ is the power of the $i^{th}$ path from transmitter $m$; $N(m)$ is the number of paths from transmitter $m$; $w_i$ is a weighting coefficient from 0 to 1 that determines the portion of the $i^{th}$ signal power that is of benefit to the Useful signal $U$. The coefficient $w_i$ depends on the time of arrival of the $i^{th}$ signal [6].

The prediction uncertainty on each path contribution $P_{m,i}$ is commonly assumed to be log-normally distributed. Thus the calculations of the useful signal $U$ or interfering signal $I$ consist in the sum of correlated lognormal components. As well, the calculation of the SINR consists in the ratio of two correlated lognormal component [7]. The correlation between contributions coming from different transmitters is usually chosen equal to 0.5. The correlation between contributions coming from the same transmitter is chosen equal to 1, for simplicity in the frame of our study.

### B. Simulation results

The simulation setup is composed of the high DVB-T transmitter located on a hill, 60m above the ground, in an urban environment. Fig. 7 shows the simulation setup. The EIRP is 60dBm. The parameters of the simulated DVB-T signal are UK parameters: 16QAM 3/4, 8MHz, 2k mode, guard interval 1/32. The guard interval is $7\mu$s, i.e. corresponding to a length of 2.1km. The SINR threshold is assumed to be 16dB. The 3D urban model predicts the propagation channel at the street-level receiver location shown in Fig. 7. The total received power is $-49\text{dBm}$. Some strong reflections, occurring in the South of the area shown in Fig. 7, generate excess-delays larger than $7\mu$s. The estimated delay-spread is $2.64\mu$s. If the predicted PDP is not taken into consideration, then the calculated interference level is null, the SINR level is limited only by the noise. However when multi-paths are considered in the calculation, the interference level appears to be only $9.1\text{dB}$ under the useful signal level, as shown in Table I.

<table>
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<th>Simulation</th>
<th>SINR 95%</th>
<th>Cover.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Not considering PDP</td>
<td>SINR 95% = SNR 95% = 39.0 dB</td>
<td>Yes</td>
</tr>
<tr>
<td>Considering PDP</td>
<td>SINR 95% = (U/I) 95% = 9.1dB</td>
<td>No</td>
</tr>
</tbody>
</table>

### IV. Conclusion

New air interfaces exhibit a wide bandwidth mainly to increase the system capacity. This impacts the radio network planning and the related measurement and simulation tools. A research project, Semafor, was set up to evaluate and possibly enhance a measurement prototype and a simulation tool to investigate the characterization of the interference levels of these networks. The hardware prototype is equipped with antenna arrays and powerful algorithms to detect low interference levels (even in the presence of strong interferers) for various waveforms (3G, WiMax, DVB). The simulator is based on a refined propagation model able to estimate accurately the paths coming from long-range obstacles, as illustrated by comparisons to real measurements. The impact of the multipath first on the reception level and then on wideband system parameters has been studied.

The prototype tools used in the frame of the project will be further adapted to the characterization of ultra wide band signals.

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