Analysis of Channel Uncertainty on OFDM/FBMC DVB-T2 Simulations

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Abstract. DVB-T2 is the second generation of terrestrial broadcasting standard widely adopted or deployed in Europe and Africa. During the network planning, the channel propagation is the challenging element for broadcasters. As it is known to be probabilistic, many methods are used to predict or evaluate the channel Power Delay Profile (PDP). The measurement method is the one used in the field trials to record the PDP at several locations and to evaluate the channel profile. Obviously, measurement errors occur on the PDP recorded values leading to the system performance evaluation flaw. Also, 5G candidate waveform Filtered Bank Multicarrier (FBMC) has been previously proposed as an alternative to Cyclic Prefix - Orthogonal Frequency Division Multiplexing (CP-OFDM) in DVB-T2 system to increase the spectral efficiency and to improve the minimum Signal to Noise Ratio required for reception. This work analyses the channel uncertainty in the simulation of native DVB-T2 and enhanced FBMC based DVB-T2 systems transmission performance using a channel PDP from field measurement in Belgium. This paper shows that uncertainties values tolerable for a good signal quality, using the quasi error-free (QEF) criteria are between 0.1 dB and 0.5 dB and between 10 and 50 ns, respectively in power and delay. Moreover, it provides details about uncertainty values predictable for FBMC based DVB-T2 case which is known to be 133% spectrally efficient compared to the 100% of native DVB-T2.

Keywords: Uncertainty measurement · RMS delay spread · Fading channel · Channel coding

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1 Introduction

During the last three last decades, the advent of terrestrial digital TV has opened up a world of new possibilities, allowed a better spectrum efficiency and improved the signal robustness again channel impairments. This technology has evolved from analog to digital technology due to the standardization of many digital technologies such as Digital Video Broadcasting-Terrestrial, first generation (DVB-T) in Europe (1997) [1], Advanced Television Systems Committee (ATSC 1.0) [2] in North America (1995), Integrated Services Digital Broadcast-Terrestrial (ISDB-T) [3] in Japan (1999) and South America or Digital Terrestrial Multimedia Broadcast (DTMB-T) [4] in China (2006). The main challenge of this technologies is the signal quality improvement and the viewer's experience enhancement. For these purposes, High Definition (HD) and Ultra High Definition (UHD) TV technologies are introduced and bring the defiance of achieving a quasi-error free performance at a low Bit Error Rate (BER). Afterwards, the more robust standards (second generation of Digital Terrestrial Television (DTT) systems) (Digital Video Broadcasting-Terrestrial, second generation (DVB-T2) (2009) [5], Advanced Television Systems Committee, third generation (ATSC 3.0) (2016) [6]...) have been developed to improve the performance highlighted by the first ones and satisfy the requirements of the signal capacity. These standards are flexible and scalable and their capacities are closer to the Shannon limit. However, the channel propagation is a relevant block to take in consideration when designing the standards.

Indeed, the channel propagation is the results of contribution of all propagation phenomena appeared during the radio signal transmission. These phenomena are the diffraction, the reflection, the multipath, the depolarization, the building penetration losses (Indoor TV reception), the attenuation in vegetation, the tropospheric refraction and ducting, the transequatorial propagation, the Doppler effect (mobile reception and multipath propagation) and the noise effect [7]. They need to be considered in a TV broadcasting system designing and performance evaluation, the network planning and broadcast service operation. Among these phenomena, the transmitted signal is severely affected by three of these phenomena such as diffraction, reflection and multipath. These phenomena are mathematically and physically characterized as large scale fading and small scale fading which caused several received signal variation. To model this fading channel and evaluate systems performance, the channel Power Delay Profile (PDP) is used. Two main methods have been proposed in order to record or predict the channel PDP. These are the path loss data measurement methods used during field measurement campaign [8,9] and the point to area prediction methods (empirical model, semi empirical model and deterministic model) [10,11]. The measurement method is mainly used to confirm the channel behaviour obtained with the prediction methods. However, some errors could appear during the measurement due the equipment inaccuracy and are viewed as errors measurement uncertainty. This paper gives details about analysis of channel measurement uncertainty in simulation of the native DVB-T2 and FBMC based DVB-T2.

To the best of the authors' knowledge, several previous works have approached the study of fading channel modeling method, channel propagation evaluation methods but a gap is left on the impact study of the channel error measurement uncertainty. Europeans DVB-T and DVB-T2 standards are the most adopted or deployed in Europe (Belgium, France, Italy, Spain) and Africa (Benin, Burkina Faso, Nigeria) in 148 countries worldwide [12]. In Belgium, DVB-T services are on air since 2007 and many field trial have been undertaken in rooftop antenna reception [13] and mobile reception. During the field measurement, channel PDP has been recorded at several measurement point. As the channel propagation is relatively the same in terrestrial propagation, this PDP constitutes the object of the error measurement study in DVB-T2 case. Futhermore, with the advent of 5G mobile network communication, several researches proposed 5G waveforms candidates (Filter Bank MultiCarrier (FBMC) [14] and Universal Filtered MultiCarrier (UFMC) [15,16]) as alternative to OFDM to DVB-T2 Transmission. Due to the similar characteristic of UFMC, FBMC and OFDM as the use of Fast Fourier Transform (FFT) in their blocks diagram and the shortcoming of OFDM (spectral efficiency losses due to the use of Cyclic Prefix (CP) and its large guard band), FBMC performance gain have been highlighted in DVB-T2 in terms of spectral efficiency (133%) and Signal to Noise Ratio (SNR) gain (1 dB). This paper gives the details about the maximum error measurement uncertainty which could be consider as negligible in DVB-T2 channel measurement.

This paper is organized as follows: Sect. 2 presents the related works; Sect. 3 presents a comparison of multicarrier modulation OFDM and FBMC; Sect. 4 presents the channel measurement setup, the modeling method, the method used to simulate the error measurement uncertainty, the system implemented and parameters; Sect. 5 presents the simulation results and discussion and Sect. 6 presents the relevant conclusion.

2 Related Works

In this part, related works about field trial, field measurements, and FBMC performance in DVB-T2 transmissions are presented.

2.1 FBMC Waveform in DVB-T2

Two studies have been recently performed on FBMC application in DVB-T2 system context. Firstly, FBMC has been proposed as alternative to OFDM in DVB-T2 to increase the spectral efficiency and decrease the minimum SNR needed at the receiver for a good signal quality. The results shown that FBMC outperforms OFDM by 1 dB SNR in SFN and urban environment [14]. Secondly, the same authors compared OFDM to FBMC and UFMC in DVB-T2 in terms of SNR gain, spectral efficiency and Power Spectral Density (PSD). The results shown that FBMC is 133% spectrally efficient than OFDM whereas UFMC is 128% spectrally efficient than OFDM. Also UFMC is 1.2 dB SNR efficient than OFDM

Table 1. Summary of papers related to FBMC application in DVB-T2 transmission

Papers	[14]		[15]	
Waveforms	FBMC, OFDM		FBMC, UFMC, OFDM	
Channels	0 dB echo, TU6		TU6	
Constellations	16, 256-QAM		256-QAM	
Number of subcarriers	8K and 32K modes		32K mode	
Cyclic prefix	1/32		1/128	
LDPC CR	1/2		3/5	
SNR gain (BER = 10^{-3})	FBMC	1 dB	FBMC, UFMC	1 dB, 1.2 dB
Spectral efficiency	–		FBMC, UFMC	133%, 128%

whereas FBMC is 1 dB SNR efficient than OFDM in urban environment [15]. While FBMC SNR gain has been highlighted compared to OFDM in the first work, the second work considers also another waveform UFMC and comparison is done between these waveforms in terms of SNR gain, spectral efficiency and complexity. Also, different simulation parameters have been considered. Table 1 presents the main parameters of these papers and their simulation results.

2.2 DVB-T2 Field Trial and Measurement

Many field trials or measurements have been done since the standardization of DVB-T2. This subsection summarizes the main trends of these field trial.

In 2016, the authors of the paper [17] proposed a redundant broadband connectivity to enhance terrestrial broadcast reception which is a backward compatible extension of DVB-T2. Indeed, the TV content is normally distributed either on terrestrial broadcast system or on broadband delivery system. In Germany, precisely in Berlin, a field trial has been done to evaluate coverage of jointly the redundancy on demand and the DVB-T2 system. This redundancy is assumed using a server which is fed with the same broadcast content as that feed to the modulator. The transmission delay introduced by the redundancy system has been measured and is less than 200 ms [17].

In the same year, the results from a field measurement campaign conducted to confirm the 4K-UHD service coverage, considering an outdoor roof-top antenna scenario in an SFN environment in Republic of Korea are presented in [18]. DVB-T2 system performance have been evaluated by recording performance metrics such as received power level, carrier-to-noise power ratio (C/N) and MER using a DVB-T2 professional receiver (ETL with DVB-T2 option manufactured by Rohde&Schwarz) at 46 different locations. The relationship between the receiver input level and MER has been established to identify the threshold value in terms of the received level and the Modulation Error Ratio (MER) [18].

In 2017, the results from a field measurement campaign conducted in two buildings in Seoul considering an indoor reception to cover HD and UHD services are shown in [19]. Measurements have been performed using a portable DVB-T2 receiver connected to a dongle-type DVB-T2 demodulator. A self-developed software program has measured physical performance metrics such as the received power level, the carrier-to-noise ratio (C/N) and the MER. The results shown that the indoor reception quality is mainly affected by the indoor structure [19].

In the same year, DVB-T2 system measurement set up is proposed and the required SNR threshold and minimum CNR are estimated using respectively the FBER (frame block error rate_ BER after LDPC decoder) and QEF (quasi error-free) criteria [20]. The results shown that in mobile outdoor reception, the BER less than about 10^{-5} and more than about 2.7×10^{-4} are respectively expected for the successful and failed receptions [20].

In 2018, DVB-T2 system performance have been evaluated using results from field measurements done in Single Frequency Network (SFN) in the central zone of the Republic of Moldova. The results have been recorded using MER performed before Quadrature Amplitude Modulation (QAM) demapper and BER after QAM demapper [21].

In 2019, DVB-T2 is the chosen standard in Indonesia as it provides services through the efficient use of the radio frequency spectrum. However, this technology is still constrained in establishing radio frequency Profile parameters that have not been to be applied to OFDM in Indonesian urban areas. These authors evaluated DVB-T2 system performance by computing the outage performance of Indonesia DVB-T2 channels and validating results using BER and Frame Error Rate (FER) [22].

In 2020, the results obtained from a field measurement of DVB-T2 signals in SFN done in Thailand are discussed in [23]. As DVB-T2 signal quality is relevant in SFN, the measurement has been performed in an SFN overlap area of three transmitted stations to evaluate the time delay, the path losses of free space and measurement, the received signal power and the MER. A relationship has been established between the PDP of each received position and the distance between the transmitter and the receiver [23].

In 2021, the results obtained from a field measurement of DVB-T2 signal performed in Jos (Nigeria) using Integrated Television Services Limited signal are presented in [24]. The signal field strength and the channel parameters have been measured and this is followed by the CNR and SNR values computation using the empirical method prediction coverage. The results shown that there is a good signal quality in the primary service areas whereas the signal is highly affected in the rocky environment [24].

Table 2 summarizes the advantages and limitations of these papers.

3 DVB-T2 and Multicarrier Modulations

3.1 DVB-T2 System Overview

DVB-T2 is a system capable of carrying several program (up to 20 HD or UHD TV chains) in an equal bandwidth. It is designed to increase the system capacity,

Table 2. Literature review on DVB-T2 field trials and measurements

Papers	Advantages	Limitations
[17]	Redundancy on demand of DVB-T2	Implementation of the server not detailed
	Service continuity for broadcasters	RoD versus PLP techniques not discussed
	Low cost redundancy solution	Modulation Error Rate tool not done
[18]	Outdoor service field trial in SFN	Overlapping area coverage of transmitters
	6 MHz bandwidth used for field trial	BER tool not used for QEF
	Input level and MER relationship	Measured channel PDP not presented
[19]	Indoor service field measurement	Mobile service case not considered
	CDF of the measured values evaluated	Error Vector Magnitude tool not used
[20]	CNR or BER for a successful reception	MER tool not discussed
	Fixed indoor and mobile outdoor cases	Measured channels PDP not presented.
[21]	Field strength, MER, C/N and BER in a SFN and only one transmitter network	Only fixed reception is considered. MISO technique is not considered
[22]	Analyse of the channel coding in DVB-T2	Constellation sizes not defined
	Measured channels PDP highlighted	BER vs SNR evolution not presented.
[23]	Performance evaluation of DVB-T2 in an SFN environment during field trial	Signal path loss in the transmitters overlapping area not discussed
	SFN propagation well detailed	Mobile reception case not considered
	Analysis of the path delay and the path loss at each reception position	EVM tool not considered
[24]	Analysis of DVB-T2 signal quality during field measurement	Only Rooftop antenna reception is considered
	Empirical method compared to measurement method	Mobile reception case not considered

the signal ruggedness and the system flexibility compared to the DVB-T system. DVB-T2 system capacity is at least 30% higher than DVB-T system capacity. Indeed, at the transmitter side, several programs can be packaged into Physical Layer Pipe (PLP). Also, in a multi-PLP system, several PLPs are fed into a baseband (BB) frame format. This frame is processed using Forward Error Correction (FEC) encoding, interleaving, and Quadrature Amplitude Modulation (QAM) constellation mapping and transmitted using Orthogonal Frequency Division Multiplexing (OFDM). FEC encoding used are Bose-Chaudhuri-Hocquenghem (BCH) and Low Density Parity Check (LDPC). While LDPC is the coding technique which further improved the system error correction capacity, BCH corrects the residual errors non corrected by the previous one. OFDM consists in the Inverse Fast Fourier Transform (IFFT) processing and CP insertion. Optional techniques like Multiple Input Single Output (MISO) and Signal Space Diversity (SSD) have been proposed in DVB-T2 to further improve its performance.

To evaluate signal quality, many tools are proposed. These are BER, Carrier to Noise Ratio (CNR), SNR, MER and Error Vector Magnitude (EVM). When AWGN is the sole impairment present, then MER is substantially equal to the SNR.

- BER is defined as the ratio of the number of erroneous bits to the number of transmitted bits. The low BER provides good system performance. In DVB-T2 system, BER is performed after LDPC decoder and BCH decoder.
- CNR is defined as the ratio of the relative signal power level to the noise level in the system bandwidth. The high CNR ratios provide enhanced quality of reception, and largely higher communications accuracy and reliability, than low CNR ratios [24]. It is used to define system robustness in presence of noise and interference.

$$CNR = \frac{P_{received}}{P_{noise}} = \frac{P_{received}}{F.K_b.T_o.B} \tag{1}$$

where P_{noise} is the received noise Input power; F is the received noise figure; $P_{received}$ is the minimum receiver Input power; B is the received noise bandwidth (MHz); K_b is the Boltzman constant; T_o is the absolute temperature (290 K); CNR is the carrier-to-noise ratio.
- SNR is defined as the ratio of the received signal strength over the noise strength within the frequency range of operation. The noise strength or noise power includes factors which cause the QAM received symbol, to differ from the ideal symbol such as additive noise, distorsion and Intersymbol Interference (ISI).

$$SNR = 10.\log(\frac{signal\_power}{noise\_power}) \tag{2}$$

- The MER is used to indicate the modulation quality of received signal at receiver side or to measure how accurate the symbols are [25]. In the real measurement, this tool takes into account the noise, the jitter, the reflection, the linear distortions and non linear distortions. Indeed, the sum of the squares of the magnitudes of the ideal symbol vectors from the constellation is divided by the sum of the squares of the magnitudes of the symbol error vectors. The result, expressed as a power ratio in dB, is defined as the MER (Eq. 3) [9]. I_j and Q_j are the transmitted symbols captured at the output the QAM modulator. δI_j and δQ_j are the difference between the transmitted symbols and the received symbols captured at the input of the QAM demodulator. The higher the MER is, the better the signal quality is.

$$MER[dB] = 10.\log(\frac{\sum_{j=1}^{j=N}|(I_j^2 + Q_j^2)|}{\sum_{j=1}^{j=N}|(\delta I_j^2 + \delta Q_j^2)|}) \tag{3}$$

In simulation case where only AWGN and fading channel are used, the MER takes into account only the noise and the channel impairment contribution.
- The EVM is the complementary parameter of MER. This parameter includes the peak power of the constellation, average constellation power and the MER. The peak power is computed using Eq. 4 and the average constellation power is computed using Eq. 5. Where M is the constellation size.

$$P_{peak} = 2.(sqrt(M) - 1)^2 \tag{4}$$

$$P_{peak} = \frac{2}{3}(M-1) \tag{5}$$

The maximum to average constellation ratio (MTA) is presented on Eq. 6.

$$MTA[dB] = 10.\log \frac{P_{peak}}{P_{avg}} \tag{6}$$

Using the MTA and the MER, on can compute EVM using Eq. 7.

$$EVM[\%] = 100.10^{\frac{-(MER+MTA)}{20}} \tag{7}$$

3.2 FBMC

OFDM is the multicarrier modulation based on the use of IFFT and FFT operations respectively at the transmitter side and the receiver side [15]. FBMC is one of the proposed multicarrier modulations for DVB-T2 transmission which has been the object of many research during the last decade. Like OFDM, it is based on IFFT and FFT operations respectively at the transmitter side and the receiver side. However, a filtering technique is applied per subcarrier which allows this modulation to be more efficient than OFDM one. The Polyphase Network (PPN) filter bank is the less complex filter bank model used in many works. Instead on using QAM symbols as input symbol, FBMC exploits Offset QAM (OQAM) symbols. This technique consists in transmitting real symbols instead of complex symbols. Indeed, FBMC processing consists in three main blocks such as OQAM pre-processing, IFFT operation and subcarrier filtering operation at the transmitter side. At the receiver side, it consists in subcarrier filtering operation, FFT operation and OQAM post-processing operation as depicted on Fig. 1.

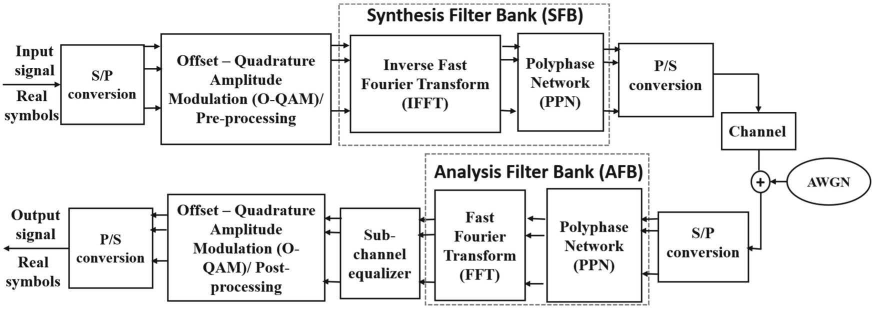

Fig. 1. FBMC block diagram

- OQAM processing
  Digital PPN filters bank are real low-pass filters which are well localized in frequency domain and their implementation method is based on Nearly Perfect

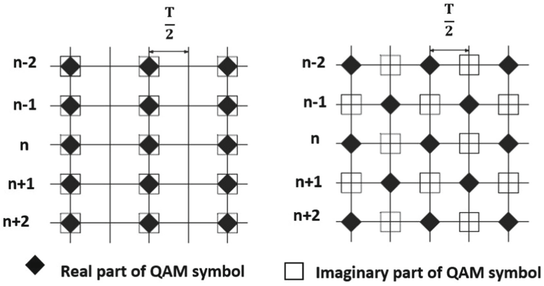

Fig. 2. OFDM (left) and FBMC (right) symbols mapping on subcarriers

Reconstruction (NPR) technique and satisfy the classical Nyquist criterion. These filters have a scrupulous characteristic such as the non overlapping of the subcarrier with an odd or even index. In frequency domain, solely the contributions of immediate neighbor subcarriers appear on the main subcarrier [25]. To deal with InterCarrier Interference (ICI), one can exploit this feature to transmit QAM symbol only on even or odd subcarrier. By this way, only the half of the system capacity is exploited. Full system capacity can be reached when all subcarriers are exploited. Using this kind of filters, orthogonality is required between two successive subcarriers to reach full system capacity. OQAM is proposed for this purpose as real symbols which are obtained from QAM symbols real part and imaginary. Therefore the IFFT operation is performed on twice the sampling time used in OFDM. Figure 2 depicts QAM and OQAM symbol mapping respectively in OFDM and FBMC modulation. One can note that QAM in phase and quadrature components are staggered by half of the symbol period (T).

- Fourier transform and Filtering operations

  PPN-FBMC is designed using the PHYsical layer for DYnamic AccesS and cognitive radio (PHYDYAS) filter. The main parameters of these filters are presented as follow:
  - The number of subcarriers is inherently an even number which is typically a power of two in order to provide efficient Fourier transform implementation.
  - The prototype filter lengths are chosen to be KN_{FFT}, $KN_{FFT}-1$ or $KN_{FFT}+1$ where K is a positive integer called overlapping factor. It is selected to be 3 or higher. In this work, an overlapping factor of 4 is used.

  Filter designing steps and characteristics are further presented in detail in [25]. Filters frequency response are presented on Fig. 3 where one can notice that the side lobe level is highly attenuated in frequency domain.
- Sub-channel equalizer designing in FBMC

  Two kind of equalizers proposed for FBMC are presented. There are Complex Finite Impulse Response (CFIR) 1 tap and 3 taps.

  CFIR 1-tap is the one tap equalizer proposed in FBMC as an alternative to Zero Forcing (ZF) in OFDM [26]. Like ZF equalization, it consists in using only the central coefficients of each sub-channel to process the equalization. CFIR 3-taps equalizers is the sub-channel equalizers with 3 taps, based on the frequency sampling approach developed in [14,15,26]. When the subcarriers number used in the FBMC system is high, CFIR 3-taps is recommended as its performance are highlighted with the increase of the subcarriers number [27]. The four steps used to perform CFIR 3-taps equalizers are presented in [14].

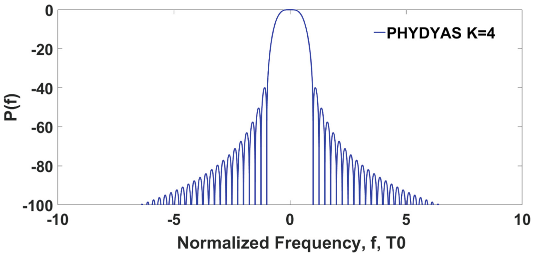

Fig. 3. PHYDYAS filter frequency response

4 Channel Measurement and Modeling Methods

To analyse the uncertainty error measurement in DVB-T2 system simulation, PDP of channel recorder by Radio Television Belge Francophone (RTBF) during the field measurement in Belgium in rooftop antenna reception condition is used. In this section, experimental bank used during the recording is presented. This is followed by the presentation of the channel modeling method.

4.1 Channel Measurement Method

Regularly, field measurements are performed by RTBF to verify the correctness of power levels in the coverage area of its emitters, using normalized measurement procedures. In the same time a dedicated equipment (DVB-T TV Test Receiver EFA, models 40/43) developed by Rohde&Schwarz performs other measurements such as BER, EVM and Power Delay Profile (PDP) at the same location, with regards to the emitter of the covered area. This papers uses some measurement results in the coverage area of the tallest emitter (about 174 m) which uses channel 36 (594 MHz) in UHF frequency band. The measurements have been done assuming that the receiver could receive only signal versions from the sole transmitter. Measurements have been recorded at 38 locations using a car which incorporates a 10 m height UHF antenna and the receiver. The main characteristics of the R&S test receiver are:

Table 3. RTBF channel PDP (26 paths)

Delays (ns)	0	360	790	1220	1750	1900	2280
Power (dB)	0	−13.3	−19.2	−23.6	−32	−26.6	−28.4
Delays (ns)	2760	3460	4070	4360	4670	4930	5340
Power (dB)	−26.8	−21.1	−26.0	−29.7	−28.9	−28.3	−27.9
Delays (ns)	5730	6090	6560	6950	7500	8150	9650
Power (dB)	−32.1	−31.2	−37.1	−33.6	−35.4	−37.2	−31.8
Delays (ns)	10270	10490	10830	11450	28330	–	–
Power (dB)	−27.1	−30.5	−35.7	−34.2	−31.3	–	–

- Frequency range: 4.5 MHz to 1000 MHz
- Level range: −50 dBm to 20 dBm
- Echo values range: power (0 to −40 dB), delay (−62.2 to 236 µs) for parameters such as 8K FFT, 8 MHz channel bandwidth
- Echo values resolution: power (0.1 dB), delays (10 ns).
- SNR values ranges depend on the mode of QAM
- SNR resolution: 0.1 dB

In this work, the measured channel PDP presented in Table 3 is exploited to evaluate the influence of uncertainty measurement (both in time and power) on the simulations of system performance and therefore on the signal quality.

4.2 Channel Modeling Method

In this part, method used to model frequency selective channel is presented. The fading distribution of RTBF channel is Rayleigh (presence of Non Line of Sight (NLoS) only) [29]. The Tapped Delay Line (TDL) model is usually used to implement multipath channels [30]. It employs a multiple number of frequency-non-selective (flat) fading generators, which are independent each other, each with the average power equal to 1. As presented on Fig. 4, the output of independent fading generator is multiplied by the tap power, respectively, in order to obtain the coefficients. The output of TDL model can be implemented as a Finite Impulse Response (FIR) filter with the following output. The output of the TDL model is presented in the Eq. 8 where N_D is the number of the taps in the FIR filter, $h_d(n)$ is the coefficient of the d^{th} tap, $x(n)$ is the input signal and $y(n)$ is the output signal.

$$y(n) = \sum_{d=0}^{N_D-1} h_d(n)x(n-d) \tag{8}$$

During the modeling, the filter implementation is not straightforward when the paths delays are not integers multiple of the sampling period. Indeed, four parameters are relevant in the channel modeling. These are the number of subcarriers

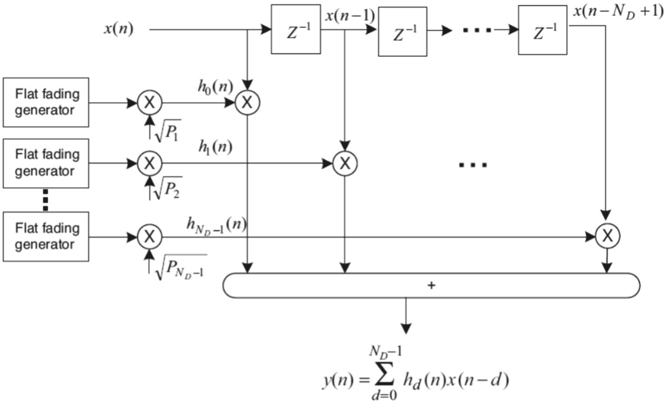

Fig. 4. TDL- based frequency selective fading channel model [29]

N_{FFT}, the sampling frequency or the sampling period which depends on the bandwidth, the OFDM symbol duration and the channel PDP. The frequency sampling is computed knowing the channel bandwidth B (Eq. 9) [31]. The symbol duration is computed based on the Eq. 10. As known, the sampling period is inversely proportional to the sampling frequency.

$$F_s = \frac{64}{7} * \frac{B}{8} \tag{9}$$

$$T_u = \frac{NFFT}{F_s} \tag{10}$$

$$T_s = \frac{1}{F_s} \tag{11}$$

In order to make the tapped delays multiple of a sampling period, a tap adjustment based on a rounding method is applied. The channel characteristics (Root Mean Square (RMS) delay spread) are maintained when using this method. Furthermore, this method allows for preserving the number of paths and the power relative to each path. It consists in the shift of the tap into the closest sampling instance. Finally, a new tap delay t'_d is obtained using Eq. 12 [30].

$$t'_d = round(\frac{t_d}{T_s} + 0.5) * Ts \tag{12}$$

where t_d is the tapped delays. Using this equation, the delay t'_d becomes a multiple of a sampling period and is used in the channel modeling. Moreover, one can normalize the tapped delays in term of number of subcarriers by canceling T_s from this equation. t'_d becomes a number without unit which is used to represent each tap when generating the channel impulse response.

The main steps of the channel modeling are summarized:

- Channel PDP definition including each path with its delay and its power.

- Sampling period computation using the channel bandwidth and the number of subcarriers.
- Paths delay positioning in term of sample FFT using the rounding method.
- Linear conversion of the path powers (fading) which is normally presented in dB.
- Paths power normalization.
- Generation of impulse response complex taps using a flat fading generator with Rayleigh distribution. This generator is modeled using two independent and identically-distributed Gaussian random variables with a zero mean and unit variance. These variables are defined using a built-in MATLAB function "randn".

Due to this channel modeling method, one can generate several independent realisations of the channel. One hundred independent channel realisations are used in this work.

Furthermore, multipath propagation is characterized by means of RMS of the channel delays spread (Eq. 13). The RMS delay spread value should be limited to the guard interval (CP duration) to avoid ambiguities.

$$\tau_{RMS} = \sqrt{\left(\frac{1}{\sum_{i=1}^{n} P_i} . \sum_{i=1}^{n} (\tau_i^2 P_i) - \tau_d^2\right)} \quad with \quad \tau_d = \frac{\sum_{i=1}^{n} (\tau_i P_i)}{\sum_{i=1}^{n} P_i} \tag{13}$$

4.3 Error Measurement Simulation Methodology

As previously presented, the channel is generated using independent gaussian distributed generators. In the receiver parameters, the resolution parameters for echoes are equal to 0.1 dB for the power and 10 ns for the delay. This means that for each echo value (path) the maximum uncertainty tolerable are ±10 ns and ±0.1 dB respectively for the delays and the powers measurement. To evaluate impact of uncertainty error measurement on the channel, the following steps are processed.

- The channel flat fading generators are maintained non-random
- Uncertainties about power, delay or both of them are randomly generated using a Gaussian distributed generator.
- Comparison of results to that obtained without uncertainty
- Increase of power and delay uncertainties
- Identification of the maximum uncertainty values for which the system performance could be considered negligible.

As 0.1 dB is considered to be the performance loss which could be considered as negligible at low BER, this criteria is used in this work.

4.4 System and Parameters

In this part, light version of DVB-T2 system implemented is presented. It consists in the random generation of binary data which undergo LDPC coding, QAM mapping, OFDM and CP insertion processing. The signal obtained is convoluted with the channel impulse response. Uncertainties is added when generating the channel impulse response and the noise is added to the signal with channel effects. The reverse operations are performed at the receiver side. System performance is evaluated after channel equalization using MER and EVM and after LDPC decoder using BER. In the FBMC case study, CP-OFDM is substituted by FBMC. Table 4 presents the main parameters of DVB-T2 system. k is equal to 1024. The simulation parameters are presented in blue color. the channel bandwidth of 8 MHz is used as this is the most exploited in DVB-T2 implementation. As the subcarriers number used in this case is 8k = 8192, CFIR 1-tap equalizer is sufficient to perform demodulation. Also, when 8192 subcarriers are used in the native DVB-T2 system, $2N_{FFT}$ subcarriers is applied in FBMC based DVB-T2 (Fig. 5).

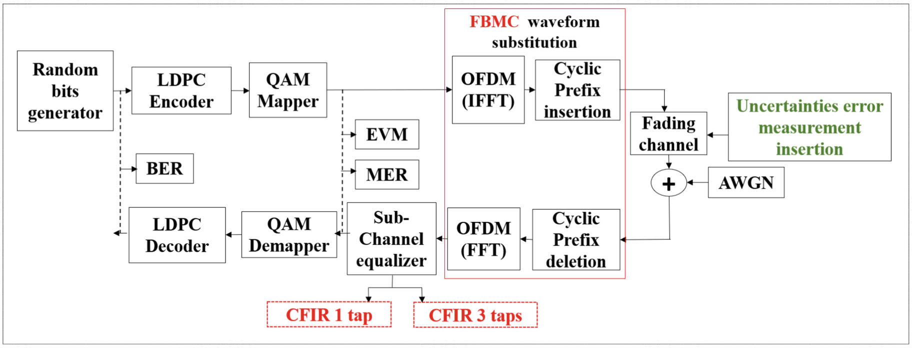

Fig. 5. System implemented

Table 4. DVB-T2 systems parameters

FFT mode	1k, 2k, 4k, ((8, 16, 32)k and ext)
Modulation	4, 16, 64, 256-QAM
FEC frame	long (64800 bits), short (16200 bits)
Code Rate (CR) LDPC	1/2, 3/5, 2/3, 3/4, 4/5, 5/6
Bandwidth	1.7, 5, 6, 7, 8, 10 MHz
CP	1/128, 1/32, 1/16, 19/256, 1/8, 19/128, 1/4

5 Simulation Results

In this section, simulation results obtained with uncertainty error measurement are presented. The mains performance evaluation tools used are BER, MER, EVM and RMS delays spread. The channel RMS delay spread is equal to 2.810^{-7} s. This value is lower than the CP duration (28.10^{-6} s). It changes with the variation of uncertainty values. The results are presented for both native DVB-T2 system and DVB-T2 system based FBMC. This section is finalized by the discussion.

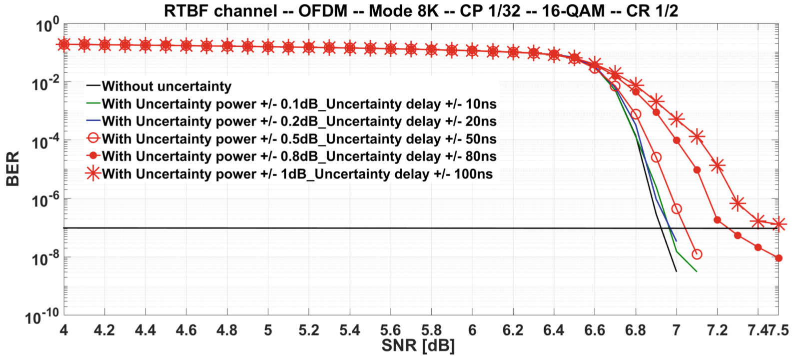

Fig. 6. Impact of uncertainty error on OFDM based DVB-T2 system: BER

Table 5. Performance of DVB-T2 system in the presence of uncertainty error using RTBF channel

AWGN only						
BER			SNR [dB]			
10^{-7}			6.2 [29]			
RTBF channel + AWGN						
–	–	±0.1 dB	±0.2 dB	±0.5 dB	±0.8 dB	±1 dB
–	–	±10 ns	±20 ns	±50 ns	±80 ns	±100 ns
BER	SNR [dB]	SNR [dB]	SNR [dB]	SNR [dB]	SNR [dB]	SNR [dB]
10^{-7}	6.92	6.96	6.96	7.05	7.26	7.5
Impact of fading channel and uncertainty						
–	Fading	Impact of uncertainty				
BER	Loss [dB]	Loss [dB]	Loss [dB]	Loss [dB]	Loss [dB]	Loss [dB]
10^{-7}	0.81	0.04	0.04	0.13	0.34	0.58

5.1 BER Evolution in Function of SNR

1. Native DVB-T2 case (OFDM based DVB-T2)

To validate the good behaviour of our simulator, simulation has been previously performed using only AWGN channel for both Native DVB-T2 and FBMC based DVB-T2 systems [14]. The results obtained have been compared to results presented in the guideline implementation using the same parameters [29]. Fading channel is applied in the system and non random fading generators are used to control the sole contribution of uncertainty variation. Figure 6 presents BER progression in function of SNR when the uncertainty error varies. Table 5 presents the results obtained at a BER of 10^{-7} and the loss obtained when compared to simulation without uncertainty. One can notice that when RTBF fading channel is used, the loss obtained is equal to 0.81 dB compared result with only AWGN. When equipment uncertainty (0.1 dB and 10 ns) are inserted, the loss is equal to 0.04 dB. This value is negligible. However, when the uncertainty increases, the loss increases and becomes significant.

2. FBMC based DVB-T2 case

When FBMC is applied in DVB-T2 instead OFDM, simulations have been performance when uncertainty values are not inserted and when uncertainty power values of ±10 ns and 0.1 dB. Figure 7 depicts the results obtained at a BER of 10^{-7}. One can noticed that the SNR values are similar in both cases (without and with uncertainties).

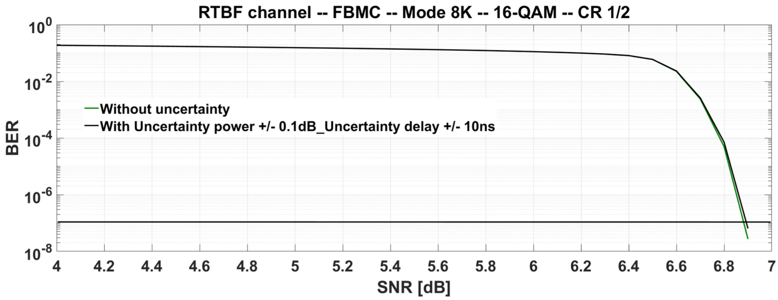

Fig. 7. Impact of uncertainty error on FBMC based DVB-T2 system: BER

5.2 MER and EVM Evolution in Function of SNR

1. Native DVB-T2 case

As previously presented, MER is the tool used to measure the signal quality. In the case of the sole use of AWGN, MER is equal to SNR. When fading channel is used, MER value includes contribution of both AWGN and fading channel.

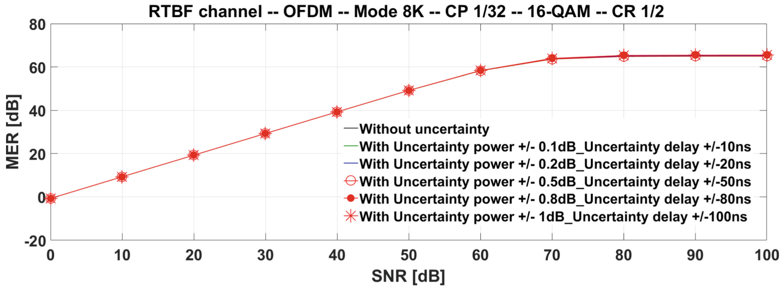

Fig. 8. Impact of uncertainty error on OFDM based DVB-T2 system: MER

Figure 8 depicts MER progression in function of SNR. One can notice that the values of MER are comparable when uncertainties are applied or not. Also, these values are less than SNR values when fading channel is used. Furthermore, MER value is saturated for SNR higher than 65 dB. This means that even if the SNR increases, there is the residual effect of the channel which still remains in the received data. As previously presented, EVM is inversely proportional to MER. Figure 9 presents EVM evolution in function of SNR When OFDM is used. One can notice that the values of EVM are comparable when uncertainties are applied or not.

2. FBMC based DVB-T2 case

Figure 10 presents MER and EVM evolution in function of SNR When FBMC is used instead of OFDM for all uncertainty value previously presented. One can note that there is no impact on the system performance in term MER and EVM when uncertainty value increases. Also, MER curve is saturated for SNR higher than 60 dB. This means that, compared to OFDM MER curve, there is the presence of the residual filter effects in the FBMC signal which decreases the MER values for high SNR values.

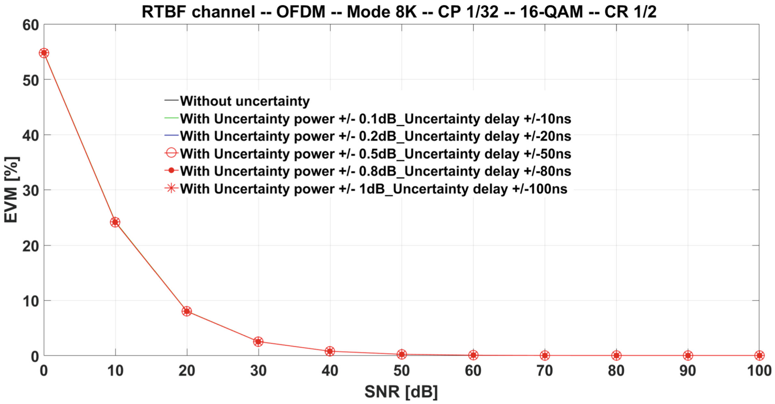

Fig. 9. Impact of uncertainty error on OFDM based DVB-T2 system: EVM

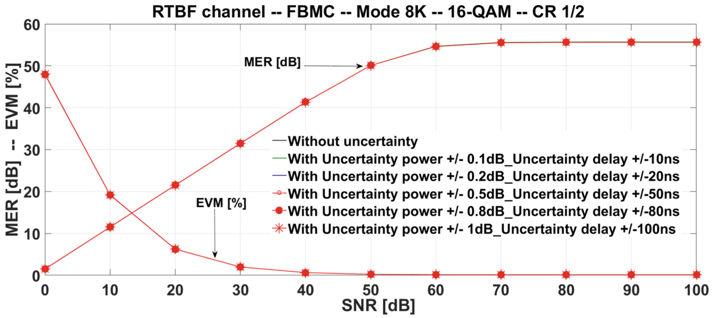

Fig. 10. Impact of uncertainty error on FBMC based DVB-T2 system: MER and EVM

5.3 Discussion

From all the results obtained, one can notice that the impact of channel uncertainty measurement in term of BER is negligible for normal measurement uncertainty values lower than 0.5 dB in power and lower than 50ns in delay in the case of the native DVB-T2 (CP-OFDM). When the uncertainties exceed these values the loss becomes significant (losses higher than 0.1 dB). In FBMC based DVB-T2 case, the impact is negligible in the normal reception condition (equipment uncertainty values: ±0.1 dB in power and ±10 ns in delay). Furthermore, the impact of uncertainty values is negligible in terms of MER and EVM for uncertainties range of powers 0.1 dB–1 dB and delays 50–100 ns. In order word, in this uncertainties range values, there is no impact on MER and EVM values. Also, the MER value expected for a rooftop antenna reception is at least 18 dB [31]. In this MER range values, the impact of uncertainty is not noticeable. This work comes to fill the gap in research about the channel uncertainty measurement appear during the trials and the channel PDP recording. Also, it gives information details about a modified version of DVB-T2 (FBMC based DVB-T2) previously proposed in [14,15]. Besides DVB-T2 technology performance investigation during the last decade, Digital Audio Broadcasting plus (DAB+) technology is also a quite recent standard developed with the purpose to provide digital audio signal to receivers in fixed, portable and mobile reception scenarios. The analysis done in this work could be investigated in this standard to help broadcasters (in particular, in African countries) in the DAB+ network deployment.

6 Conclusion

This work presents the simulation based impact of channel uncertainty measurement in native DVB-T2 and FBMC based DVB-T2 systems. For uncertainties ranges of powers 0.1 dB–1 dB and delays 50–100 ns, it is proven that the impact is very negligible in terms of MER and EVM for both systems.

However, the impact becomes relevant in term of BER for channel path powers greater than 0.5 dB and path delays greater than 50 ns for the native DVB-T2 system. This paper proves the range of uncertainty foreseen by the manufacturer and give details about the margin which can be exceeded by broadcasters during field and channel measurement. Also, it tackles the uncertainty range values predictable if FBMC was adopted like multicarrier modulation in the next generation of the European broadcasting standard. Furthermore, as most of European countries first deployed DVB-T system, the migration to DVB-T2 was effective in some countries where it still a challenge for other countries like Belgium. Indeed, the advent of 5G allows the development of 5G broadcast, it could provide audiovisual content to mobile receivers. Nevertheless, DVB-T2 presents many advantages against 5G broadcast and namely, the provision the rooftop antenna reception service which is not the specificity of 5G broadcast.

In perspectives, the work can be pursued as follows:

- Study of the impact of errors relative to the channel estimation in DVB-T2 system
- Study of impact of channel uncertainty measurement when MISO technique is applied in DVB-T2
- Evaluation of the impact of channel uncertainty during field measurement.

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