LDM Core Services Performance in ATSC 3.0

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***Abstract*— ATSC 3.0, the new generation digital terrestrial television (DTT) standard, has been designed for facing the new challenges of the future broadcasting systems. ATSC 3.0 has been built using the most recent cutting-edge technologies. Layered Division Multiplexing (LDM) is one of the major components of the new system baseline. LDM provides a tool to make flexible use of the spectrum for delivering simultaneous services to stationary and mobile services. This paper presents the performance evaluation of ATSC 3.0 core services in mobile scenarios using LDM. Simulation results are presented to analyze the influence of different LDM ensemble configuration modes for mobile reception. The simulation results have been also confirmed by laboratory tests under different channel models. The Signal to Noise Ratio threshold values confirm the excellent behavior of ATSC 3.0 and LDM in mobile and portable scenarios.**

***Index Terms*— ATSC3.0, indoor performance, laboratory measurements, Layered Division Multiplexing, mobile performance, new generation broadcasting systems, simulations.**

I. Introduction

The physical layer of the Advanced Television Systems Committee (ATSC) 3.0 standard has been designed to be a flexible, robust and efficient new generation tool for delivering high quality video and audio contents. A major goal of the design process has been to furnish the system with as much flexibility for adapting the standard to a variety of markets as well as the ability to enable dynamical configurations that facilitate the fast adaptation to the rapidly changing devices and services marketplace. The comprehensive work carried out in the Ad-hoc groups [1],[2] has led to a DTT standard that includes state-of-the-art technologies as well as the appropriate architecture to integrate smoothly new techniques that will come in the future. This new candidate standard, ATSC A/322 [3], presents an important quality leap, and therefore, it is not backwards compatible with the previous ATSC A/53 standard [4]. Even though, the high flexibility of the system will allow its own evolution, guaranteeing support of future ATSC 3.0 versions.

As the number of portable devices has rapidly increased, the delivery of high-quality TV mobile services has become one of the top priorities for the new generation broadcast systems. The optimization of fixed and mobile services has been considered equally important, and thus, new multiplexing techniques that allow a better balance between both services have been considered. As a consequence, one of the key features that makes the standard unique is the inclusion of LDM that enables the use of a single RF channel for delivering high capacity services to fixed receivers and low complexity-robust services to mobile receivers[5]-[12]. LDM splits the total transmission power into two components (layers) that overlap in frequency (upper and lower layers). It has been both theoretically and practically proved that this technique can offer notable gains in terms of performance when comparing it with other classical multiplexing approaches, such as Time Division Multiplexing (TDM) or Frequency Division Multiplexing (FDM) [13]. In addition, in [14] it has also been demonstrated that the required complexity increase for adopting this technology is close to 15%. This value is not critical for a new generation system, especially when in return the system mobile performance threshold can be improved by a value in the range of 3 to 7.2 dB, depending upon the specific configuration [15].

In the recent years, the term mobile has become a very broad meaning term. From a broadcaster's perspective, the National Association of Broadcasters (NAB) has presented a more focused definition of what is considered as mobile service [16]. The NAB association expects that the new ATSC 3.0 system should be robust enough to guarantee a correct reception with pedestrian handheld receivers in outdoor and indoor environments. Vehicular built-in receivers, handheld in-vehicle devices and portable devices used in indoor scenarios should also correctly receive TV services. Besides, a successful mobile reception at ground speeds of at least 150 km/h is expected feasible.

The main objective of this paper is to study the performance of ATSC 3.0 in mobile scenarios for delivering multiplexed

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core services as defined by the broadcast industry [17]. The first part of the paper will be focused on studying the use cases and basic requirements for the new broadcast standard. The main ATSC 3.0 signal characteristics involved in mobile reception will be studied by means of computer simulations. The outcome of this first part is going to be crucial to understand where the gain of the LDM technology comes from and to show the influence of some of the signal configuration parameters in mobile scenarios. Afterwards, comprehensive laboratory measurements results will be presented, which will draw the first performance boundaries for the ATSC 3.0 system reception.

The paper is organized as follows. Section II summarizes the core broadcast services defined in ATSC 3.0 while Section III describes the ATSC 3.0 transmitter and receiver. Then, Section IV introduces a numerical analysis of the key ATSC 3.0 signal parameters for mobile reception and using LDM modes. Afterwards, Section V introduces the laboratory measurements. Finally, Section VI provides the performance results for different configurations and tested scenarios, while Section VII summarizes the main conclusions and contributions of this paper.

II. ATSC 3.0 Core Broadcast Services

There are three main technical challenges that a new broadcasting system must overcome in order to preserve the prevailing role of the terrestrial television in the wireless video delivery [18]. In the first place, it should provide tools for a flexible and robust use of the spectrum, secondly, it should include the latest technology improvements intended to increase the spectrum efficiency, and finally, it must improve mobile and indoor reception robustness. The ATSC 3.0 core services include an ensemble of various broadcast services, some targeting portable/mobile receivers and others delivered with bitrates and robustness requirements typical of fixed reception.

The efficiency of the new standard will be associated to the video coding technologies. This is an area where significant improvements have been achieved from past to new generation of codec standards. A paradigmatic example is High Efficiency Video Coding (HEVC) that can achieve a significant gain when compared to previous standards [19] [20]. On average, HEVC offers a 40% gain over H.264 [21] for delivering High Definition (HD) contents (720p or 1080p).

With these gain values in mind, assumed a video throughput of about 3 Mbps allocated to the mobile/indoor services is considered in this paper. This throughput can convey three Standard Definition (SD) or one HD services using HEVC. The stationary service, on the contrary, can range from 8 to 25 Mbps, in order to be able to guarantee the delivery of several HD and/or Ultra High Definition (UHD) contents [22].

III. Overview of LDM in ATSC 3.0

A. *ATSC 3.0 LDM Main configuration Parameters*

ATSC 3.0 presents a wide range of different configuration modes depending on the desired robustness and capacity. ATSC 3.0 is based on Orthogonal Frequency Division Multiplexing (OFDM) with a set of modulation options ranging from QPSK to 4096 non-uniform QAM. It is possible to configure two different Low Density Parity Check (LDPC) code lengths and twelve code rates for different robustness. There are also twelve possible guard interval (GI) lengths from about 30 to 700 msec and 16 possible scattered pilot patterns (PP), that help the receiver estimate the channel conditions on several reception scenarios, including fixed, mobile and portable and taking into account challenging conditions such as harsh SFN echo configurations. The standard provides three possible FFT sizes (8K, 16K and 32K) depending on the necessary protection against Doppler of the target service. In line with previous standards, ATSC 3.0 has included the concept of Physical Layer Pipes (PLPs). PLPs are independent configurations of physical layer resources, in order to convey a variety of services with different independent bitrates, robustness and multiplexing choices.

This paper considers two LDM layers each one configured as a single Physical Layer Pipe (PLP). The system robustness is then evaluated using two different services and assuming equal robustness for video, audio, and metadata.

On the case of a single PLP per layer, the standard provides a convolutional interleaver with four possible interleaving lengths ranging from approximately 50 to 200 msec.

A basic configuration parameter of LDM is the injection level (IL). The IL defines how deep the lower layer (LL) is buried below the upper layer (UL) and how the transmission power is distributed between the two layered signals. This value can range from 3.0 to 10.0 dB in steps of 0.5 dB.

B. *ATSC 3.0 LDM Transmitter*

A block diagram of the main data flow for the ATSC 3.0 LDM transmitter system architecture is shown in Fig. 1. The system architecture consists of four main parts: Input Formatting, Bit Interleaved and Coded Modulation (BICM), Framing & Interleaving, and Waveform Generation (pilots, OFDM and GI insertion). For simplicity, signaling and preamble information are not shown in this diagram.

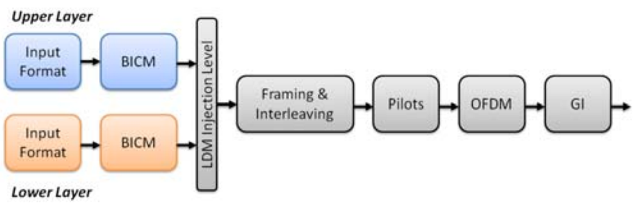

Fig. 1. ATSC 3.0 LDM Transmitter block diagram

In a LDM system composed of two layers, most parts of the transmitter are shared by both layers (shown in grey color in Fig. 1) with the exception of input formatting and BICM modules (shown in blue and red in Fig. 1 for UL and LL, respectively). In this way, each data stream can be separately configured in terms of channel coding and modulation according to its target receivers (fixed, mobile, portable).

C. ATSC 3.0 LDM Receiver

Fig. 2 shows the main building blocks of an ATSC 3.0 LDM receiver. The synchronization, Waveform Detection (GI removal and OFDM) and equalization blocks are common for the two layers while an independent decoding block (DeBICM) is needed for each layer.

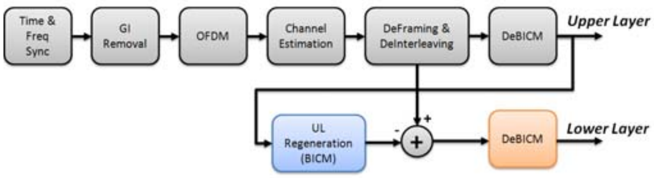

Fig. 2. ATSC 3.0 LDM Receiver block diagram

Besides, the upper layer signal cancellation from the received signal is required for lower layer decoding [23].

IV. Key Factors for Core Services Reception

This section presents the physical characteristics of an ATSC 3.0 signal that are relevant as key performance indicators for correct reception in mobility.

Besides, a short study is carried out in order to shed some light on the possible receiving performance issues of the core services defined previously. This study is based on obtaining the Signal to Noise Ratio (SNR) thresholds for correct reception. These thresholds are results of computer simulations and assume perfect time and frequency synchronization, while considering ideal channel and Additive White Gaussian Noise (AWGN) estimations. The correct reception condition is a Bit Error Rate (BER) value at the output of the outer coder lower than 10^{-6} [24]. This value is a reliable tradeoff between simulation time and system performance. The RF channel frequency used during the computer simulation phase is 590 MHz.

A. Injection Level penalty on LDM

LDM is based on splitting the available transmission power into two layers, and due to this power split the UL will suffer from inter-layer interference. At the receiver, the LL acts as interference for the UL. As a result, the UL SNR threshold in LDM depends on the single layer SNR threshold and the defined injection range, as shown in (1). SNR_{UL} stands for the SNR threshold of the UL signal in the LDM system while SNR_{SL} is the SNR threshold value of the single layer configuration and Δ is the injection level between both layers. All units are in decibels (dB).

$$SNR_{UL} = SNR_{SL} - 10\log_{10}\left(\frac{1-10^{\frac{(SNR_{SL}+\Delta)}{10}}}{1+10^{\frac{\Delta}{10}}}\right). \quad (1)$$

Following (1), in Fig. 3 the SNR_{UL} threshold is shown as a function of Δ and the SNR threshold of the single layer configuration.

The lower the injection level, the more power is shared with the LL. Therefore, the UL signal power is lower and, consequently, the SNR_{UL} threshold increases. For instance, in Fig.3 vertical lines show that if the desired SNR_{UL} threshold is kept constant at a value of 0 dB, the UL single layer configuration should guarantee an error free reception threshold of {-3, -2.5, -2.1, -1.75} dB, for Δ={-3,-4,-5,-6} dB injection levels, respectively.

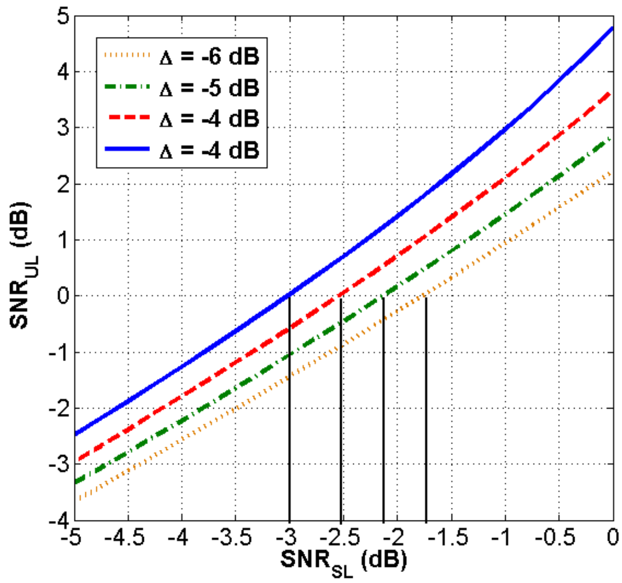

Fig. 3 Upper layer minimum SNR depending on the selected injection level and selected configuration receiving threshold.

B. Inter-Carrier Interference (ICI)

One of the main novelties of ATSC 3.0 standard in comparison with the previous A/53 is the adoption of OFDM as the physical layer waveform [25]. On the one hand, OFDM is one of most efficient techniques for delivering services in severe multipath environments. On the other hand its main weakness is the orthogonality loss that occurs in mobile environments. As explained in [26], the impact of ICI is usually measured through the relationship between the existing maximum Doppler frequency, f_d, and the carrier frequency space, $\Delta f = 1/T_u$, which depends on the OFDM symbol duration, T_u. It has been demonstrated in [27] that this ICI leads to the presence of a Doppler noise. Doppler noise increases exponentially as the receiver speed goes up.

The overall shape of the ICI and its relevance on the final threshold can be seen in Fig. 4. In this figure, the dashed blue line represents the ICI power obtained through experimental analysis from the behavior of the received OFDM physical waveform considering a Typical Urban 6 paths (TU-6) channel model with different normalized Doppler values, f_dT_u.

The continuous blue line plots the theoretical upper bound for Doppler degradation described in [26], which aligns well with the practical results of the presented simulations. In addition, the dashed black line represents the total transmitted signal power (0 dBm) and the colored dashed lines show the allowed Additive White Gaussian Noise (AWGN) power for an error free reception according to the selected modulation scheme and code-rate. For instance, if QPSK modulation and

4/15 code rate is selected the total tolerable AWGN power is 2.9 dBm (violet line).

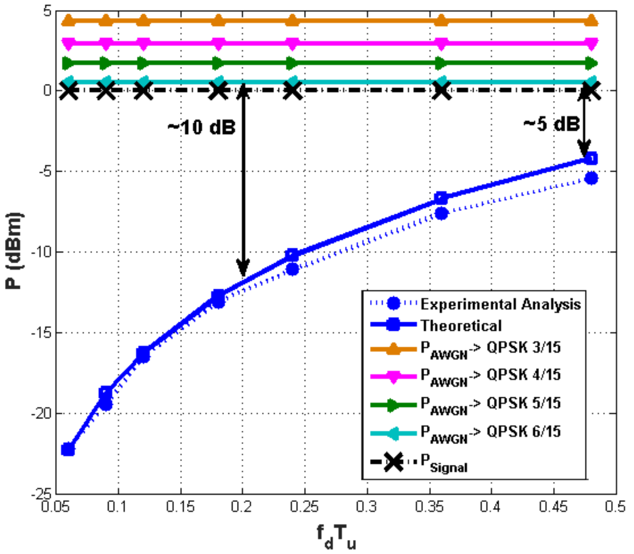

Fig. 4. ICI influence in a TU-6 channel and the tolerable AWGN power for different signal configurations.

When the tolerable AWGN power values are compared with the ICI power values in the analyzed cases, it can be seen that the difference is at least 5 dB for the worst case. In this case, there will be some degradation on the receiver performance, but for many of the rest cases, especially with differences higher than 10 dB, AWGN masks completely the impact of ICI..

These results confirm the viability of using higher FFT sizes (16K, 32K) for mobile scenarios.

C. *Time Interleaving (TI) Depth*

The main objective of this subsection is to confirm the impact of different TI lengths on the receiver performance in mobility.

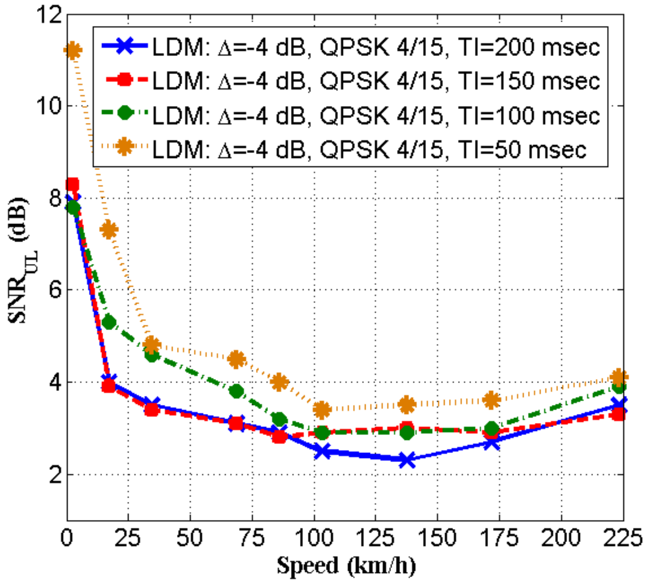

Fig. 5. UL SNR thresholds for different receiving speeds and the four ATSC 3.0 time interleaving lengths.

Fig. 5 shows the results of the simulations carried out for evaluating the performance in terms of SNR_{UL} threshold, using the four different TI depths described in the ATSC 3.0 standard (200, 150, 100 and 50 msec) which correspond to 1024, 887, 724 and 512 rows of a convolutional interleaver, respectively.

Increasing the TI length provides higher gains at low speed scenarios (speed < 20 km/h), where critical fading appear (about 3 dB difference between the extreme TI depths). For high speed scenarios (speed > 20 km/h), the time variability of the channel acts as a natural interleaver itself, and therefore, the gain is lower (ranging from 0.5 to 1.5 dB for minimum to maximum TI depths respectively).

D. *SNR estimation impact on LDPC decoding*

This subsection presents a discussion on the impact of an SNR miscalculation in the LDPC decoding performance. It is well known that the LDPC decoding algorithm takes as input the soft decision values or metrics, which are also known as Log-Likelihood Ratios (LLR). The LLR reliability depends on the channel estimation, ρ, and the overall noise power, N_0, as shown in (2):

$$LLR\ (I_r, Q_r / I_t, Q_t) = \frac{1}{2\pi \times N_0} e^{-\left(\frac{(I_r-\rho I_t)^2-(Q_r-\rho Q_t)^2}{2\times N_0}\right)}, \quad (2)$$

where (I_t,Q_t) and (I_x,Q_x) represent the transmitted and received cell pairs respectively.

As discussed in subsection III-B, when the ICI is high (high receiver speeds), there is a Doppler noise contribution that cannot be neglected and should be taken into account. Fig. 6 shows two performance curves in terms of SNR threshold for a QPSK 3/15 signal over a TU-6 channel for different normalized Doppler values (f_dT_u).

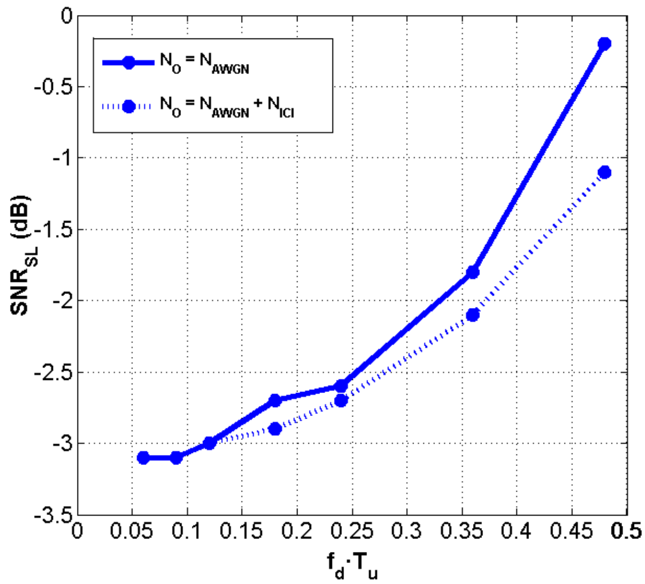

Fig. 6. SNR thresholds for different mobile conditions and noise estimation algorithms.

The continuous line ($N_0=N_{AWGN}$) represents the case where the ICI power is not considered for the overall noise calculation, whereas the dashed line ($N_0=N_{AWGN}$ + N_{ICI}) represents the case where the overall noise power, Gaussian plus Doppler, is taken into account.

For high Doppler scenarios, a SNR threshold gain of almost 1 dB can be achieved if the Doppler Noise contribution is considered. Nevertheless, for low speed scenarios, there is a small gain, always lower than 0.5 dB, or even no gain for pedestrian speeds.

E. Code Rate

This subsection is analyzes the impact of using different code rates in mobile scenarios. Fig. 7 shows the SNR threshold values for the UL with several code rate configurations. The FFT size is 16K and the GI length is 150 msec. The modulation is QPSK and the code rate ranges from 3/15 to 6/15, covering capacities ranging from about 2 Mbps to 4 Mbps respectively. This range has been defined previously on the description of the ATSC 3.0 core services. Finally, it should be mentioned that in this case the LDM signal has a -4 dB injection level and the maximum TI length defined in ATSC 3.0 (200 ms) is used.

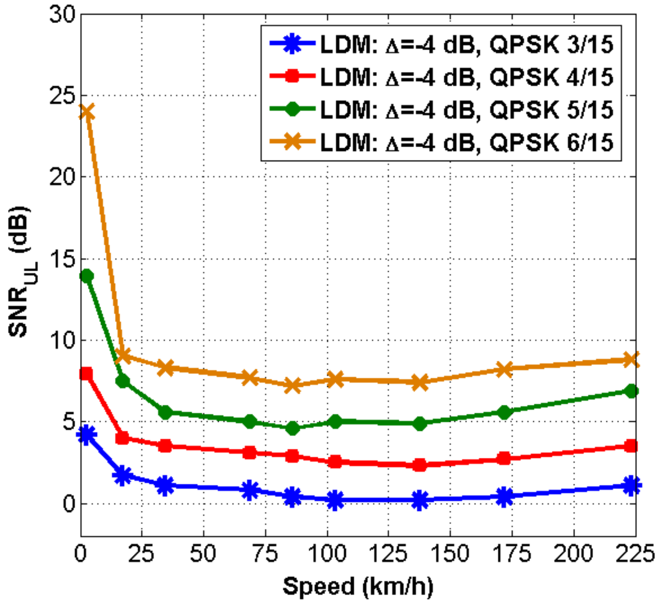

Fig. 7 SNR thresholds for different code rates in ATSC 3.0

On the one hand, the difference in SNR threshold for different code rates depends on the speed of the receiver, with differences of about 2 dB between consecutive code rates for high speed scenarios (speed > 20 km/h). However, the differences in SNR threshold for low speed scenarios (speed < 20 km/h) can be up to 10 dB considering consecutive code rates.

On the other hand, the SNR thresholds at low speeds are higher because the biggest challenge is not the ICI, but the possible flat fading that may happen due to the channel slow time variability. Therefore, in order to overcome this drawback, the time interleaver should be increased. Thus, depending on the target use case, the time interleaving length is more important than the ICI on a specific FFT size associated to a certain receiver speed.

Finally, the performance curves are almost flat for speeds that range from 10 km/h to 175 km/h, meaning that the ICI degradation due is not significant and remains masked under the AWGN. However, for very high speeds (speed > 175 km/h) the ICI impact and exceeds the AWGN. In this case the SNR threshold is degraded accordingly, as explained in subsection III-B.

V. ATSC 3.0 Laboratory Measurements

This section describes the different steps involved in evaluating the performance ATSC 3.0 LDM core services by laboratory measurements. These tests target the system performance under non-ideal transmission conditions: transmitter Modulation Error Rate (MER), clock errors, quantification errors, and sampling rate mismatches between transmission and reception.

First of all, the signal configurations under test are presented. They are based on requirements and numerical considerations described in Section II and Section IV. Afterwards, the most representative channel models for the use cases are described and, finally, the laboratory measurements set-up is described, including the processing methodology.

A. Signal Configuration

ATSC 3.0 LDM layers are added at the Bit Interleaving Coded and Modulation (BICM) output, and thus they share some configuration parameters for the OFDM physical waveform: TI, GI, and FFT size. For the study of the ATSC 3.0 LDM core services, a 16K FFT has been selected with a 150 msec GI length (1024 samples), which is a good compromise between the Doppler resilience tolerance for the UL and the overhead due to the GI for the LL. The chosen pilot pattern is $PP_{6,2}$, where the separation of pilot bearing carriers in frequency is D_x=6 and the number of symbols forming one scattered pilot sequence in time is D_y=2. This offers a density strong enough to perform accurate channel estimation under the worst multipath scenarios. For all the considered mobile/indoor configurations, the stationary service has been fixed to a good tradeoff between robustness and capacity. Additional important configuration parameters matching ATSC 3.0 core services requirements described in Section II, can be found in Table I.

The capacity, C (Mbps), shown in Table I is calculated based on (3):

$$C=\log_2 M\times CR\times\frac{S_{samples}}{S_{samples}+GI_{samples}}\times(1-PP_{overhead})\times S_{BW}, \quad (3)$$

where M stands for the modulation order, CR for the total code rate calculated as a combination of LDPC and BCH protection codes *(CR = CR_{LDPC} x CR_{BCH})*. CR_{LDPC} is obtained from Table I while CR_{BCH} takes a fixed value of 133/135 for long length LDPC codes (64K). $S_{samples}$ stands for the samples of each OFDM symbol depending on the FFT size, while $GI_{samples}$ stands fot the number of samples of the GI. $PP_{overhead}$ is the pilot pattern overhead obtained as $(1/D_x \times D_y)$ while S_{BW} is the signal bandwidth. In this case, for a 6 MHz channel, an occupied bandwidth of 5.75 MHz is considered.

TABLE I
LDM SIGNAL CONFIGURATIONS FOR THE USE CASES.

MAIN CHANGING PARAMETERS			
TI Depth (msec)	Injection Level	Upper Layer	
		MOD-CR$_{LDPC}$(*)	Capacity (Mbps)
200	-4 dB, -5 dB	QPSK 3/15	2.0
		QPSK 4/15	2.6
50		QPSK 5/15	3.3

MAIN COMMON PARAMETERS				
Bandwidth (MHz)	FFT / GI (samples)/ PP	Frame Length	Lower Layer	
			MOD-COD(*)	Capacity (Mbps)
6	16K|1024| PP$_{6,2}$	200 ms	64QAM 7/15	13.7

(*)MOD-COD: Modulation and Code-Rate Combination

In addition, two injection levels, Δ={-4,-5} dB, have been selected. These values offer a balance between enhancing the mobile layer performance and maintaining a reasonable coverage for fixed services.

Finally, the maximum and minimum TI lengths defined in ATSC 3.0 (50 and 200 msec) have been also included in order to study the TI implication in a real system.

B. Channel Models

Following the OFDM physical waveform definition, the next step is to define the channel models that will represent best the ATSC 3.0 core services application scenarios, including mobile and indoor portable cases [18].

Considering the wide acceptance of the TU-6 channel model for mobile reception performance evaluation the results in this paper will be restricted to this case [28]. Besides, Pedestrian Indoor (PI) and Pedestrian Outdoor (PO) [29] will be considered for handheld reception in indoor and outdoor scenarios, respectively. These models have been used in previous standard design processes in Europe. TU-6, PO and PI are the most used channels in broadcasting and therefore, a direct comparison with a lot of previously presented mobile performance results is feasible.

C. Laboratory set up

The implemented laboratory test bench is depicted in Fig. 8. The overall analysis process can be split into two different phases.

Firstly, the ATSC 3.0 signal must be generated, passed through the desired channel model and finally stored in a hard disk. The first half of this process is software based, where the signals are generated, as In Phase and Quadrature samples (IQ) files, in a PC running an ATSC 3.0 baseline physical waveform software implementation. The hardware part consists of a general purpose Vector Signal Generator (VSG) with the capability of modulating the IQ files into the selected radiofrequency (RF) channel, which is defined in 590 MHz. The transmitter is connected to a RF channel emulator where the desired channel models (TU-6, PI and PO) are implemented. Finally, its output is directly recorded on a hard disk by a Vector Signal Analyzer (VSA), which digitalizes the signal fed into its RF input.

During the second phase, which is based on software, all the data stored in the hard disk has to be post-processed in order to obtain the system performance. For this purpose, increasing values of AWGN power are added by software to the stored IQ file, using steps of 0.2 dB. The starting and ending noise power values are choices based on the simulations results from Section III. As the tested channel models are mobile, the noise is injected symbol by symbol in the frequency domain, guaranteeing a controlled constant relation between the signal and noise powers. Afterwards, all the data is processed with an ATSC 3.0 Software Defined Radio (SDR) receiver, in order to obtain the SNR thresholds. The implemented channel estimation and carrier recovery methods can be found in [29].

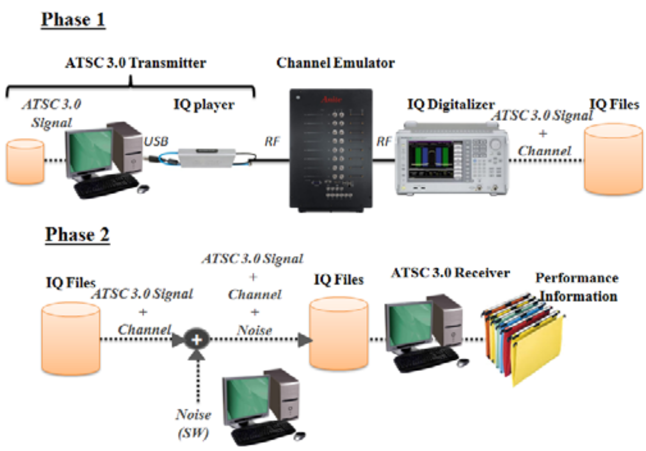

Fig. 8. Laboratory measurements set-up

In these laboratory tests, the error free reception condition is a null FEC Block Error Rate (FBER) [29]. In other words, the reception is erroneous when there is at least one erroneous FEC block within the analyzed signal time length, which has been established in 10 seconds. For the low speed cases (TU6 at 3 km/h, PI and PO channel models), 20 different measurements of 10 seconds have been carried out in order to increase the number of channel realizations. The reason is that for low speeds, a long observation time is necessary for relevant channel state changes, while at higher speeds, the channel varies much quicker and less time is required.

VI. RESULTS

This section describes the performance evaluation of the LDM signal configurations of Table I based on laboratory measurements and using the channel models presented in Section V.B. As being this paper is focused on ATSC 3.0 mobile performance only UL performance results are presented in this section. The results have been divided in two different subsections: mobile and indoor core performance.

A. Mobile Core Services

In this subsection, the core services performance for mobile scenarios based on laboratory measurements is analyzed. Fig. 9 and Fig. 10 show the SNR threshold for the UL configurations defined in Table I for different receiver speeds. Results are obtained for 200 and 50 msec TI length, respectively.

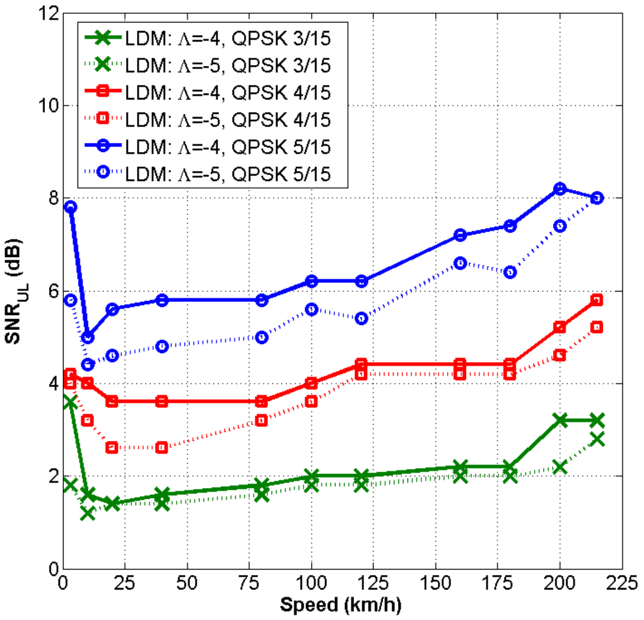

Fig. 9 . Performance evaluation of ATSC 3.0 for different code rates and injection levels in mobile scenarios for 200 msec TI length.

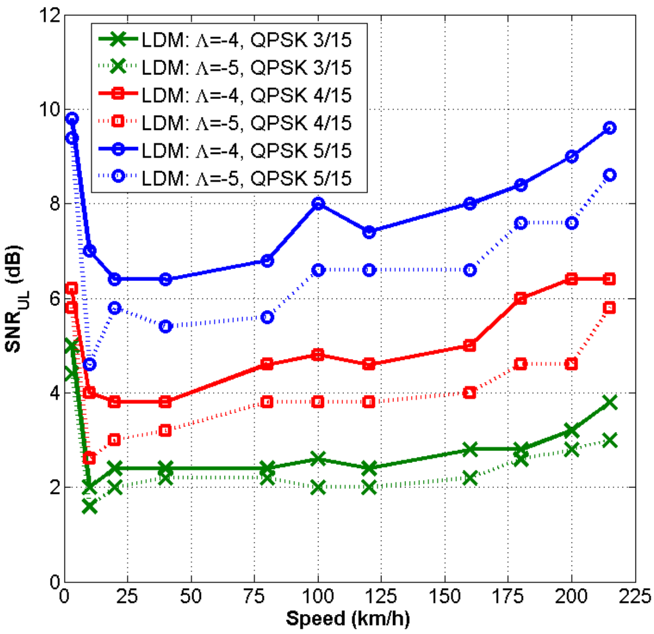

Fig. 10 . Performance evaluation of ATSC 3.0 for different code rates and injection levels in mobile scenarios for 50 msec TI length.

The results show the same behavior as simulations with exception of low speed values where the obtained SNR thresholds are lower than expected. This is due to a channel modeling initialization difference in simulations and hardware tests. In simulation and hardware cases there are different realization seeds of the TU6 channel model at 3km/h.

On the one hand, QPSK 3/15, which is the most robust configuration tested, shows an almost flat performance for speeds in the range from 30 to 175 km/h with differences lower than 0.5 dB. However, a decrement in the robustness means an increment in the performance slope with differences of up to 1.5 dB for QPSK 4/15 and 2.0 dB for QPSK 5/15. This is because the in these cases the receiver speed makes the SNR thresholds closer to the ICI power and, thus, the degradation increases. Higher speeds (speed > 175 km/h) show always additional degradation as the receiver uses well-known channel estimation, interpolation and filtering algorithms that are not optimized for very high speeds and the performance could be improved for these challenging scenarios.

On the other hand, the change in the IL between -5 and -4 dB suggests performance degradation, in any case lower than 2.4 dB, with a median degradation value of 0.6 dB, which agrees with the simulation results in Section III.

Finally, the SNR threshold for different TI lengths also follows the simulations on Section III. For high speed reception (speed > 20 km/h) there is a median gain value of 0.6 dB between the longest (200 msec) and the shortest (50 msec) TI length values. In case of low speed reception (speed < 20 km/h), the gain due to the use of longer TI causes an increase up to 2.6 dB. Furthermore, the median value of the gain for 3 km/h is 1.9 dB while it reduces down to 0.6 dB for 10 km/h. This is due to the longer time measured for pedestrian speed (3 km/h) in comparison to the one carried out at 10 km/h. The first case has included more realizations of the slow fading channels and, consequently, shows a higher influence of the TI length on the SNR threshold.

The performance under the PO channel model has been also tested and the conclusions are similar. Table II show the SNR threshold for the UL considering different injection levels (IL) and TI lengths.

TABLE II
ATSC 3.0 PEDESTRIAN OUTDOOR PERFORMANCE SNR (DB).

Pedestrian Outdoor					
UL Configurations		Time Interleaving Depth & Injection Level (dB)			
		1024		512	
		-4dB	-5dB	-4dB	-5dB
QPSK	3/15	2.0	1.0	2.6	2.8
QPSK	4/15	3.2	3.2	3.0	3.4
QSPK	5/15	5.4	4.2	5.6	5.2

On the one hand, the gain due to the increment in the IL from -4 to -5 dB ranges between 0 and 1.2 dB, with a median degradation of 0.5 dB, which agrees with the simulation results in Section II. On the other hand, the gain due to longer TI length is between 0.2 and 1.8 dB. The gain takes high values because the PO channel assumes pedestrian speeds (3 km/h) and critical fadings may appear.

All in all, considering the best results in terms of TI length (200 msec) and IL (-5 dB), the UL SNR thresholds for speeds lower than 175 km/h are always lower than 2, 4.2 and 6.4 dB for code rate 3/15, 4/15 and 5/15, respectively.

B. Indoor Core Services

In this subsection, the performance of core services are analyzed for indoor scenarios. Indoor reception has been identified as one of the key business model for the broadcasting industry.

The minimum SNR reception thresholds for indoor scenarios for the ATSC 3.0 configurations defined in Table I are gathered in Table III. For this purpose, the TU6 at 3 km/h and the PI channel models have been tested.

TABLE IIII
ATSC 3.0 INDOOR PERFORMANCE SNR (DB).

UL Configurations		Pedestrian Indoor: Time Interleaving Depth & Injection Level (dB)			
		1024		512	
		-4dB	-5dB	-4dB	-5dB
QPSK	3/15	2.2	1.0	2.6	2.4
QPSK	4/15	4.0	3.6	4.6	4.0
QSPK	5/15	5.8	5.4	7.2	6.8

UL Configurations		Typical Urban 6 Paths 3 km/h: Time Interleaving Depth & Injection Level (dB)			
		1024		512	
		-4dB	-5dB	-4dB	-5dB
QPSK	3/15	3.6	1.8	5.0	4.4
QPSK	4/15	4.2	4.0	6.2	5.8
QSPK	5/15	7.8	5.8	9.8	9.4

The results obtained follow the same tendency observed in the study of mobile core services. The gain due to the increment in the IL ranges between 0.2 and 1.8 dB, with a median degradation value of 0.7 dB. The gain in longer TI cases is higher, especially under TU6 channel conditions, ranging from 0.4 to 3.6 dB, with a median value of 1.6 dB.

The PI channel model shows better performance results than TU6 at 3km/h, with gains ranging between 0.2 and 2.6 dB. These remarkable differences are due to the differences between the measured realizations for the different tested configurations. It is widely known that TU6 is a more demanding channel model than the PI and associated results are usually regarded as conservative.

All in all, considering the best results in terms of TI length (200 msec) and IL (-5 dB), the UL SNR thresholds indoor reception is always lower than 1.8, 4.0 and 5.8 dB for code rate 3/15, 4/15 and 5/15, respectively.

VII. CONCLUSIONS

In this paper, the ATSC 3.0 LDM core services have been described, and afterwards, the main technical challenges that the mobile/indoor receivers must face have been addressed. It has been proved that technologies included in the ATSC 3.0 baseline are sufficient to deal with the new generation scenarios' receiving issues. Results confirm that ATSC 3.0 contains the technical resources to drive the broadcasting services through the new generation systems. The physical layer of ATSC 3.0 has included the best performing available techniques, providing a very flexible system design. Among other things, the addition of LDM, a new multiplexing technique, provides the capability of enhancing the mobile services in order to deliver HD programs to mobile and indoor scenarios.

The performance of ATSC 3.0 LDM signals has been evaluated by means of computer simulations and laboratory tests. The obtained results showed that a decrement in the injection level has an associated increment of the SNR threshold for mobile/indoor layer reception.

It has been proved that in addition to the AWGN, mobile receivers, especially at high speeds, are also influenced by an additional ICI noise that has to be taken into account in the noise estimation process. That could reduce the SNR threshold down to 1 dB. An expected outcome of this work is the proof that a longer time interleaving length increments the robustness of the signal in mobility, especially at pedestrian speeds, with a decrement in the correct reception SNR threshold of up to 3 dB.

The results have been confirmed using practical laboratory tests with real equipment in mobile and indoor scenarios. The results are very close to the simulated values, demonstrating the ATSC 3.0 capability to address the requirements of the new generation core services.

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