IEEE 1900.7-2015 PHY Evaluation on TVWS Scenarios

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Abstract. White space communications have attracted a particular interest after some national regulators have authorized TVWS unlicensed secondary usage. The IEEE 1900.7 working group has defined a specific air interface tailored to these applications. The standard, is based on an Filter Bank Multi Carrier (FBMC) physical layer and a CSMA-CA MAC sublayer. In this paper, the Modulation and Coding Schemes (MCS) of the IEEE 1900.7-2015 are considered to assess simulated expectations on throughput and coverage under various typical TVWS deployment scenarios: Fixed Long Range Access, campus WLAN (in Fixed Urban/Suburban environments), Indoor Femtocells (a TVWS low power transceiver for WLAN-like applications). Expected rate and coverage maps are provided for these scenarios.

Keywords: IEEE 1900.7-2015 · TV white space (TVWS) · Dynamic spectrum access · Physical layer · FBMC

1 Introduction

In the recent years, there has been a worldwide concern related to spectrum shortage. As an example, in June 2010, the White House issued a Presidential Memorandum stating that the National Telecommunications and Information Administration (NTIA) shall collaborate with FCC to make available a total of 500 MHz of Federal and non-federal spectrum over the next 10 years, suitable for both mobile and fixed wireless broadband use. One of the means to make new spectrum available is through sharing, and the Digital Switch Over (DSO) in TV bands, which has resulted in making the so-called TV White Space (TVWS) UHF spectrum available, was the first actual example where such a mechanism has been allowed. TVWS availability depends on TV broadcast frequency usage profile, thus changing across time and space. TVWS usage relies on unlicensed secondary Dynamic Spectrum Access (DSA) under the principle on a non-harmful interference with incumbent users [1].

In the USA, the FCC proposed rules for the Unlicensed Operation in the TV Broadcast Bands [2], with the final set of rules in 2009 [3] and an additional memorandum in 2010 [4], along with a notice in 2011 [5]. In Japan, MIC has

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published rules for secondary operation in TV white space [6]. In Europe, the Ofcom UK was the first regulator to establish rules for TVWS usage [7,8]. Subsequently, Ofcom organized a nation-wide trial where several technologies were tested [9]. Following up the approval of the European Parliament and Council the first Radio Spectrum Policy Programme (RSPP) in March 2012 [10], the European Commission released a Communication [11] in which shared use of TV White Spaces in the 470–790 MHz band is identified as a major opportunity. Then, regulatory actions have taken place in this area. In a first report, European Regulation (CEPT) has defined technical considerations for TVWS operation in Europe [12]. Then, ECC Report 159 established technical and operational requirements for the possible operation of cognitive radio systems in the "white spaces of the [470–790] MHz band" [13]. CEPT thoroughly addressed the way forward in European TV White Spaces, assessing both geolocation database and spectrum sensing as enabling technologies and setting out technical requirements for the use of TVWS. Finally, ETSI established some requirements for TVWS equipment in answer to the R&TTE Directive and delivered the Harmonized EN 301 598 [14].

Alongside these regulatory harmonization initiatives, a set of standardization bodies developed technology standards to facilitate the implementation of TVWS radios. First, the CogNea consortium developed the ECMA 392 TVWS standard for WLAN-like application [15]. Then, IEEE 802.22 [16], and more recently IEEE 802.11af [17] issued standards for WRAN and WLAN applications respectively. Finally, IEEE 802.15.4m has been developed to address WPAN operation in the TVWS [18].

All broadband TVWS standards (ECMA 392, IEEE 802.22, IEEE 802.11af) are based on Cyclic Prefix - Orthogonal Frequency Division Multiplexing (CP-OFDM) physical layer (PHY), often inherited from previous standard developments such as IEEE 802.16e or IEEE 802.11a. These standards have been adapted to make them suitable for TVWS operation. Although this approach was the best to guarantee fast market readiness, it had some difficulties to face the TVWS specific requirements in terms of interference control [1]. For this reason, IEEE DySPAN Standards Committee (formerly known as SCC41) created an ad hoc group on White Space (WS) Radio in March 2010 "to consider interest in, feasibility of, and necessity of developing standard defining radio interface (medium access control and physical layers) for white space radio system". Subsequently, the 1900.7 working group on "Radio Interface for White Space Dynamic Spectrum Access Radio Systems Supporting Fixed and Mobile Operation" [19] was created.

The IEEE 1900.7-2015 standard [20] is the result of a clean slate technology analysis where the working group tried to identify the most suitable technology to TVWS requirements. The chosen technology is based on a Filter Bank Multi Carrier (FBMC) PHY and a contention based CSMA-CA MAC, in order to cover the scenarios described in [21]. The technology benefits of the IEEE 1900.7-2015 FBMC PHY vs classical OFDM approached have been addressed in a recent paper [21].

In this paper, our focus is to put the performance of the IEEE 1900.7-2015 PHY into the perspective of typical TVWS scenarios as identified by the European QoSMOS project in [22], namely Rural Broadband Access and indoor TVWS Femtocells. The paper investigates the standard modulation and coding schemes (MCS) and express throughput and coverage for these scenarios.

2 Scenarios and Path Loss Models

2.1 TVWS Rural Broadband Access

In this scenario, a fixed base station serves customer premises equipment (CPE) to deliver content access (cf. Fig. 1). This is the first scenario associated to TVWS as this was the first use case considered in standardization pioneering work, such as the one of IEEE 802.22 wireless regional area network (WRAN). The good propagation properties of sub-GHz UHF frequency and the authorized EIRP for fixed TVWS stations by the FCC (4 W) provide TVWS with good assets for this scenario as illustrated in Fig. 1.

Fig. 1. Rural broadband access (left) and campus (right) scenarios

From a technical viewpoint this scenario also encompasses the campus WLAN use case. For long range communication in UHF bands, the ITU-R P.1546 [24] propagation model used by broadcasters is appropriate. However, in order to use closed form expressions in the path loss model, [23] suggests using the Okamura-Hata model with antenna hights correction that fits the empirical model of ITU-R P.1546 quite well. This will simplify the performance evaluation provided hereafter. Hence, under this scenario we consider the light urban scenario for which the path loss (PL) model is given by:

$$PL_{Urban}(d) = 9.55 + 26.16 \log f - 13.82 \log h_B - C_H + (44.9 - 6.55 \log h_B) \log d \quad (1)$$

Where f is the central frequency (in MHz), h_B is the antenna height of the fixed base station, d the distance between the base station and the CPE, C_H is a correction factor depending on the receiver antenna height h_M defined by:

$$C_H = 0.8 + (1.1 \log f - 0.7) h_M - 1.56 \log f \quad (2)$$

Where h_M is the height (in meters) of the CPE antenna. In the case of suburban deployments, PL shall be corrected as:

$$PL_{Suburban}(d) = PL_{Urban}(d) - 2(\log(f/28))^2 - 5.4 \tag{3}$$

2.2 TVWS Indoor Femtocell

This scenario considers an indoor access point such as in classical WLAN scenarios for homes of larger buildings. UHF good propagation conditions makes it possible to expect indoor to outdoor coverage as illustrated in Fig. 2.

Fig. 2. Indoor scenario with indoor to outdoor coverage

In this case ITU-R recommendation P.1238 [23] is more suitable than the Okamura-Hata model.

$$PL_{Indoor}(d) = 20\log f + N\log d + L_f(n) - 28 \tag{4}$$

Where N is the power loss coefficient. In the LOS case, $N = 20$. In the case of inner-wall penetration, N shall be increased and we will use $N = 35$ as recommended in [22]. Propagation through floors is modelled using the floor penetration loss factor $L_f(n)$, which is recommended to be 9, 19 and 24 dB for one, two and three floors, respectively, at 900 MHz. Although it is expected that TVWS frequencies experience lower penetration losses, these values will be used as a conservative estimate.

3 IEEE 1900.7-2015 PHY Layer

3.1 Overview

The IEEE 1900.7-2015 PHY uses an FBMC modulation, which has been preferred to CP-OFDM, due to superior behavior with regards to adjacent channel leakage ratio (ACLR) and flexibility performance [21,24]. FBMC was introduced in the 60 s by [25,26]. It is a multi-carrier approach, but unlike CP-OFDM where the *sinc* kernel filter ensures subcarriers orthogonality with respect to the FFT operator, FBMC uses a prototype filter that filters each sub carrier. A proper

Table 1. IEEE 1900.7-2015 PHY modes

Mode	N	Intercarrier spacing	2 MHz channel	8 MHz channel
4 K	4096	3.75 KHz	504 (1.86 MHz)	2016 (7.56 MHz)
1 K	1024	15.00 KHz	124 (1.86 MHz)	504 (7.56 MHz)
0.5 K	512	30.00 KHz	64 (1.92 MHz)	252 (7.56 MHz)
0.25 K	256	60.00 KHz	32 (1.92 MHz)	124 (7.44 MHz)

design of the prototype filter enables to trade time and frequency localization, and thus to control ACLR [27]. Because the prototype filter's response spreads each subcarrier over several adjacent subcarriers, another dimension is used to maintain orthogonality. In the framework of IEEE 1900.7-2015, the offset QAM (OQAM) approach is used. OQAM consists in a complex to real conversion where real and imaginary parts of each complex symbol are multiplexed in consecutive time samples into Pulse Amplitude Modulation (PAM) symbols. In order for this pre-processing not to impact data rate, the PAM symbols are up-sampled by a factor of 2. Then, the output real numbers are multiplied by an offset QAM sequence to form a new complex symbol: $h_{k,l} = (-1)^{k.l}(j)^{k+l}e_{k,l}$. These symbols are then filtered through a polyphase network. The IEEE 1900.7-2015 standard specifies two different sizes for the prototype filter: K = 3 or K = 4 governing the level of protection of adjacent channels. Also, for the sake of flexibility, several modes are proposed (Table 1). They consider different number of carriers, and two channelization modes (2 or 8 MHz). Thus, IEEE 1900.7-2015 can be used in any country authorizing TVWS operation and can cover medium to broadband channels with flexible bandwidth (2, 4, 6, 8, 10... MHz). Of course the use of non-contiguous fragments is possible also.

The block diagram of the IEEE 1900.7-2015 transmitter is shown in Fig. 3. The transmitter architecture is composed of two main elements: forward error correction block and data mapping and modulation block. Forward error correc-

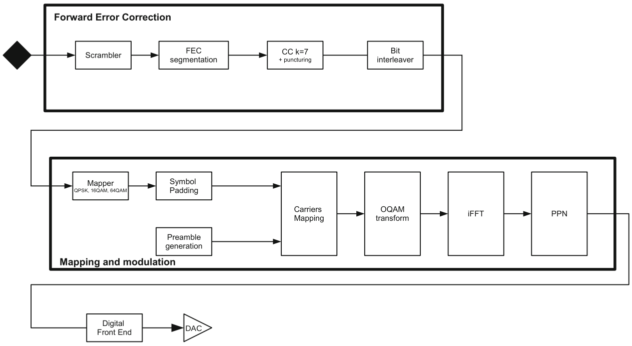

Fig. 3. IEEE 1900.7-2015 PHY transmitter block diagram

Table 2. MCS parameters

MCS	Modulation	Coding rate	Peak throughput (2 MHz) [Mbps]	Peak throughput (8 MHz) [Mbps]
0	BPSK	1/2	0.93	3.78
1	QPSK	1/2	1.86	7.56
2	QPSK	3/4	2.79	11.34
3	16QAM	1/2	3.72	15.12
4	16QAM	3/4	5.58	22.68
5	64QAM	2/3	7.44	30.24
6	64QAM	3/4	8.37	34.02
7	64QAM	5/6	9.30	37.80

tion (FEC) is implemented using a standard convolutional encoder. The code may be punctured to support variable encoding rates. The convolutional code is segmented by blocks of fixed size. The trellis is closed at the beginning and the end of each FEC block. The output of the encoder is forwarded to a bit interleaver of size multiple of the output length of the encoder.

The second block maps and modulates the encoded bits to the multicarrier modulation. The coded data are mapped to QPSK, 16QAM or 64QAM modulation symbols, depending on the desired data rate. Symbols are then padded to make the transmitted burst length an integer multiple of multicarrier symbols. The generated block of QAM symbols is mapped to active carriers and modulated to an offset-QAM before being transformed into a time domain signal using FBMC waveform. A modulation and coding scheme (MCS) index is defined to describe the combination of the modulation and coding schemes that are used when transmitting data (Table 2. Summarizes the possible MCS and the associated peak throughput (Mode 1K), where sampling rate is set to 15.36 Msps and subcarrier spacing is set to 15 KHz as in LTE.

3.2 Receiver Architecture

Most of the published FBMC receiver architectures are based on PolyPhase Network (PPN) receivers [28]. In this case, the filter bank process is applied in the time domain before the frequency domain transform (FFT) using a polyphase filter. It reduces the size of the FFT but makes the receiver less tolerant to large channel delay spread or synchronization mismatch of the FFT. Therefore, this strategy is not well adapted to scenarios with large delay spread. In [29] the authors describe a high performance receiver architecture denoted FS-FBMC (Frequency Spreading FBMC). One advantage of this architecture comes from the fact that time synchronization may be performed in the frequency domain independently of the position of the FFT [30]. This is realized by combining time synchronization with channel equalization. Moreover, good performance for channel exhibiting large delay spread is achieved [31]. As suggested in [31], it gives flexibility in the choice of the intercarrier spacing to support high Doppler spread in combination with robustness against fading channel. Finally, it was shown that FS-FBMC implementation could result in limited extra complexity compared to its OFDM counterpart [28] (typically 30 % additional computational logic). Such a receiver architecture will be considered in the following for performance evaluation.

4 Performance Evaluation

4.1 Parameters and Approach

The evaluation of the cell coverage using IEEE 1900.7-2015 PHY layer is realized assuming the mode 1K, 2 MHz and 8 MHz bandwith, and the parameters of the draft standard (sampling rate = 15.36 Msps, subcarrier spacing = 15 KHz). We have first evaluated by simulations the minimal required signal to noise ratio (SNR) to ensure a 10^{-3} bit error rate (BER) for all the MCS. The channel estimation and synchronization are assumed perfect. The performance are given for an additive white gaussian noise (AWGN) channel and a standardized channel: the Extended Typical Urban (ETU) channel. This channel model is a 9 tap channel with a delay spread up to 5us. Taps and associated relative power are given in Table 3.

Table 3. Extended Typical Urban (ETU) channel

Tap index [sample]	0	1	2	3	4	8	25	35	77
Relative power [dB]	−1	−1	−1	0	0	0	−3	−5	−7

Table 4 gives the SNR value for a BER of 10^{-3} over AWGN and ETU channels. In the ETU channel case, the resulting BER at the output of the receiver has been evaluated and averaged for 2000 channel realizations assuming a perfect synchronization, perfect channel estimation and a “FS based” receiver structure.

Table 4. Required SNR on AWGN and ETU channels for each MCS (@BER = 10^{-3})

MCS	1	2	3	4	5	6	7
$SNR_{AWGN}[dB]$	4.2	7.6	10.0	14.2	17.6	20.0	21.2
$SNR_{ETU}[dB]$	7.33	12.76	12.82	18.60	20.92	23.68	36.00

4.2 Simulation Results

Performance evaluations have been carried out for the scenarios introduced in Sect. 2. In the case of the rural broadband access, transmit power has been set to 36 dBm (4 W). The path loss has been computed to maintain the minimal SNR required in the case of AWGN and ETU channel models. In the following, channel estimation and synchronization are assumed perfect. One can expect a typical implementation loss of 1dB in actual implementation. Then the maximal range has been computed according to Eq. 1 for urban environment and to Eq. 3 for suburban environment. Figure 4 shows these range estimates for a 2 MHz and a 8 MHz profile. Results are provided for MCS 1 to MCS 7.

In the case of the indoor scenario, the TX power was limited to 20 dBm (100 mW). Minimal SNR in the AWGN case is considered, bearing in mind that strong attenuation factors are already introduced in the distance calculation based on Eq. 4. Figure 5 shows these range estimates for a 2 MHz and a 8 MHz profile, considering 3 different situations: same floor, through 1 floor, through 2 floors. Results are provided for MCS 1 to MCS 7.

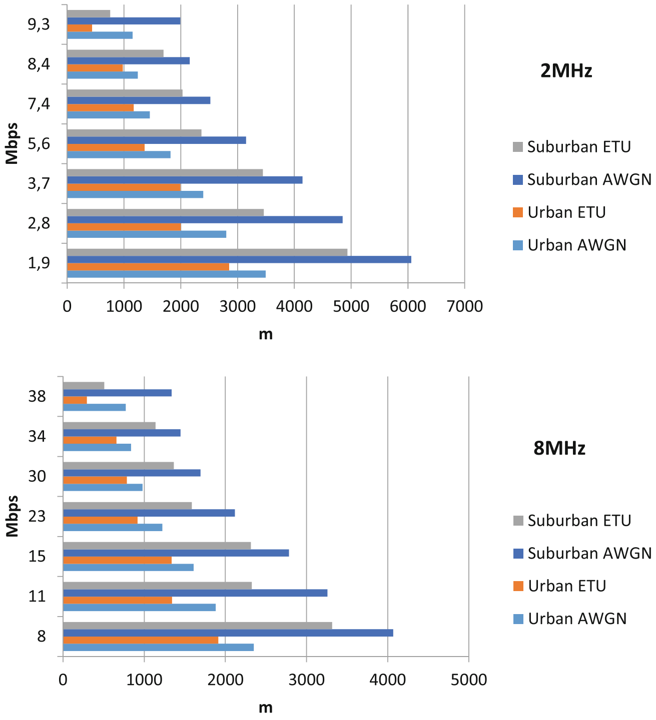

Fig. 4. Max. data rate [Mbps] vs. max. range [m] in rural broadband scenario (Color figure online)

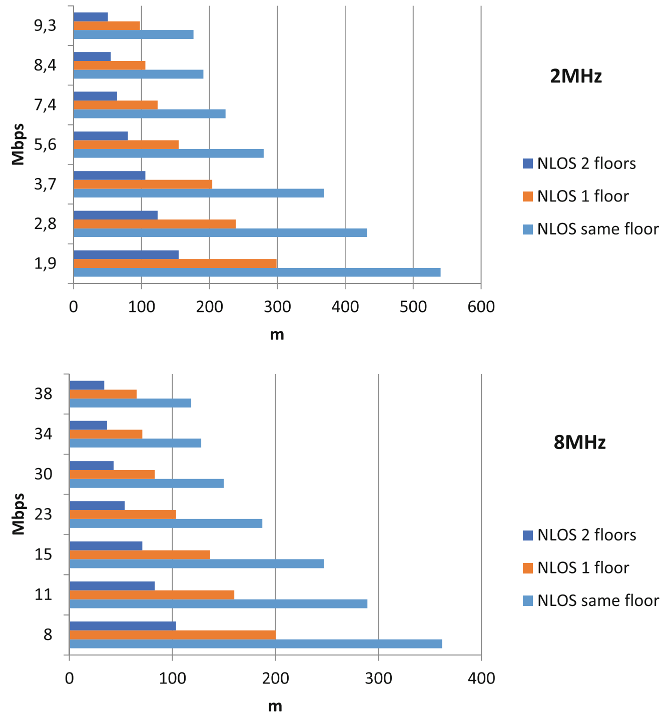

Fig. 5. Max. data rate [Mbps] vs. max. range [m] in indoor scenario (Color figure online)

5 Conclusion

In this paper, communication range are estimated for the 7 MCS of the IEEE 1900.7-2015 standard. These evaluations are provided for two typical TVWS scenarios: rural broadband access with 4 W Tx power and indoor femto-cells with 100 mW Tx power.

Simulations show that in the rural broadband access case, a range of 2 km at 8 Mbps to 23 Mbps depending on channel conditions, with an 8 MHz bandwidth (equivalent to one single European TV channel) can be reached. This makes IEEE 1900.7-2015 technology very suitable for this scenario.

In the indoor case, where TX power is limited to 100 mW (similar to the Tx power of WiFi), range can reach 100 m at 8 Mbps when crossing 2 floors and 38 Mbps when on the same floor (considering 8 MHz bandwidth), making IEEE 1900.7-2015 suitable for indoor and indoor to outdoor connectivity, even in large buidling. This makes IEEE 1900.7-2015 suitable for low CAPEX large building or campus coverage (e.g. shopping malls, airport, university campus, libraries).

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