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An Investigation of Orthogonal Frequency Division Multiplexing Modulation Technique as a Candidate for Cognitive Radio Networks

[1]Efe Orumwense, [2]Ireyuwa Igbinosa
[1 2]School of Electrical, Electronic and Computer Engineering, University of KwaZulu-Natal, Durban, 4041, South Africa.
Email: [1]efe.orumwense@gmail.com, [2]yvwa123@gmail.com

ABSTRACT

As the development of modern wireless communication techniques is increasing very fast in recent years, the demand for reliable high data rate transmission has also increased significantly. These have led to the problem of spectrum scarcity and cognitive radio technology is seen as a potential solution to increase spectrum usage efficiency. Cognitive radio however requires an adaptive physical layer in order to perform its cognitive capabilities efficiently. Orthogonal Frequency Division Multiplexing (OFDM) is the most favoured modulation technique being used nowadays for high speed data communications. In this article, orthogonal frequency division multiplexing OFDM as a modulation technique for cognitive radio networks is discussed and the challenges that arises from its employment. OFDM is also compared with four other modulation techniques DFT-spread OFDM (DFTS-OFDM), Constant Envelope OFDM (CE-OFDM) and Filter Bank Multi Carrier (FDMC) to show each technique's sensitivity to various impairments and why OFDM is employed by cognitive radio will be investigated.

Keywords: *Cognitive radio, Physical layer, Orthogonal Frequency Division Multiplexing OFDM, DFT-spread OFDM, Constant Envelope OFDM, Filter Bank Multicarrier*.

1. INTRODUCTION

With the recent advances in the world of wireless communication, Cognitive Radio has gradually paved its way into modern day technology becoming more popular by the day and evolving to become an alluring and attractive solution to spectral congestion and shortage problems. Since the introduction of the concept of cognitive radio a few years ago by Mitola [1], a lot of research have been active in its regards. Up till this present day, there is still no agreement on the exact definition of Cognitive Radio but however several definitions have erupted from different contexts in which it was used. Adopting the definition by the Federal Communication Commission (FCC), "Cognitive Radio: A radio or system that senses its operational electromagnetic environment and can dynamically and autonomously adjust its radio operating parameters to modify system operation, such as maximize throughput, mitigate interference, facilitate interoperability, access secondary markets" [2].

Cognitive radio (CR) is built on the basis of intelligence, awareness, learning, adaptability, reliability and efficiency. The basic idea behind cognitive radio is for effective spectrum utilization and to provide highly reliable communications whenever and wherever needed. The spectrum utilization can be improved significantly by granting permission to the secondary user to utilize a licensed spectrum when it is not in use by the primary user. The spectrum owners are known as the primary users which are ordinary mobile terminals and their associated base stations while the temporary users are the secondary users which possess the intelligence and ability to sense a vacant band in the spectrum and use it whenever and wherever it is available to them. The secondary user should be able to access the vacant spectrum band without the knowledge of the primary user so as not to interrupt transmission or cause interference.

Cognitive radio is a promising radio technology which aids and enables the secondary users to sense which portion of spectrum are available, select best available channel, coordinate spectrum access with other users and vacate the channel when a primary user reclaims the spectrum usage rights. For CRs to achieve this objective, it needs a physical layer (PHY) that is highly flexible and adaptable which will serve as an interface for the transmission medium. OFDM is often employed by cognitive radio network as a preferred modulation technique for achieving high data rate transmission due to its robustness against narrow band interference or severely frequency-selective channel fades caused by long multipath delay spreads and impulsive noise [3].

OFDM can be seen as either a modulation technique or a multiplexing technique and its introduction into cellular world has been driven by two main benefits which are:

- **Flexibility** - enables each transceiver have access to all subcarriers within the cell layer.
- **Easy equalization** – where OFDM symbols are longer than the maximum delay spread resulting in flat fading channel which can be easily equalized [4].

Although there are other available techniques which have previously been proposed in other literatures such as DFT-spread OFDM (DFTS-OFDM), Constant Envelope OFDM (CE-OFDM) and Filter Bank Multicarrier (FMBC), but the reason why OFDM is mostly employed in recent IEEE standards instead of other available techniques will be investigated and its performance will be evaluated.

This paper is organized as follows, in the next section OFDM and other modulating schemes will be examined. In the section three, why OFDM is chosen as a preferred modulating scheme will be investigated. The forth section will look at the challenges which the cognitive OFDM system faces in carrying out this task and the possible approaches in solving them. The fifth section is a review of their applications to current systems and standards. Simulations and result is given in section six and finally, section seven concludes the article.

2. SYSTEM ARHICTECTURE AND TRANSMISSION MODEL

In this section of the article, we will look at the basic block diagram of four modulation multi carrier systems and investigate their performances then compare it with OFDM. We will also introduce their signal processing blocks and examine their signal complexities. From the block diagram of the four modulation techniques presented in Fig. 1, it can be seen that all the transmitter schemes include an Inverse Fourier Transform (IFFT) block and the differences between them are mainly in the surrounding signal processing blocks.

2.1 OFDM

In the block diagram of OFDM transmitter as represented in Fig.1(a), the strength of the system lies in the fact that the modulation and demodulation can be carried out simply by the aid of Inverse Fast Fourier Transform (IFFT) and Fast Fourier Transform (FFT) respectively. The use of the Fast Fourier Transform (FFT) algorithms is to eliminate arrays of sinusoidal generators and coherent demodulation required in parallel data systems and makes the implementation of the technology cost effective [5]. Also the Inverse Fast Fourier Transform (IFFT) significantly reduces the amount of calculations by exploiting the regularity of the operations in the system [5]. The time domain samples of an OFDM symbol can be calculated using an N point IFFT as:

$$x_n = \sum_{k=0}^{N-1} H_k e^{j\frac{2}{N}nk} \ , \ n = 0, 1, \dots\dots.., N-1, \quad (1)$$

where H_k is the complex modulation value for the sub-carrier with index k. Before transmission takes place, a Cyclic Prefix (CP) is added to each symbol. The main importance of the CP is to assist in reducing inter-symbol interference (ICI) and inter-carrier interference (ISI).

2.2 CE- OFDM

In CE-OFDM, The complex modulation symbols are aligned in a complex conjugated manner to achieve a real-valued IFFT output as depicted in Fig.1 (b). Then, phase modulation is applied to the real-valued time domain signal and the CP is added to form the transmitted signal. The transmitted symbol before adding the CP is expressed as:

$$t_n = e^{j2\pi m x_n}, \quad n = 0, 1 \dots\dots, N-1 \ , \quad (2)$$

where m is the modulation index of the phase modulator and x_n is defined in [1] but with the restriction of $X_k = X^*_{N-k}$. The phase modulator can be driven with its real valued signal there by achieving a constant envelope output signal. The spectral distribution of the transmitted signal will be determined by the modulation index m of the phase modulator. CE-OFDM is aimed to solve the high PAPR arising from an OFDM signal but some disadvantages are that the complex conjugated pairing reduces its data rate by a factor of two there by having a low data rate transmission and also CE-OFDM severely suffers from FM threshold effect [7].

2.3 DFTS-OFDM

In the DFTS-OFDM system [8], the complex modulation data set is pre-processed, the complex modulation values which are to be transmitted are however grouped and a Discrete Fourier Transform (DFT) is applied as shown in Fig.1(c). Then the output of the DFT is used to modulate the subcarriers. The output of the IDFT will be a signal with 'single-carrier' properties, i.e. a signal with low power variations, and with a bandwidth that depends on the block of modulation symbols. The transmitted signal can be shifted in the frequency domain by shifting the IDFT inputs to the mapped DFT outputs. This technique has a slightly lower PAPR value compared to the conventional OFDM transmission.

2.4 FMBC

FMBC systems [9], [10] make use of a specially designed filtered bank structure. Firstly, the complex modulation values are spread over several carriers and filtered by a prototype filter. This means that a larger FFT will be required to construct the transmission signal as shown in Fig.1(d). Before transmission, the symbols are overlapped such that they can be separated at the receiver due to the fact that the filter bank is designed in a way that it fulfills the Nyquist criterion. The transmitted signal in FMBC is the sum of the outputs of a bank of N filtersf_k. At any given time instant m, the discrete-time baseband equivalent of the transmitted signal t_m, is given by

$$t_{(m)} = \sum_{n=-\infty}^{\infty} \sum_{k=0}^{N-1} d_{k,n} f_k(m - \tau n), \quad (3)$$

where $(d_{k,n})$ denotes the input symbol sequence of the $k-th$ filter and τ is the symbol period. $m$indicates the time in the filter-sample and transmitted signal domains while n corresponds to the symbol index. Since no CP is used in FBMC to reduce the channel induced inter-symbol interference, a more complex signal processing is needed to be applied and this will result to the channel equalization in the receiver chain to be more complex than the other schemes.

3. EMPLOYING OFDM TRANSMISSION IN CR SYSTEMS

OFDM is a multi-carrier modulation technique being employed by cognitive radio because of its capability of overcoming problems relating to high bit-rate communications. The symbol stream bearing the data is split into several lower-rate streams which are transmitted on different carriers. This splitting increases the symbol duration by the number of orthogonal overlapping carriers or subcarriers. This method actually help OFDM reduce the dispersion effect of multipath channels encountered with high

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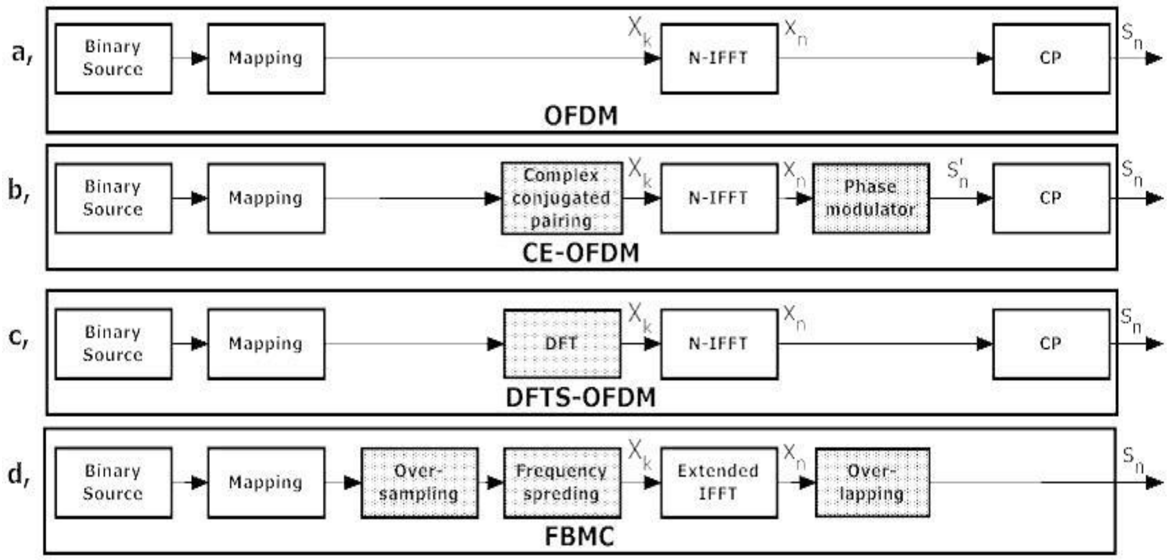

Fig.1 Block diagram of the transmitter schemes

data rates and reduces the requirement for complex equalizers as required for other modulation methods.

In a cognitive radio network comprising of cognitive radios, a cognitive radio is regarded as a secondary or unlicensed user in a licensed band. The main aim of the cognitive radio is to sense and identify available or unused bands in the spectrum and exploits them without causing any interference to the primary or licensed users so as to increase spectrum utilization and efficiency. OFDM has the capability to notch the parts of its carriers which are coincidentally within the region of primary user's band. This kind of OFDM flexibility simplifies the application of CR dynamic spectrum access. A typical example of a CR system is the IEEE 802.2 standard where the spectrum allocated for TV channels are the primary users and the standard based systems are the secondary users. In a CR-OFDM system, the cognitive engine is responsible for making intelligent decisions and configuring the radio and PHY parameters. This decision made by a cognitive radio is based on the information from the policy engine as well as local and network spectrum sensing data. At the PHY layer of the cognitive radio, CR can communicate with various radio-access technologies in the environment or even improve the quality of communication depending on the environment characteristics by simply changing the configuration parameters of the OFDM system.

OFDM has the ability to fulfill various requirements of a Cognitive radio making it the best transmission technology for CR systems. We present these requirements and investigate how OFDM can fulfill these requirements.

3.1 SPECTRUM SENSING

A cognitive radio incorporates multiple sources of information, determines its current operating settings, and collaborates with other cognitive radios in a wireless network. The main functions of a CR are spectrum sensing, spectrum management, spectrum mobility and spectrum sharing [11]. The cognitive ability of a CR helps the CR to learn the spectrum holes in its environment that is why it is considered as one of the critical elements in CRN design. Spectrum sensing is a key technique used by cognitive radios in a cognitive radio network in determining fallow frequency spectrum bands. Basic requirement of cognitive radio is to scan the radio frequency spectrum and determine fallow bands which can be used in an opportunistic manner to increase spectrum efficiency. Conversion from time domain to frequency domain in an OFDM system is accomplished by using FFT so therefore all the points in the time-frequency grid of the operating band can be scanned without any additional hardware or computation due to the re-use of the hardware of the FFT cores. FFT is applied to the received signal in [12] and[13] and using the output of FFT, the receiver tries to detect the presence of a primary signal in the band. In [14], the number of FFTs is adapted to increase the efficiency in the cooperative sensing environment. The signal of a primary user is usually spread over a group of FFT output samples because the band-width of a primary user is expected to be larger than the considered bandwidth divided by the FFT size. Putting this fact into consideration, the FFT output is filtered for noise averaging to obtain a better performance [15]. It is however seen that the presence of FFT circuitry in OFDM systems eases the hardware requirements of the CR and also its computational requirements for spectrum sensing is also reduced owning to the fact that FFT is applied to the receiver to convert the received signal to the frequency domain for easy data detection.

3.2 SPECTRUM UTILIZATION

When a CR has successfully been able to detect available band in the spectrum, the next step is to freely use and manage the band without causing interference to other users. Due to the unique nature of OFDM signaling, it can provide cognitive radio a flexible spectrum mask and control waveform parameters such as signal band-width, power level and center frequency for easy spectrum utilization and management. The spectrum of an OFDM signal can be shaped adaptively to adequately fit into the required spectrum mask by simply disabling a set of subcarriers that could cause interference with other users. With this, a cognitive radio can be able to decide on the best spectrum band to meet the *Quality of Service* requirements over all available spectrum bands.

3.3 INTEROPERABILITY

Interoperability is a powerful tool in CR domain that enables intelligent wireless communication across any boundary and over any dimension. This ubiquitous connectivity can define the ultimate adaptive system over heterogeneous networks, varied spectrums, and diverse geographical boundaries and over different communication policy and regulations. Achieving an interoperable system, OFDM is one of the best signaling candidates, OFDM was successfully launched in various technologies including IEEE 802.11a and IEEE 802.11g wireless local area network (LAN) standards, digital audio broadcasting (DAB), digital video broadcasting (DVB), WiMAX and other long-range and short-range communications. With the knowledge of signal parameters of intended users, CR systems employing OFDM can conveniently communicate with other OFDM based systems with great ease.

3.4 ADAPTIVITY

Another major requirement of a cognitive radio is adaptation to its environment. Cognitive radio has the ability to adapt its waveform to interoperate with other friendly communication devices. It can automatically locate the most suitable communication channel for transmission and allocate the best frequency to transmit in a free band of the spectrum. Due to the fact that OFDM is flexible in this regard as the number of parameters for adaptation is quite large, it has recently become the most favorable. A typical OFDM system can change its modulation order, coding and its transmission power so as to suit the channel quality or user requirements [15]. In multiuser OFDM systems, the subcarrier allocation to users can be done adaptively so as to achieve a high system throughput, reduced bit-error rate (BER), reduce interference to primary users, increase coverage and also unit battery life [16].

OFDM for broad band communications also have the ability to operate using simple one-tap equalizers in the frequency domain, in avoiding Inter-Symbol Interference (ISI) a Cyclic Prefix (CP) is introduced to each symbol with a duration longer than the maximum channel-delay spread and can adaptively change the length of the CP to maintain an ISI-free signal while maximizing system throughput. It can also change its subcarrier spacing to reduce Inter-Carrier Interference or the peak-to-average power ratio (PAPR) [17].

3.5 MULTIPLE ACCESSING AND SPECTRAL ALLOCATION

In order to fully exploit wireless radio resource and then increase spectrum efficiency, cognitive radios shall sense and recognize environments so that the secondary user system(s) may coexist with primary communications systems, i.e. the resources available for the cognitive system can either be used effectively or shared among other users. OFDM supports most of the multiple-accessing techniques used to accomplish this task. For example code division multiple access (CDMA) can be used together with OFDM, in which the transmission is known as multi-carrier code-division multiple access (MC-CDMA) or multi-carrier direct-spread code-division multiple access (DS-CDMA).

In frequency division multiple access (FDMA), Individual frequencies are assigned to individual users on demand and allocates a single channel to one user at a time. Orthogonal frequency-division multiple access (OFDMA) is a special case of FDMA recently gaining much usage popularity especially in worldwide interoperability for microwave access (WiMAX) standard. OFDMA offers very flexible multiple accessing and spectral allocation capabilities for CR without additional hardware complexities and its support these various multiple accessing techniques accelerates the adoption of CR in future wireless systems.

4. COGNITIVE OFDM – CHALLENGES

Due to intelligent features of CR such as adaptability, awareness and learning, it has always been a promising solution to various wireless communications problems. But however, as this new technology evolves, more challenges seem to appear there by raising more fascinating research topics. In the section, we will be looking at the challenges that occur in OFDM based cognitive networks. Challenges that arise from the implementation of OFDM on cognitive radio networks will be listed and their possible approaches for solving them will be discussed. Although there are other challenges that are unique to classical OFDM systems like PAPR, sensitivity to frequency offset and phase noise, but in this paper we will be focusing on challenges issues relating to OFDM based cognitive radio systems.

4.1 SYNCHRONIZATION

OFDM is highly sensitive to time and frequency synchronization errors and this makes it an important issue that needs to be addressed. With its introduction to cognitive radio, new aspects are introduced to the problem especially narrow band interference (NBI) which can possibly interfere with the preambles (pilot sequences) [18]. Also, the incomplete subcarrier set might be an issue for preambles and pilots might fall into the unused subcarriers if used. In multiple user access, the subcarriers can be assigned to different users and in keeping the orthogonality between subcarriers and avoiding interference, all the users should be synchronized to the receiver. Longer preambles are required in a CR-OFDM system when compared to other conventional systems. However, new preambles structures are introduced and their performance for time and frequency synchronization is investigated.

4.2 MUTUAL INTERFERENCE

In a typical OFDM cognitive radio network, spectrum shaping means determining the subcarriers to be used by the OFDM system while maintaining a low level interference with the primary users. The spectrum sensing information acquired from the system is used to select the subcarriers to be used by the secondary users. This problem can be solved by using energy detectors over each subcarrier [19] where a detection criterion is used to determine used subcarriers.

4.3 MUTUAL INTERFERENCE

In an OFDM system, there is a power leakage from used subcarriers to unused subcarriers which causes interference known as mutual interference to licensed users and this is because side lobes of modulated OFDM subcarriers are large [20]. Numerous methods have been proposed in the literatures to reduce mutual interference. One of these methods is to make the *sinc* function decay faster by windowing the time domain OFDM samples and applying a raised-cosine window [21]. But this however reduces the system throughput due to the temporal extension of time domain signal to maintain orthogonality. Another method is to adaptively deactivate the subcarriers that are adjacent to the subcarriers occupied by the secondary users [21]. By doing this, the interference will significantly reduce as most of the interference comes from the neighboring subcarriers. However one disadvantage of this method is that it reduces spectrum efficiency. In [22, 23] it was proposed that instead of deactivating the neighboring subcarriers, their values can be determined actively in order to cancel the interference in the deactivated bands. In this way, the system throughput can be improved but it is however complex as it requires optimization. Another method was also proposed in [24, 25] where the subcarrier weights are determined in such a way that the sidelobes of the transmission signal are minimized according to an optimization algorithm which allows several optimization constraints. This way, more than 10dB reduction in the sidelobes of the OFDM signal can be achieved.

4.4 SIGNALING TRANSMISSION PARAMETERS

An OFDM system can easily adjust its waveform by turning off some subcarriers in order to exploit the available spectrum holes, but the receiver however should be aware about the subcarriers that are deactivated and the subcarriers to be used. Detection of those unused subcarriers can be executed blindly and therefore cause an overhead so signaling of this information should be performed carefully so as to prevent interference to the primary users while keeping the bandwidth loss at minimum. A method was proposed in [26] to reduce the overhead due to signaling and this is achieved by activating or deactivating the subcarriers over a block of subcarriers instead of the intended individual subcarrier. Thus the signaling overhead can be reduced by a factor of each block's size. So also parameters like FFT size and CP size can also be changed and this information is sent to the receiver depending on the channel quality and available resources. Tone-boosting can also be used as proposed in [27] where a cognitive unit detects a primary signal within the band and sends a tone with maximum power but with very short time duration over the detected signal band. The reason for this is to notify other users that a primary user exist within the band which can also help to reduce interference to the primary user.

4.5 DESIGNING EFFECTIVE PRUNING ALGORITHM

After determining which subcarriers are to be used, there might be some other subcarriers that are turned off in other to exploit available spectrum holes. In the very scenario, the efficiency of FFT algorithms can be increases and/ or execution time can be decreased by removing operations on input values which are zero, a process known as pruning. So as to achieve higher system performance, effective pruning algorithms is important cognitive OFDM systems. Specific implementation of pruning technique for CR-OFDM systems can be seen in [28].

5. COGNITIVEOFDM APPLICATIONS

During the past decade, OFDM has been proposed as an efficient modulation scheme for a lot of applications and wireless standards. OFDM has been in full employment by various IEEE standard working groups and due to the cognitive features posed by a cognitive radio such as Dynamic Frequency Selection (DFS), Transmit Power Control (TPC), channel sensing and primary user detection recently developed standard are also considering its implementation. In this section some cognitive OFDM applications will be discussed.

5.1 WIRELESS LAN NETWORKS

IEEE 802.11 was the first international standard for WLAN which evolved in 1997 and it is probably the most commonly known OFDM based standard. Its specification defines a set of requirements for the physical layer (PHY) and a medium access control (MAC) layer. For high data rates, the standard provides two PHYS – IEE 802.11b for 2.4-GHz operation and IEEE 802.11a FOR 5-GHz operation. But recently is has been upgraded to have cognitive features with the IEEE 802.11h and IEEE 802.11k standards. The IEEE 802.11h provides the system with more control over signal range and interference level and it allows the WLAN systems to share the 5-GHz spectrum with primary users. An example is the military radar systems.

The IEEE 802.11k standard is proposed for the radio resource management. It defines several types of measurements like the channel-load reports, the noise histogram report which provides methods to measure interference levels and station-statistics report. Other reports such as the sharing of client statistics and the tracking of hidden nodes are included in this standard. Applying both the 802.11h and 802.11k standards to current 802.11-based WLAN systems has significantly improved the efficiency and performance of wireless networking. It is important to note that 802.11 standards mainly use OFDM making it the signaling choice for future technologies.

5.2 WiMAX – IEEE 802.16

The first WiMAX standard, IEEE 802.16a [29], operates in a 10 – 60 GHz range where only line-of-sight (LOS) communication is possible and later evolved to the IEEE 8021.16d which supports the operation in 2 to 11 GHz range allowing for a non-line-of-sight (NLOS) communications. The IEEE 802.11e standard updates and

extends this standard to allow for mobile subscriber stations travelling at vehicular speeds and a scalable version of orthogonal frequency multiple access (OFDMA) is introduced to improve the overall system performance. OFDMA PHY mode is perhaps the most remarkable supported by WiMAX. Employing OFDM signaling, OFDMA PHY mode enables a Base Station (BS) to support multiple fixed or mobile users at the same time and also offers multiple FFT sizes, CP sizes and pilot schemes. Users can also be able assigned different bandwidths, time durations, transmitting power levels and modulation orders based on various parameters such as user carrier-to-interference noise ratio (CINR), received signal strength indicator (RSSI) or the available bandwidth.
WiMAX also supports advanced antenna techniques as well, even though these antenna techniques are not requirements, they are well-matched for cognitive radio and very useful for achieving high data rates and spectral efficiency. CR receiver can use these antenna techniques to adaptively cancel interference caused by unintended transmitters [30] whose aim is to achieve a coexistence of WiMAX devices in unlicensed bands.

5.3 IEEE 802.22 STANDARD

Owing to the cognitive features such as channel sensing, licensed user detection, dynamic frequency selection and transmit power control of this standard, is can also be regarded as the CR standard [31]. Although this standard is not finalized yet, it is anticipated that it will be based on OFDM transmission as well. This standard is designed mainly to target rural and remote areas since it is reusing TV bands. Its topology is designed as a fixed point-to-multi-point communication where the BS acts as the master controlling all the operation parameters of users within the cell and users can share sensing information with the BS through distributed sensing. In the IEEE 802.22 standard, the sensing requirement is based on fast and fine sensing. The challenge involved in the design of this standard is the initialization of new users who desire to communicate with the BS. The initial users will have to scan parts or all of the TV bands to locate the current BS operating frequency and time. This can be very challenging because users are also expected to differentiate between incumbent signals and BS signal [32].

6. SIMULATION AND RESULTS

In this section, we focus on the comparison of the different modulation techniques as previously described above. The amplitude fluctuation of transmitted signal is examined through signal metrics. The simulation was performed with normalized transmitted signal energy using AWGN channel. In literature, the type of metrics considered when describing the dynamics of the transmission signal $s(t)$ is the Peak Average Power Ratio (PAPR) and it is defined as

$$PAPR(s(t))_{dB} = 10log_{10}\left(\frac{\max\{|s(t)|^2\}}{E_8}\right) \quad (4)$$

where $|s(t)|$ the amplitude of the transmission is signal and E_8 is the average energy of the signal.

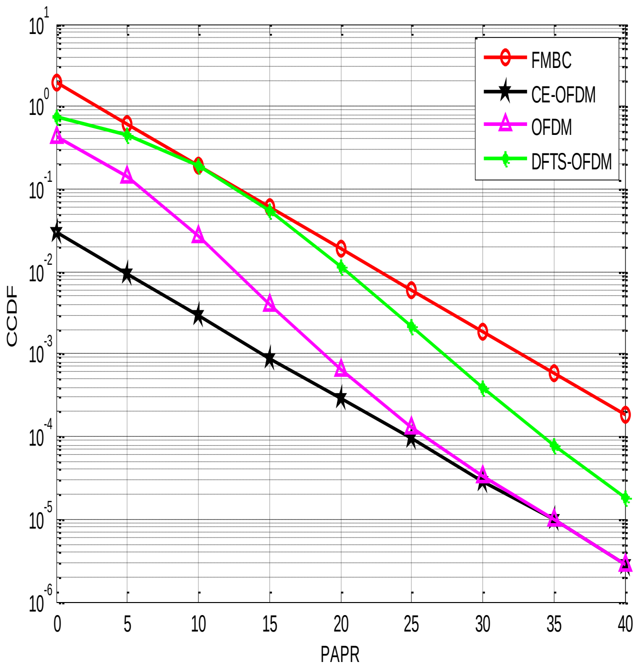

Fig 2.CCDF of the PAPR values of the transmitted signals

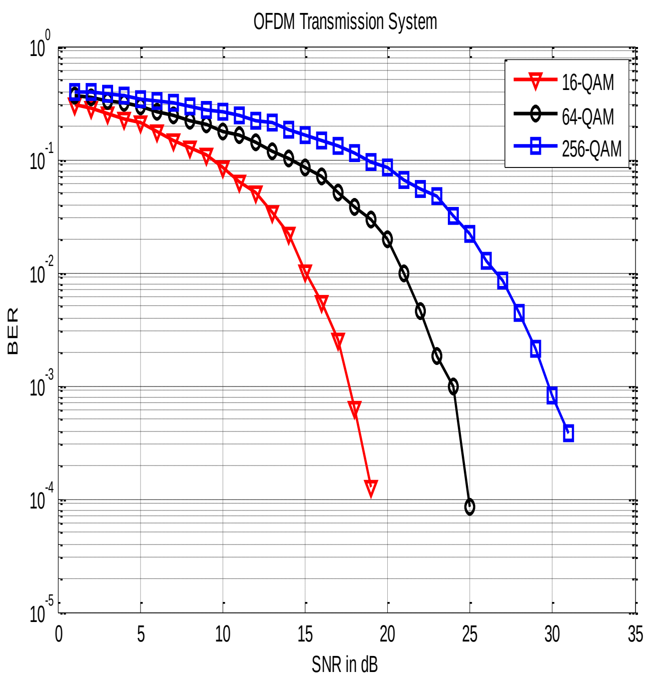

Fig. 3. BER versus SNR in an OFDM transmission system

The PAPR values of the total entire signal transmission are analyzed in Fig. 2, where the complementary cumulative distribution functions (CCDF) of the PAPR values are shown. It can be seen that CE-OFDM possesses the lowest PAPR values followed by OFDM when compared to the other techniques. FMBC and DFTS-OFDM performs the worst. PAPR reduction scheme can be done on OFDM using the

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constant envelope modulation and a complete reduction can be effectively carried out using the continuous phase modulation (CPM) in a CE-OFDM system. In Fig. 3, the BER (Bit Error Rate) in M-ary QAM OFDM scheme was measured. The figure compares BER performance of M-ary QAM OFDM Bit, showing the results of 16-QAM, 24-QAM and 256-QAM modulation simulations. It was found out that the performance gain between M-ary QAM OFDM-based systems are relatively very high. In OFDM, although sub-carriers overlap, this does not create any problem since they are orthogonal, that is the peak of one occurs when the others are at zero. The analysis of BER performance have suggested that OFDM is better than the other modulation techniques analyzed.

7. CONCLUSION

In this paper, we introduced four possible choices of modulation schemes for cognitive radio network and investigated why OFDM modulation scheme is mostly employed. OFDM offers a great deal of flexibility, adaptability, awareness and interoperability with current technologies which makes it easier to employ in CR systems. It is also seen to have met and satisfy most of the requirements of a cognitive radio. Although there are some challenges OFDM encounters in carrying out its task, it can still be regarded as a decent provider of PHY for CR and also as an effective and reliable method of data transmission. In future work, some other aspects such as effect of analog components and channel equalization can be investigated and compared to the other modulation schemes to see which best fits CR requirements.

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AUTHOR PROFILE

Efe Francis Orumwense received his B.Sc. (Hons) degree from the School of Engineering, University of Benin, Benin City, Nigeria in 2009. He is currently a research fellow at the Radio Access and Rural Telecommunication (RART) in the University of KwaZulu-Natal (UKZN) and he just completed his Master’s degree from the school of Electrical, Electronic and Computer Engineering, University of KwaZulu-Natal, Durban, South Africa. His research interest includes cognitive radio technology, wireless network security, and orthogonal frequency division multiplexing systems.

Ireyuwa Igbinosa is a Graduate of Manchester Metropolitan University,Manchester, United Kingdom,in Electrical Electronics Engineering, (Masters by Research). He is also a Graduate Member of the Institution of Engineering and Technology (MIET) and Currently a Doctoral Researcher at the Center for Radio Access Technology, University of KwaZulu-Natal, Durban South Africa.