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Implementation and Evaluation of OFDM and FBMC Systems

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Abstract

In today's world, the growth of communication systems is at the speed of light. Every day, the number of people using communication system is increasing rapidly. In this modern generation of 4G, Orthogonal Frequency Division Multiplexing (OFDM) is the latest modulation technique which is used to achieve high data rate and it is also used to transmit data without Inter-Symbol Interference (ISI) and Inter-Carrier Interference (ICI). The concept of OFDM is difficult to understand as it is a modern 4G wireless technique and various problems such as Peak-to-Average Power Ratio (PAPR) also takes place. In this paper, discussion of the various parameters of OFDM behaviors such as Carrier Frequency Offset (CFO) estimation, Cyclic Prefix and Bit Error Rate (BER) is done. OFDM is also used in a number of applications which is also described in this paper.

Keywords: **:** Orthogonal Frequency Division Multiplexing (OFDM), FBMC (Frequency Band Multi Carrier), Inter-Symbol Interference (ISI),Inter-Carrier Interference (ICI), Peak-to-Average Power Ratio(PAPR), Carrier Frequency Offset (CFO), Cyclic Prefix(CP), Bit Error Rate(BER).

INTRODUCTION

High speed data rate transmission is needed in order to meet the requirements of the tremendous growth in the communications. Apart from the high data rate, future communication system will also support the high rate of voice, video as well as wireless communication links [1]. Orthogonal Frequency Division Multiplexing (OFDM) has considerably achieved a success in providing high data rate transmission. OFDM modulation techniques include multicarrier modulation techniques [2] and high capacity transmission. As OFDM is having high bit rate as well as multicarrier modulation technique, Digital Audio Broadcasting (DAB), Digital Symmetric Lines (DSL) and Digital Video Broadcasting (DVB) uses OFDM technique.

The Development of OFDM started in 1960's with the progress of the development of Multi Carrier Modulation Technique (MCM) [3]. The structure of OFDM was patented by Chang in 1966[4] and overlapping of multiple signals was published. Weinstein and Ebert [5] proposed Discrete Fourier Transform (DFT) for the OFDM modulation. Digital Signal Processing (DSP) is also used in OFDM implementations by which FFT [6] algorithm can be implemented. Use of OFDM at the commercial level started in 1980's [7]. Peled and Ruiz implemented the use of Cyclic extension and Cyclic Prefix (CP) [8].

BASIC PRINCIPLE OF OFDM SYSTEM

The basic principle of OFDM modulation technique is to split the high data stream into a number of lower rate data streams. These data streams are transmitted over a number of subcarriers. But whenever high data rate is there, there is always a problem of noise and other interferences. Peak-to-Average Power Ratio (PAPR) is also one of it.PAPR is the ratio of instantaneous maximum power to the average power given by a signal. The transmission rate can be increased by overlapping sub channels in frequency domain. Different modulation techniques such as Fast Fourier Transform (FFT) [23]and Inverse Fast Fourier Transform(IFFT)[24] are used to for modulation as well as demodulation of filters at the transmitter and receivers.OFDM has been widely used in today's high speed digital communication such as 4G,5G and LTE systems.OFDM combines a large number of low data rate carriers to construct a composite high data rate communication system.Orthogonality is used to give the carrier a valid reason to a closely spaced, even overlapped without inter-carrier interference. The high data is modulated over a single carrier frequency and bandwidth is occupied by each signal. Thus in these case of frequency selection, Inter-symbol Interference (ISI) and Inter Carrier Interference (ICI)[22] occurs. Flat fading occurs in OFDM because the total bandwidth is divided into number of subcarriers and the channel spectrum into number of orthogonal sub channels. Several modulation techniques such as FDMA, CDMA, TDMA are used over a number of years, the problem such as multipath fading, less spectral efficiency, Bit-Error Rate (BER) etc. still occurs. High spectral efficiency, Flat fading of channels are the main advantages of OFDM.OFDM signal spectrum is shown in Figure 1.

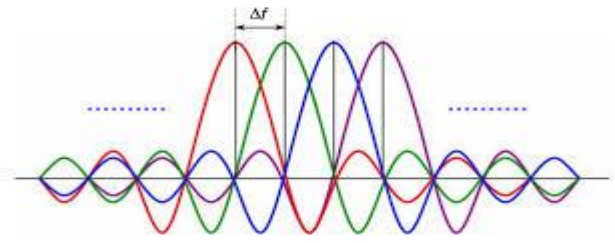

Figure 1. OFDM signal spectrum

Block Diagram of OFDM systems

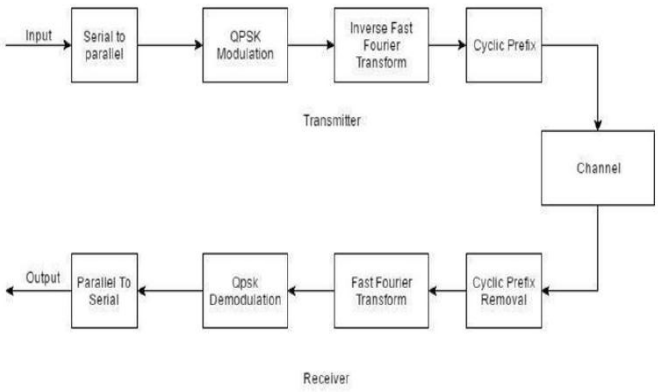

Figure 2: OFDM system Block Diagram

The transmitter generates the user information bit sequence which is subjected to channel coding and it is divisible by number of sub carriers. These reduce the probability of error at the receiver side. The bits are then converted into symbols by using different modulation techniques such as 16-QAM, 64-QAM, BPSK, QPSK, PSK, etc. The selection from these modulation techniques depends on the condition of channels as well as to maintain the balance Bit-Error Rate and the frequency channel. Inverse Fourier Fast Transform (IFFT) is used to convert this frequency domain into sample data and to convert the symbol sequence into parallel format. Again by using IFFT, the sequence is again converted into the serial format. Initially the guard time is provided because of the cyclic extension with of the OFDM symbol. Digital to Analog Convertor (DAC)[19] and Analog to Digital Convertor (ADC)[20] is used in the transmitter as well as receiver. The generated digital sequence is converted to analog signal by using DAC. After that the transmit antennas are used to transmit the RF modulated signal to the receiver. These signals are digitalized by using ADC and demodulation of RF [25] is also performed at the receiver.FFT is used to convert the sequence to the parallel format.

WORKING OF OFDM SYSTEMS

As it is mentioned above that in OFDM modulation technique, every sub-carrier is orthogonal to each other. Various mathematical relationships are used in OFDM because it includes various carrier signals and its frequencies. In frequency spectrum of OFDM, the sidebands of the signals overlap each other and still the signal can be received without any carrier interference. The concept of orthogonality is used here. If the integration of the product of the two signals is zero, then the two signals can be said orthogonal to each other [21].

$$(f, g) = \int f(x)g(x)dx \qquad (1)$$

In the above equation if $f(x) = \cos(x)$ and $g(x) = \sin(x)$ for a single period, the result will be zero if they are orthogonal. If two sinusoid waves of frequency m and n are multiplied, then the product is given by:

$$f(t) = \sin mwt * \sin nwt \qquad (2)$$

The product of the integration of both the signals is given by:

$$f(t) = \cos \int \frac{1}{2}(m-n) - \frac{1}{2}\cos(m+n)\, wt. \qquad (3)$$

Thus, the harmonics is created between all the signals and $\sin mx, \sin nx, \cos mx, \cos nx$ is all orthogonal to each other.

The main formula that is used in OFDM is as given as

$$x(k) = \frac{1}{N}\sum_{i=0}^{N-1} \mathrm{x(i)} e^{j2\pi ki/N} \qquad (4)$$

Peak-to-Average Power Ratio (PAPR) reduction techniques

In OFDM modulation, High Peak-to-Average Power Ratio is one of the major practical problems. In high PAPR, multiple subcarriers or sinusoids are added together to transmit the signal [16]. The ratio of the maximum instantaneous power and the average power is the actual definition of PAPR. In other words, it can also be said that maximum power occurring in OFDM transmission to the average power of the OFDM transmission. Mathematically, it defined as

$$\frac{P_{peak}}{P_{average}}.$$

The Application of OFDM

Many wireless communication standards have adopted OFDM modulation technique. High-definition television (HDTV), Terrestrial broadcasting, and satellite terrestrial interactive multi-service infrastructure are introduced in China [9]. Many IEEE standard working groups such as WirelessLAN has considered OFDM techniques. Multiband OFDM (MB-OFDM) has been used as a candidate for the IEEE 802.15.3a working group designed for ultra-wideband (UWB) systems [10-15]. Cognitive radio has emerged as a promising technology to solve the current spectrum scarcity problem [26]. OFDM can be used to construct the transceiver of cognitive radio by virtue of its flexibility for sub-channel assignment and power allocation. OFDMA is one of the most promising radio transmission techniques for LTE of the 3rd Generation Partnership Project (3GPP) [16] and the International Mobile Telecommunications-Advanced Systems (IMT-AS) [17].OFDM-based Wireless Asynchronous Transfer Mode (WATM) [18] transmission system has been proposed in Europe to be suitable for the future broad-band mobile multimedia communications.[1-27]

RESULTS AND DISCUSSION

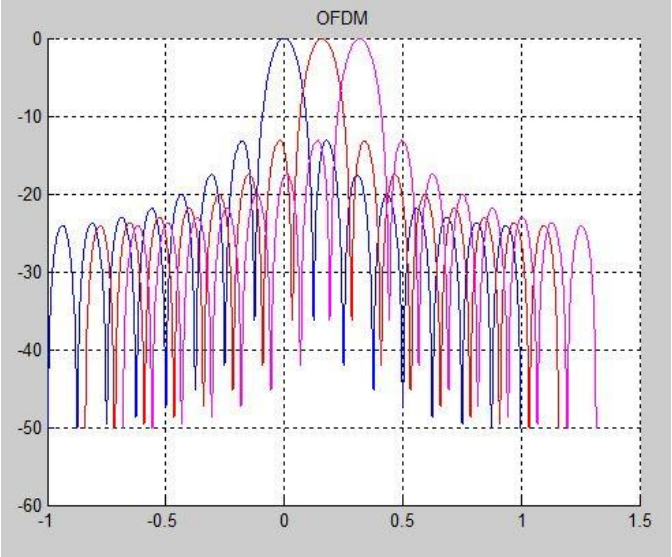

Figure 3: OFDM signals

Figure 3 shows the OFDM signals that are generated due to the sub channel carriers. Sidelobes are larger in OFDM signals.

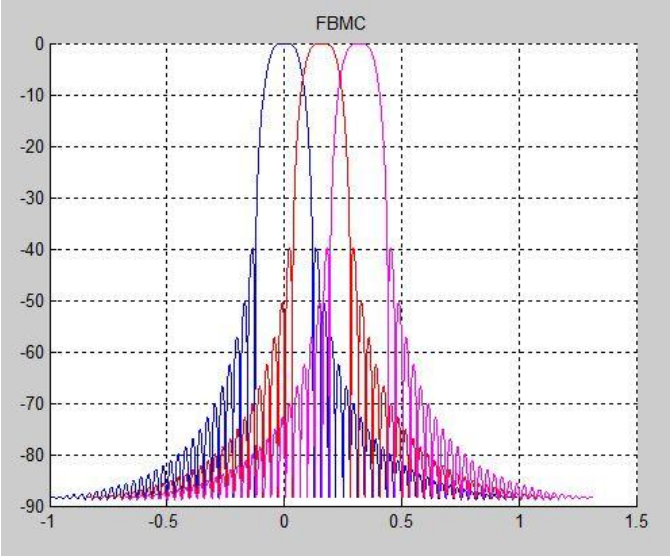

Figure 4: FBMC signals

Figure 4 shows the FBMC signals generated by sub channel carriers. Sidelobes in FBMC is very lower compared to OFDM signals.

By performing various experiments, it can be said that FBMC is an advancement of OFDM.In FBMC, multicarrier system based on filter banks is replaced. IFFT is replaced by synthesis filter bank (SFB) an FFT is replaced by analysis filter bank (AFB).

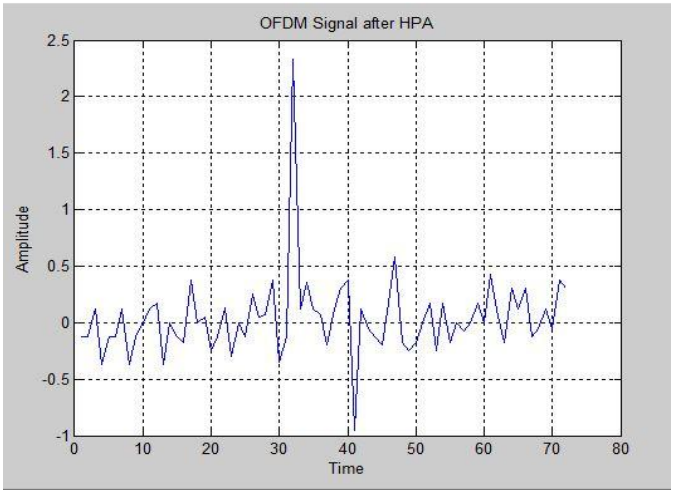

Figure 5: OFDM signals after HPA

Figure 5 shows the OFDM signals that are generated after High Power Amplifier. Thus it can be seen in figure that distortion is generated in OFDM signals due to nonlinear HPA.

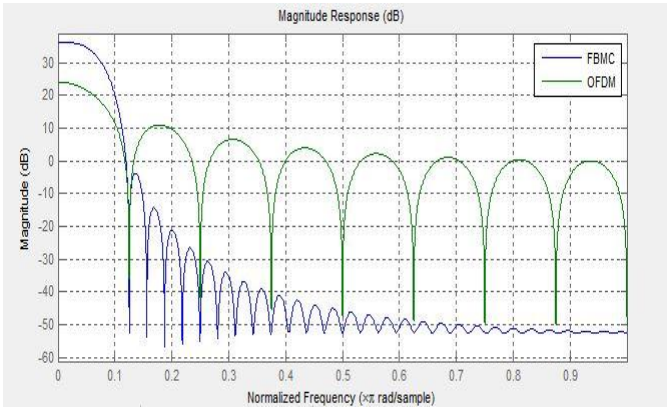

Figure 6: Magnitude Response Of OFDM and FBMC

Figure 6 shows the magnitude response of OFDM and FBMC using the normalized frequency .OFDM is having higher magnitude while FBMC is having lower magnitude.

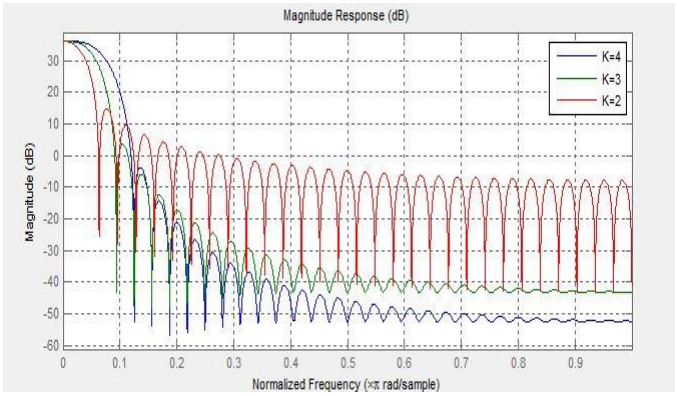

Figure 7: Prototype Filter Comparison

Figure 7 shows the prototype filter comparison of OFDM and FBMC. Rectangular window filter is used in OFDM while FBMC uses filter with the Nyquist criteria and it reduces the spectral leakage problem of OFDM.Due to these technique, the problem ISI as well as ICI can be prevented.

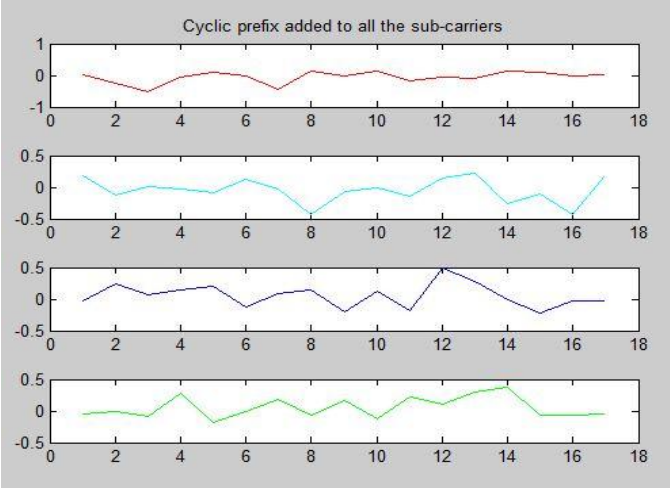

Figure 8: Cyclic Prefix added to OFDM

Figure 8 shows the signals that are generated when extension is added to cyclic prefix. Signals for all the different sub carriers with cyclic prefix are shown in these figure.

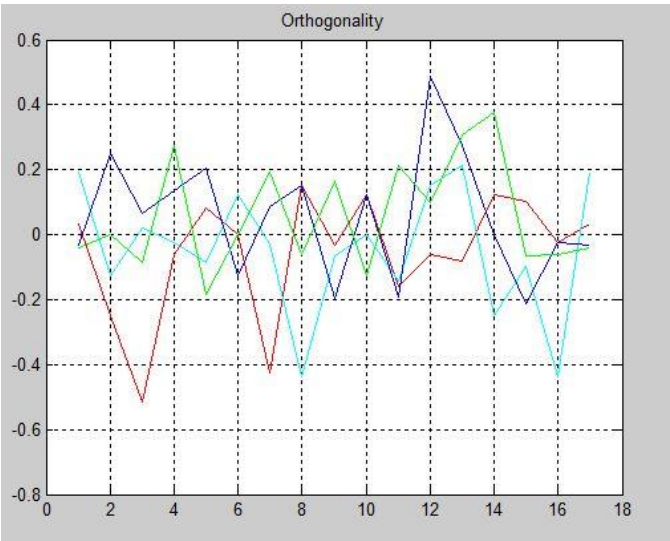

Figure 9: Orthogonality

Figure 9 shows the orthoganality in OFDM signals. Different signals are having different orthogonality as shown in figure.

Thus from the above it can be said that FBMC is more accurate than OFDM. FBMC has less interference than OFDM..Sidelobes are larger in OFDM compared to FBMC. While implementing, FBMC is more complex compared to OFDM. Sensitivity is high for Carrier Frequency Offset (CFO) in OFDM .When OFDM is used for Multiple Inputs, Multiple Outputs(MIMO), it is highly flexible.

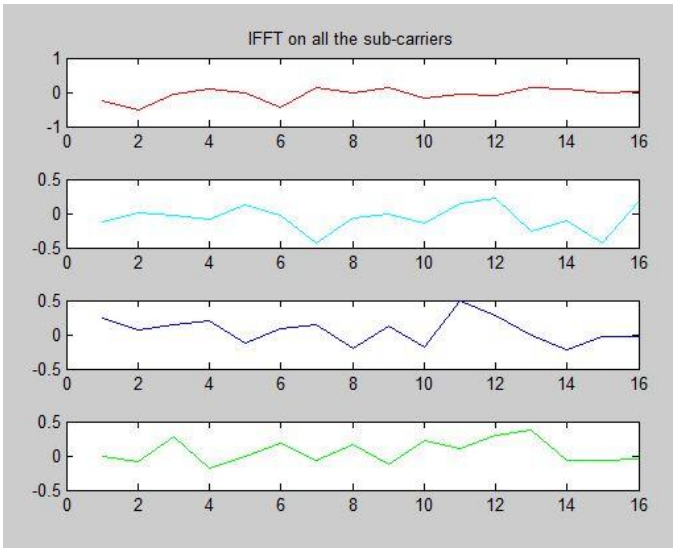

Figure 10: IFFT on all subcarriers

Figure 10 shows the effect of IFFT on all subcarriers. Due to IFFT, frequency domain is converted into sample data and the symbol sequence into parallel format. Again by using IFFT, the sequence is again converted into the serial format.

The following table shows the result of BER vs SNR of OFDM as well as FBMC signals. From these both analysis, BER performance is improved in FBMC compared to OFDM.

Table 1: Analysis of OFDM

SNR(dB)	BER
10	54.71%
20	46.27%
25	32.80%
30	18.51%
35	3.125%

Table 2: Analysis of FBMC

SNR(dB)	BER
0	10.22%
5	7.50%
10	4.62%
15	2.27%
20	1.45%
25	0.36%
30	0.009%

In OFDM, Bandwidth (BW) is required due to Cyclic Prefix while in FBMC no Bandwidth is required. Moreover, FBMC has more concentrated spectrum of sub channels than OFDM. The lost symbols can be recovered by OFDM by using the channel coding. The problem of Inter-Symbol Interference (ISI) and Inter-Carrier Interference (ICI) that is generated because of the signals can be removed by OFDM. The major problem of PAPR that occurs in OFDM is removed by different methods like clipping and filtering. Numerous numbers of channels is divided into number of sub channels of narrowband flat fading. OFDM makes channel equalization more easily compared to signal carrier systems that uses adaptive equalization technique.

CONCLUSION

In recent years, the demand for the high for high data rate in wireless communication has been gradually increasing.OFDM is one of the most emerging modulation technology in multi carrier which can solve the problems.OFDM behaviors, principles and analysis of different techniques like Peak-to-Average Power Ratio (PAPR) reduction and frequency offset estimation which improves the performance of OFDM for wireless communications, OFDM have a high spectral efficiency and also has a strong anti-multipath interference capability in a high-speed data transfer conditions. The paper has also explored the applications of OFDM and its overview for wireless communication. The future work will be focused on finding out the performance parameters of different PAPR and CFO techniques by using different extensive stimulations.

REFERENCES

[1] Lian, Hua, Ruimei Zhao, Boning Hu, and Huawei Pang. "Simulation and analysis of OFDM communication system." In *Industrial Mechatronics and Automation (ICIMA), 2010 2nd International Conference on*, vol. 2, IEEE, (2010): 677-680.

[2] Fu, Yu, and Chi Chung Ko. "A new ICI self-cancellation scheme for OFDM systems based on a generalized signal mapper." In *Wireless Personal Multimedia Communications, 2002. The 5th International Symposium on*, vol. 3, IEEE, (2002): 995-999.

[3] Wu, Yiyan, and William Y. Zou. "Orthogonal frequency division multiplexing: A multi-carrier modulation scheme." *IEEE Transactions on Consumer Electronics* 41, no. 3 (1995): 392-399.

[4] Koo, Chang-Soo, and Robert Lind Olesen. "Quality control scheme for multiple-input multiple-output (MIMO) orthogonal frequency division multiplexing (OFDM) systems." U.S. Patent 7,864,659, issued January 4, 2011.

[5] Weinstein, Stephen B. "The history of orthogonal frequency-division multiplexing [History of Communications]." *IEEE Communications Magazine* 47, no. 11 (2009):26-35.

[6] Skinner, D. "Pruning the decimation in-time FFT algorithm." *IEEE Transactions on Acoustics, Speech, and Signal Processing* 24, no. 2 (1976): 193-194.

[7] Armstrong, Jean. "OFDM for optical communications." *Journal of lightwave technology* 27, no. 3 (2009): 189-204.

[8] Peled, Abraham, and Antonio Ruiz. "Frequency domain data transmission using reduced computational complexity algorithms." In *Acoustics, Speech, and Signal Processing, IEEE International Conference on ICASSP'80.*, vol. 5, IEEE, (1980) :964-967.

[9] Hwang, Taewon, Chenyang Yang, Gang Wu, Shaoqian Li, and Geoffrey Ye Li. "OFDM and its wireless applications: A survey." *IEEE transactions on Vehicular Technology* 58, no. 4 (2009): 1673-1694.

[10] Fisher, R. "IEEE 802.15 WPAN High Rate Alternative PHY Task Group 3a." *IEEE 802.15. 15-04/137r3* (2004).

[11] Siriwongpairat, W. Pam, Weifeng Su, Masoud Olfat, and KJ Ray Liu. "Multiband-OFDM MIMO coding framework for UWB communication systems." *IEEE Transactions on Signal Processing* 54, no. 1 (2006): 214-224.

[12] Hwang, Taewon, Chenyang Yang, Gang Wu, Shaoqian Li, and Geoffrey Ye Li. "OFDM and its wireless applications: A survey." *IEEE transactions on Vehicular Technology* 58, no. 4 (2009): 1673-1694.

[13] Foerster, Jeff. "Channel modeling sub-committee report final." *IEEE P802. 15 Working Group for Wireless Personal Area Networks (WPANs), IEEE P802. 15-02/490r1-SG3a* (2003).

[14] Koo, Bon-Wook, Myung-Sun Baek, Young-Hwan You, and Hyoung-Kyu Song. "High-speed MB-OFDM system with multiple antennas for multimedia communication and home network." *IEEE Transactions on Consumer Electronics* 52, no. 3 (2006): 844-849.

[15] Capoglu, Ilker Rafet, Ye Li, and Ananthram Swami. "Effect of Doppler spread in OFDM-based UWB systems." *IEEE Transactions on Wireless Communications* 4, no. 5 (2005): 2559-2567.

[16] Jiang, Tao, Yang Yang, and Yong-Hua Song. "Exponential companding technique for PAPR reduction in OFDM systems." *IEEE Transactions on broadcasting* 51, no. 2 (2005): 244-248.

[17] Barakabitze, Alcardo Alex, and Md Abbas Ali. "Behavior and Techniques for Improving Performance of OFDM Systems for Wireless communications." *International Journal of Advanced Research in Computer and Communication Engineering* 4, no. 1 (2015):237-245

[18] Johnston, Cesar A. "Network interface card for wireless asynchronous transfer mode networks." U.S. Patent 6,064,649, issued May 16, 2000.

[19] Riihonen, Taneli, and Risto Wichman. "Analog and digital self-interference cancellation in full-duplex MIMO-OFDM transceivers with limited resolution in A/D conversion." In *Signals, Systems and Computers (ASILOMAR), 2012 Conference Record of the Forty Sixth Asilomar Conference on*, IEEE, (2012): 45-49.

[20] Tang, J. M., and K. Alan Shore. "Maximizing the transmission performance of adaptively modulated optical OFDM signals in multimode-fiber links by optimizing analog-to-digital converters." *Journal of Lightwave Technology* 25, no. 3 (2007): 787-798.

[21] Candès, Emmanuel J., and Michael B. Wakin. "An introduction to compressive sampling." *IEEE signal processing magazine*25, no. 2 (2008): 21-30.

[22] Huang, Jianzhong, Shengli Zhou, Jie Huang, Christian R. Berger, and Peter Willett. "Progressive inter-carrier interference equalization for OFDM transmission over time-varying underwater acoustic channels." *IEEE Journal of Selected Topics in Signal Processing* 5, no. 8 (2011): 1524-1536.

[23] Hillerkuss, D., R. Schmogrow, T. Schellinger, M. Jordan, M. Winter, G. Huber, T. Vallaitis et al. "26 Tbit s− 1 line-rate super-channel transmission utilizing all-optical fast Fourier transform processing." *Nature photonics* 5, no. 6 (2011):364-371.

[24] Wang, Luqing, and Chintha Tellambura. "A simplified clipping and filtering technique for PAR reduction in OFDM systems." *IEEE signal processing letters* 12, no. 6 (2005): 453-456.

[25] Karthaus, Udo, and Martin Fischer. "Fully integrated passive UHF RFID transponder IC with 16.7-/spl mu/W minimum RF input power." *IEEE Journal of Solid-State Circuits* 38, no. 10 (2003): 1602-1608.

[26] Sun, Hongjian, Arumugam Nallanathan, Cheng-Xiang Wang, and Yunfei Chen. "Wideband spectrum sensing for cognitive radio networks: a survey." *IEEE Wireless Communications* 20, no. 2 (2013): 74-81.

[27] OFDM signal spectrum

Available on:http://www.revolutionwifi.net/revolutionwifi/2015/3/how-ofdm-subcarriers-work