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IEEE 1900.7 Standard for White Space Dynamic Spectrum

Access Radio Systems

Stanislav Filin, Dominique Nogu , Jean-Baptiste Dor , Baher Mawlawi, Oliver Holland, Muhammad Zeeshan Shakir, Hiroshi Harada, Fumihide Kojima

Abstract

Various measurements and studies have shown that some licensed frequency bands are underutilized at certain times and in certain locations. In particular, TV bands have been shown to have unused spectrum. Such observations have triggered strong interest in white space dynamic spectrum access among researchers, wireless equipment manufacturers, and standards development organizations. The IEEE Standards Committee on Dynamic Spectrum Access Networks has created the White Space Radio Working Group in June 2011 to develop the IEEE 1900.7 standard for white space dynamic spectrum access radio systems. The standard was published in February 2016. This paper gives an overview of key concepts and technologies of the IEEE 1900.7 standard, including use cases and requirements, physical layer and MAC sublayer.

I. Introduction

The IEEE Standards Committee on Dynamic Spectrum Access Networks (IEEE DySPAN-SC), operating under the IEEE Communications Society, is developing standards related to the improved use of spectrum. This includes aspects such as techniques and methods for interference management, coordination of wireless technologies, and network management and information sharing.

Meanwhile, a specific type of dynamic spectrum access – white space access – had gained momentum among researchers, wireless equipment manufacturers, and standard development organizations. This was motivated by two factors. First, measurements and studies have indicated that a lot of time some licensed frequency bands are under-utilized. In particular, TV bands have been shown to have unused spectrum, whereby later measurements have only confirmed such result [1]. Secondly, several countries have adopted radio regulations for secondary user operation in TV white space (TVWS) frequency bands. For example, the FCC has published several documents allowing secondary user access to TVWS for portable devices [2]. In the UK, Ofcom

has published several related documents and has recently approved license-exempt access to TVWS based on its framework [3]. In Japan, MIC has published rules for secondary operation in TVWS [4].

Inspired by such new opportunities, several standards development organizations have started development of radio interfaces for operation in TVWS. ECMA International has developed the standard ECMA-392 for MAC and PHY for operation in TVWS. IEEE 802 has developed three standards, IEEE 802.22, IEEE 802.11af, and 802.15.4m, covering radio interfaces for wide area, local area, and personal area networks operating in TVWS. Further, IEEE 802 has developed the standard IEEE 802.19.1 for TVWS coexistence.

IEEE DySPAN-SC created the IEEE 1900.7 White Space (WS) Radio WG in June 2011 to develop the IEEE Standard 1900.7 for Radio Interface for White Space Dynamic Spectrum Access Radio Systems Supporting Fixed and Mobile Operation. The development process in IEEE 1900.7 was performed in several stages. First, use cases and general requirements for the standard were created. Also, network topology and target frequency bands were selected. Then, the draft development took place. The finalized draft standard was reviewed by an external group of experts within a Sponsor Ballot process during and was approved by IEEE-SA SB in December 2015.

IEEE 1900.7 standard for WS dynamic spectrum access radio system is oriented to operate in TVWS frequency bands. It is based on filter bank multi carrier (FBMC) physical layer and carrier sense multiple access with collision avoidance (CSMA-CA) MAC sublayer with several additional features improving operation in fragmented TVWS spectrum.

This article gives an overview of the key concepts and technologies included in the IEEE 1900.7 standard. Section II summarizes use case document and development directions selected by the WG. Section III gives an overview of the physical layer. Section IV introduces MAC sublayer. Section V concludes the article and outlines future standardization directions in the IEEE 1900.7 WS Radio WG.

II. Use Cases and Requirements

Development of a use case document at an early stage of standardization serves multiple purposes. It helps to understand what kind of applications are targeted for the IEEE 1900.7 standard, what benefits are expected compared to existing technologies, and what requirements are needed to be satisfied to implement such use cases. Use case categories and requirements are summarized in Figure 1.

Number of users	Low	Wireless backbone networks	High
		Fixed wireless access/mesh backbone network	
		Maritime wireless access/mesh backbone network	
		High speed vehicle wireless access backbone network	
		Wireless access networks	Data rate
		Home/office network	
		Land mobile network	
		Wireless Internet of things networks	
		Digital signage network	
		Infrastructure/environment monitoring network	Low
	High	Transportation logistics network	

Figure 1. Use cases and requirements.

Wireless backbone networks category combines use cases where WS radio system is used to provide backbone connectivity to base stations of another system, for example, to WiFi access points. All uses cases in this category are characterized by small number of users per one WS radio base station, high data rate per user, and large coverage area requirements. Mobility requirement increases with use cases inside the category from fixed to medium speed to high speed users.

Wireless access networks category includes home/office and cellular networks using WS for their operation. Use cases in this category have medium number of users and medium data rate per user requirements. Coverage area of one WS radio base station is expected to be of medium size and can be adjusted by selecting transmission power for a particular deployment scenario. Expected user mobility could be low or medium speed.

Wireless IoT networks category combines machine-to-machine communication use cases where WS radio system is used as a distribution/collection network for digital signs, smart homes, marine/forest, industrial and infrastructure objects or moving vehicles. All uses cases in this category are characterized by large number of users per one WS radio base station, low data rate per user, and large coverage area requirements. Also, most of the applications in this use case category will tolerate large delays but will require support of discontinuous transmission and reception for power saving.

Such a rich variety of use cases was created by active contribution from various stakeholders representing different geographical regions and different interest groups. This created very wide range of general requirements that are very difficult to support in

one standard. The developed standard is basically focused on supporting the wireless access networks category of use cases. Use cases in other two categories can be implemented using IEEE 1900.7, but the standard is not fully optimized for such applications. This will be considered in the future revisions of IEEE 1900.7.

Different use cases require different types of network topology: point-to-multipoint, mesh, and support of relay stations and device to device communication. To speed up the standard development, IEEE 1900.7 working group decided that the support of point-to-multipoint topology is mandatory, while support of other types of topology is optional. Based on the actual contributions received and included into the standard, only point-to-multipoint topology is supported in IEEE 1900.7.

The scope of IEEE 1900.7 standard is not limited to TVWS frequency bands. However, the equipment produced based on IEEE 1900.7 shall follow national and international radio regulations. That is why TVWS frequency bands was selected at the beginning of 2013 as target frequency bands for the first standard developed by the IEEE 1900.7 WS Radio WG.

III. Physical Layer

Radio regulations for secondary user operation in TVWS frequency bands require that no harmful interference is caused to primary users [2], [3]. First, same channel operation is not allowed for neighbor primary and secondary users. This is currently ensured by contacting TVWS database that indicates allowed channels for a particular location of a secondary user. Secondly, an adjacent channel leakage ratio (ACLR) of a secondary user transmitter is regulated in order to prevent interference to primary users operating in other channels, in particular, in adjacent ones. In USA ACLR is restricted to be at least 55 dB [2]. In the UK a range of ACLR options is defined, where WS radio transmitters with better ACLR are allowed to transmit at higher power [3]. Strict ACLR requirements are specific to operation in TVWS frequency bands. For example, ACLR requirements for TVWS operation are at least 10 dB stronger than the ones for LTE operation [6]. This requires a careful selection of a physical layer technology for TVWS operation.

Orthogonal Frequency Division Multiplexing (OFDM) has been widely used in wireless broadband systems including IEEE 802.11, IEEE 802.16, IEEE 802.22, and LTE due to very efficient implementation using IFFT/FFT operators. However, OFDM modulation uses a *sinc* frequency prototype filter and thus has bad frequency localization, with significant energy being spread into the sidelobes. For example, the

first OFDM sidelobe level is -13dBc. This results in a difficulty to satisfy TVWS ACLR requirements and makes OFDM not very suitable for the TVWS operation [7].

IEEE 1900.7 WG selected a filter bank multi carrier (FBMC) modulation as it is more suitable for TVWS operation. FBMC was first introduced in 1960s [8], [9]. An example of FBMC modulator and demodulator is shown in Figure 2. Complex QAM symbols mapped to data subcarriers arrive to the input of offset-QAM (OQAM pre-processing). They undergo a complex to real conversion where real and imaginary parts of each symbol are multiplexed in consecutive time samples and modulated using pulse amplitude modulation (PAM). In order to maintain the same data rate the PAM symbols are up-sampled by a factor of two. These PAM symbols are then multiplied by an offset QAM sequence to form a new complex symbol. Each of these complex symbols is up-sampled by a factor of $M/2$, where M is the number of subcarriers used for data transmission, and then filtered using a polyphase network G .

FBMC modulation has shown very good simulated ACLR performance in the context of TVWS [10]. Figure 3 illustrates using the IEEE 1900.7 FBMC for transmission of data in two spectrum fragments 2 MHz each separated by an unused 2 MHz spectrum fragment. For comparison, LTE CP-OFDM spectrum mask is also shown. FBMC significantly outperforms CP-OFDM in terms of ACLR performance. Also, it is well suited for aggregation of fragmented spectrum using only one RF part that is a very important feature in context of a fragmented TVWS spectrum. In FBMC a modulated signal is digitally shaped and a transmitter is able to dynamically adapt to the spectrum made available for secondary usage. This property can be exploited to address fragmented spectrum through spectrum pooling mechanisms or to adapt spectrum mask for local radio regulations. Also, an implementation of FBMC in a flexible TVWS transmitter has confirmed that a FBMC modulation could meet ACLR requirements of FCC [7]. Compared to OFDM FBMC brings a 9 dB power margin for the same adjacent interference level [11].

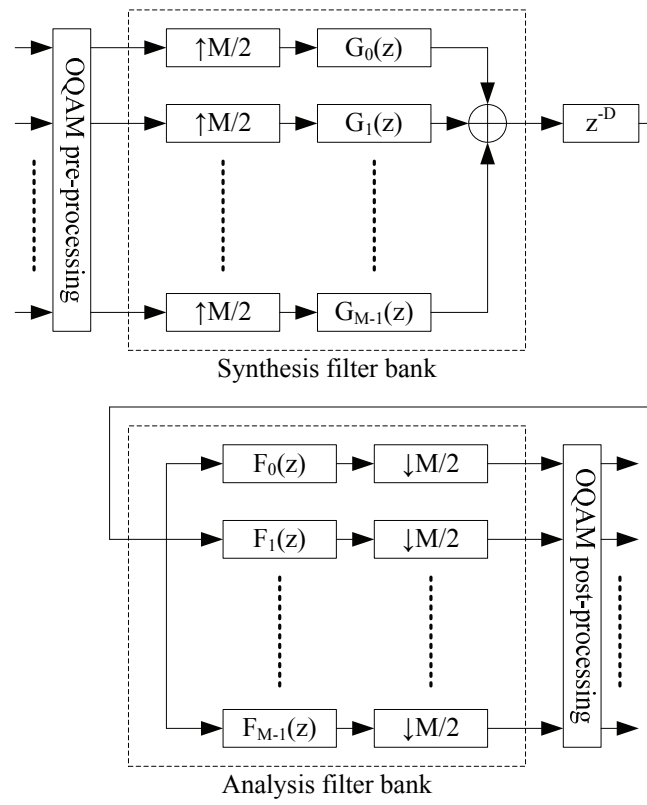


Figure 2. FBMC modulator and demodulator example.

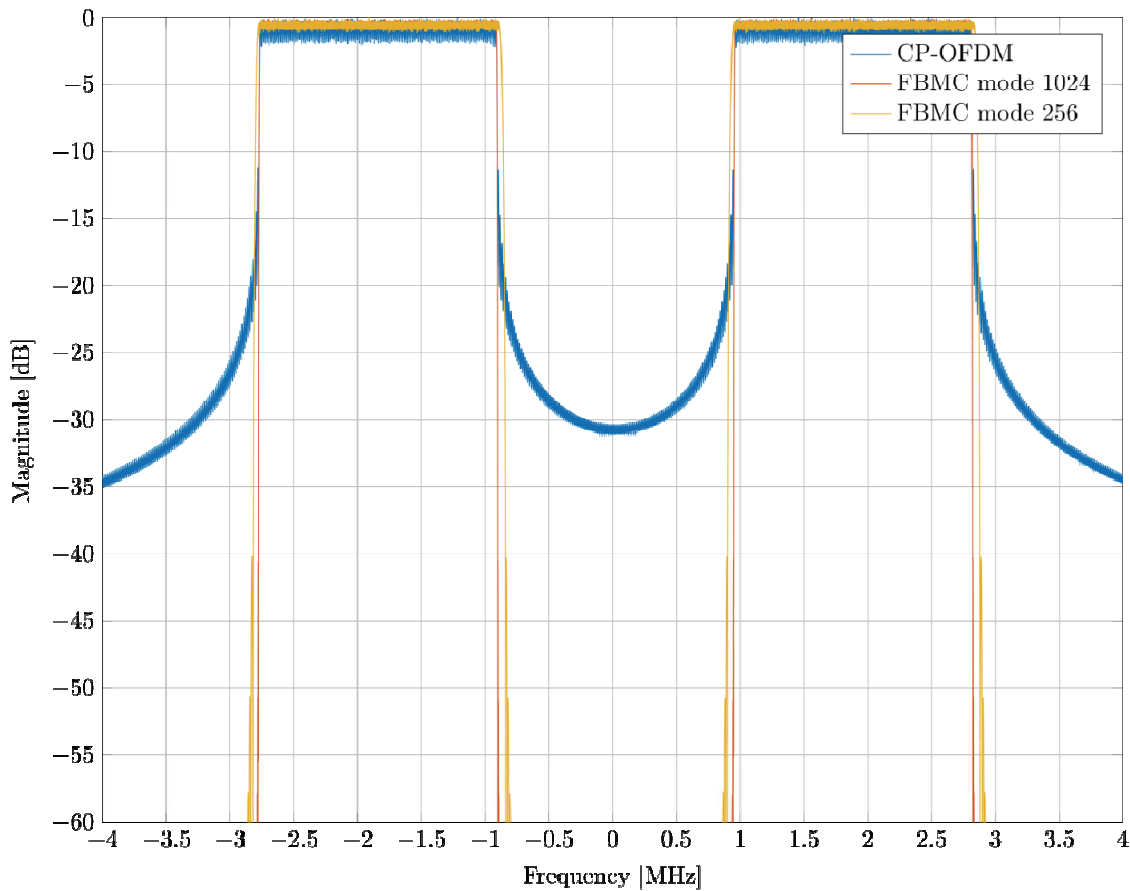


Figure 3. FBMC based IEEE 1900.7 and CP-OFDM based LTE spectrum mask example.

One of the main shortcomings of FBMC is supposed to be its implementation complexity. However, this becomes insignificant in case of TVWS operation due to increased complexity of OFDM filter required to meet ACLR requirements. At a transmitter side the complexity of a filtered OFDM is the same or even higher than the complexity of a FBMC transmitter that does not require an additional filter [7], [10]. At a receiver side the complexity of a FBMC receiver is only 30% to 50% higher than the complexity of an OFDM receiver with a need for some additional memory. This can be implemented at a very limited footprint and cost using current silicon technology.

To summarize, FBMC modulation provides an efficient way to satisfy very strict ACLR requirements, to digitally adapt transmitter spectrum mask to local radio regulations, and to perform aggregation of fragmented spectrum using only one RF part. Due to these reasons it is well suited for WS operation and was selected for the IEEE 1900.7 standard physical layer. Also, FBMC is considered for other TVWS transceiver design and implementations, for example, in [12].

IEEE standard 1900.7 specifies four modes of operation as shown in Table 1. Different modes use different numbers of subcarriers. Also, each mode can operate in 2 MHz or 8 MHz channel depending on bandwidth of TV channel and application. For example, low data rate applications like M2M communication and high data rate applications like wireless broadband access can be efficiently supported by selecting an operating channel bandwidth.

Table 1. IEEE 1900.7 subcarrier and bandwidth modes of operation.

Total number of subcarriers	Intercarrier spacing, kHz	Number of used subcarriers in 2 MHz channel	Number of used subcarriers in 8 MHz channel
4096	3.75	504 (1.86 MHz)	2016 (7.56 MHz)
1024	15	124 (1.86 MHz)	504 (7.56 MHz)
512	30	64 (1.92 MHz)	252 (7.56 MHz)
256	60	32 (1.92 MHz)	124 (7.44 MHz)

The architecture of the IEEE 1900.7 transmitter is shown in Figure 4. The transmitter architecture is composed of two main elements: a forward error correction (FEC) block and a data mapping and modulation block. FEC is implemented using a standard convolutional encoder (CC). 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 at the end of each FEC block. The output of the encoder is forwarded to a bit interleaver of a size equal to a multiple of the output length of the encoder. The coded data is mapped to BPSK, QPSK, 16-QAM or 64-QAM modulation symbols. Modulation symbols are then padded to make a transmitted block to be an integer multiple of multicarrier symbols. The generated block of QAM symbols is mapped to active subcarriers and modulated using OQAM and FBMC. Finally, the baseband signal is conditioned by a digital front end module and undergoes a digital-to-analog conversion.

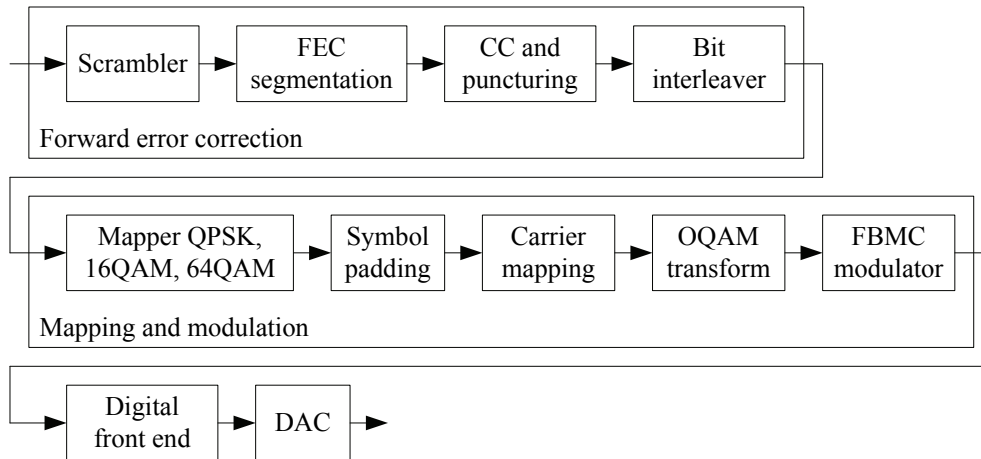


Figure 4. IEEE 1900.7 transmitter architecture.

IEEE 1900.7 standard defines 8 modulation and coding schemes (MCS) ranging from BPSK 1/2 to 64-QAM 5/6. In 2 MHz operating channel this results in physical layer data rate between 0.93 Mb/s and 9.3 Mb/s, in 8 MHz channel between 3.78 Mb/s and 37.8 Mb/s. Different MCSs are used to address different propagation channel conditions and support different applications.

Finally, Figure 5 shows an example where IEEE 1900.7 physical layer is using three non-continuous 8 MHz channels with different allowed power spectral density. Also, in the third channel IEEE 1900.7 transmitter occupies only 6 MHz to share this channel with a professional microphone system. Different MCSs can be used in different channels to guarantee equal quality of service in all three channels regardless of the used transmission power.

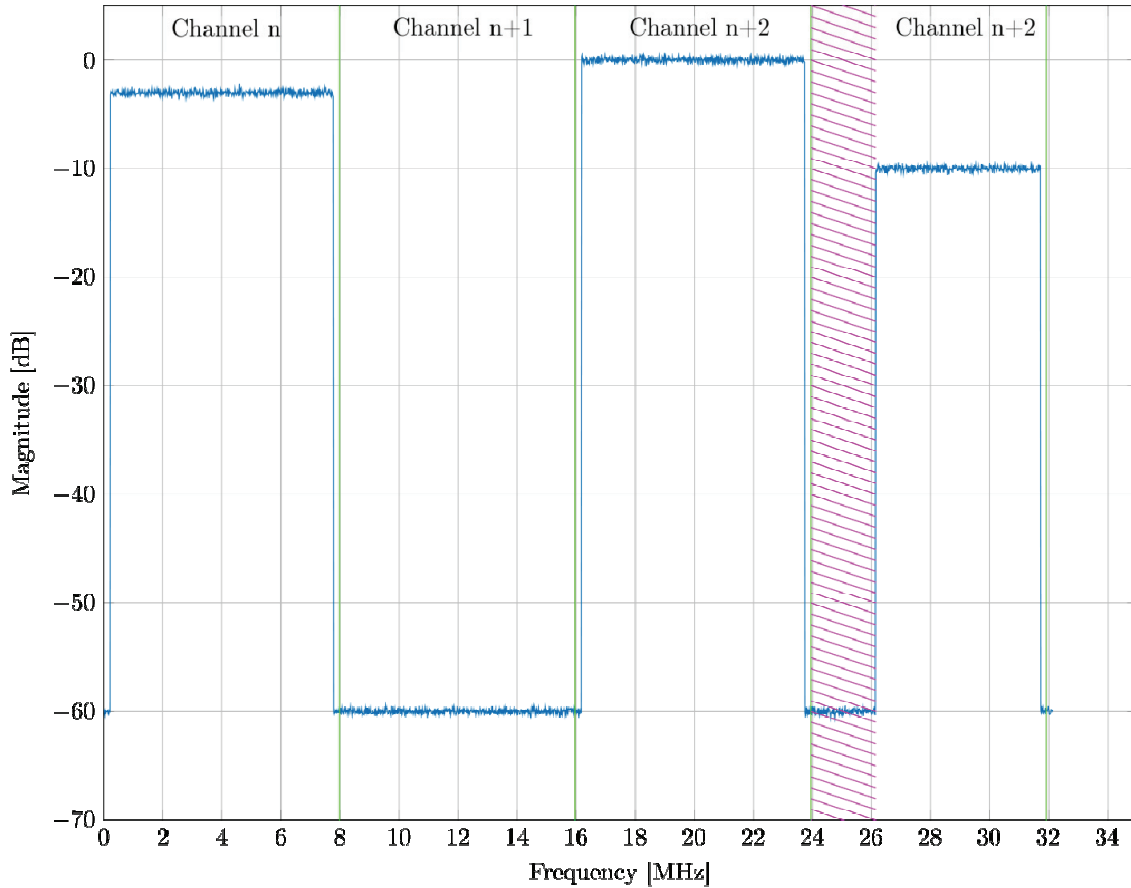


Figure 5. Example of flexible channel aggregation.

IV. MAC Sublayer

The IEEE 1900.7 MAC sublayer is based on a Carrier Sense Multiple Access with Collision Avoidance method with Request-To-Send and Clear-To-Send handshake mechanism that is similar to, for example, IEEE 802.11 multiple access method. A basic network operates in a master-slave mode, where one device is designated as master (network coordinator) and others are associated with the master as slaves.

The basic timing structure used for a frame exchange is a superframe. A superframe is composed of 256 medium access slots. Each superframe starts with a beacon period (BP). A BP is composed of 16 beacon slots. It is followed by a contention access period used for transmission of data and control and management messages. All devices that share the same channel use the same superframe structure. The duration of a superframe of 256 medium access slots is short enough for a beacon to be transmitted often and long enough for control and management information not to cause too much overhead.

A network coordinator device indicates its presence in a network to other devices by

transmitting beacon frames. This allows other devices to perform the network coordinator discovery. Under TVWS operation, before a slave device has finished discovery of a master device, operating channels are unknown. Also, TV channels may be highly fragmented. This requires a special way of mapping of a beacon frame to subcarriers. If a beacon frame is spread among all 2 MHz portions of an operating channel, discovery of a master device by a slave device becomes virtually impossible due to very large number of possible combinations. In IEEE 1900.7 standard, a beacon frame is repeated in each 2 MHz part of an operating channel making master device discovery considerably faster. 2 MHz channel separation was selected to accommodate both 6 MHz and 8 MHz TV channels in different countries.

Additionally an optimized channel switching mechanism is implemented to maintain the connectivity when leaving a channel for a primary user. However, as is typical in standardization, the exact channel switching algorithm is left up to implementation.

In addition to primary user protection, coexistence among different secondary systems in TVWS is very important. Self-coexistence mechanisms between different IEEE 1900.7 systems are embedded in the CSMA-CA mechanism. Coexistence between IEEE 1900.7 system and other systems is left outside of MAC sublayer definition and can be realized, for example, using IEEE 802.19.1 standard [13], [14].

To summarize, IEEE 1900.7 MAC sublayer is based on a traditional CSMA-CA method with RTS/CTS handshake mechanism. Optimized network coordinator discovery and fast channel switching mechanisms were added as specific features for TVWS operation. While the current MAC description is quite basic, it has a lot of flexibility to add new features in future releases of the IEEE 1900.7 standard.

V. Conclusions

White space radio systems can provide a cost-efficient solution for a variety of applications by dynamically accessing unused parts of licensed frequency bands as secondary users. Currently, radio regulations in several countries allow such forms of secondary access to white spaces in TV bands.

IEEE DySPAN-SC has created White Space Radio Working Group in June 2011 to develop IEEE 1900.7 standard for white space dynamic spectrum access radio system. The standard has been approved by IEEE-SA SB in December 2015.

The IEEE 1900.7 physical layer is based on FBMC modulation. This modulation gives designers and manufacturers a flexibility to select between implementation complexity and level of reduction of interference emitted in an adjacent channel. Also it

allows low complexity implementation of aggregation of multiple non-continuous channels. This makes FBMC modulation a perfect choice for fragmented spectrum in TVWS frequency bands with very strict requirements on ACLR to protect primary users.

The IEEE 1900.7 MAC sublayer is based on Carrier Sense Multiple Access, which is well known due to wide use in WiFi networks. However, the fragmented and changing nature of TVWS requires special efforts for practical system design. In a point-to-multipoint topology a slave device needs to discover a master device before it can start communication. IEEE 1900.7 provides beacon transmission scheme that allows fast master device discovery.

The published IEEE 1900.7 standard is mainly targeted to support wireless access network category of use cases. This allows IEEE 1900.7 to serve as a complimentary radio interface to realize 5G mobile broadband use cases in TVWS frequency bands. Now the WS Radio WG is preparing to develop an amendment to the standard. The amendment will concentrate on more efficient support of two categories of use cases: high data rate wireless broadband communication and massive M2M communication. This will allow IEEE 1900.7 to be further integrated into the 5G roadmap.

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Biographies

Stanislav Filin [SM] works as a senior researcher in NICT. He is chair of the IEEE 1900.7 WG on WS Radio. He served as a chair and as a technical editor of the IEEE 802.19.1 TG on WS Coexistence. In 2014 he received IEEE SA SB award for contribution to the development of the IEEE standard 802.19.1.

Dominique Noguét [M] is program leader at CEA-LETI, where he was the head of the Wireless Technology Department until 2016. He has been involved and managed a number of research programs in Europe such as the FP7 QoS MOS project on Cognitive Radio and TVWS. He has been involved in wireless standardization with the IEEE since

2008, and was a key contributor to the 1900.7 WG. His fields of interest include flexible and cognitive radio.

Jean-Baptiste Doré obtained his MSc degree in 2004 and his PhD in 2007. He started working at NXP semiconductors as a signal processing architect for DVB-T products. In 2009 he joined CEA-LETI as a research engineer. His main research topics are signal processing, HW architecture optimizations, PHY and MAC layers. He has published around 40 papers in international conference proceedings and book chapters, and is the main inventor of more than 10 patents.

Baher Mawlawi received his MSc in advanced systems of radio communications from CentraleSupélec, Paris, France and his PhD in wireless communication from INSA, Lyon, France. He worked for CEA-Leti Grenoble, France from 2012 to 2015 on designing novel wireless communication protocols to support dense networks scenarios. He published many papers and he is the inventor of several patents. Since 2016 he joined Schneider-Electric (Business Industry) – Isle d’Espagnac, France as expert in wireless communication protocols.

Oliver Holland [M] is a senior researcher at King’s College London, working on spectrum sharing technologies among others. He has an established record in spectrum-related standards activities, including leadership of various standards, and has undertaken project, academic, event and other leaderships, within the IEEE and elsewhere. He has achieved various accolades for his work, most recently creating and leading a team/submission/idea that won the 0.5m EUR European Union Collaborative Spectrum Sharing Prize.

Muhammad Zeeshan Shakir [SM] is a lecturer in computer networks in the School of Engineering and Computing, University of the West of Scotland, where he is a member of the research center for Artificial Intelligence, Visual Communications and Networking. His research interests include design and performance analysis of wireless communication systems and 5G technologies. He has published more than 75 journal and conference papers, contributed to 7 books, and authored 3 research monographs.

Hiroshi Harada is professor of Graduate School of Informatics, Kyoto University. He is also executive research director of NICT. He joined the Communications Research Laboratory, Ministry of Posts and Communications, in 1995 (currently NICT).

Since 1995 he has researched SDR, cognitive radio, broadband wireless access systems, and wireless smart utility network. He has served as chair of IEEE DySPAN standards committee (formerly IEEE 1900), and as vice chair of IEEE 802.15.4g, 802.15.4m, and 1900.4.

Fumihide Kojima [M] received the D.E. degree in electrical communications engineering from Osaka University, Japan in 1999. Currently, he is Director of Smart Wireless Laboratory, Wireless Network Research Institute of National Institute of Information and Communications Technology (NICT). His current research interests include intelligent MAC protocol for the smart utility networks.