A Survey on OFDM and IEEE WLAN Standard

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ABSTRACT
In the today's multimedia communication scenario, the demand for high data rate, reliable, high quality digital data increased quickly. Due to the high data rate transmission and the capability to reduce the frequency selective fading into flat fading by separating the available spectra into multiple subcarriers, orthogonal frequency division multiplexing (OFDM) is a promising technique in the current broadband wireless communication system. This paper gives the progress of orthogonal frequency division multiplexing form historical aspect. All over the world OFDM is of the great interest by researchers and research laboratories which contributes the use of DFT, addition of cyclic prefix to remove the intersymbol interference and pilot insertion to reduce interference from multipath and co-channels. OFDM is not only used in cellular environment but also for LAN standard 802.11a/b/g/n. Also this paper will survey on the landscape of the IEEE 802.11 standard and give an overview of various amendments. In this paper we described the background and some of the striking early development of OFDM, with explanation of the motivations for using it and the history of the WLAN standard, showing where, why, when and by whom it was developed.

Keywords
Orthogonal Frequency Division Multiplexing (OFDM), Inter Symbol Interference (ISI), WLAN, IEEE 802.11a/b/g/n standard

Review Methodology
To review the papers we have adopted the 3+ stage approach. In 3+ approaches, there are basically 5 stages. The stages are numbered as 0, 1, 2, 3, and 3+ which are equal to 5. The analysis which is done in each phase is as follows:

Stage 0: In this stage, we just look at the title, author, year of publication, publisher to get the feel of paper. By this we get an overview of the paper.

Stage 1: In this stage, we broaden our scope by precisely looking for important questions of the paper.

Stage 2: In this stage, the scope is wider we go in details of implementation of methods, assumptions, results, future scope etc.

Stage 3: In this stage, we evaluate the details of the paper. Is the research problem significant and is the problem is novel. Is solution that given in the paper fully solves the problem?

Stage 3+: In this stage we find to know that what are some alternative approaches to address problem and how can research result be improved.

1. INTRODUCTION
There has been a rapid growth in the field of wireless in past decades due to high mobility. It has the ability to give the consumer to be in continuous contact. However wireless channels have some disadvantages like multipath fading, interference, time variation that make them difficult to deal with them. Single carrier modulation uses a single carrier frequency to transmit all data symbols sequentially. The main drawback of this technique is that it is susceptible to multipath fading or interference because it uses only one carrier frequency. If multipath distortion nulls the frequency then the entire link experiences severe performance degradation. So, multicarrier modulation is considered as an effective approach due to its robustness in dealing with these impairments rather than the single carrier modulation. Multicarrier modulation is nothing more than a parallel data transmission system. In 1966, Chang proposed the concept of first multicarrier transmission [2].

Transmission of binary data over the single side band voice channels were implemented by Doelz et al. in 1957. [1] This was the first multichannel modulation system before Chang.

In the classical parallel data transmission system the total available bandwidth is divided into N overlapping frequency sub channels. Each sub channel is modulated with a separate symbol and all sub channels are frequency multiplexed to avoid inter-carrier interference (ICI), or crosstalk, from adjacent sub-carriers. The carriers frequency were spaced that signals do not overlap. Guard bands, or empty spectral regions were placed between the signals to ensure that they could be separated with the use of filters at the receiver. This separation between subcarriers leads to waste of the available bandwidth. This is shown in figure 1 (a). To overcome this insufficient utilization of the spectrum an effective approach is required for efficient share of the available bandwidth among a large number of users, which can offer higher data rate and cope with the harsh mobile environment. A modulation that efficiently deals with selective fading environment and inter-carrier interference is orthogonal frequency division multiplexing (OFDM). This principle is displayed in Fig 1(b). OFDM saves almost 50 percent of the available bandwidth compared to FDM.

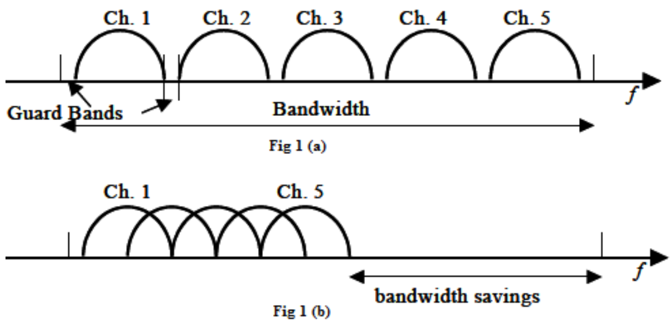

Fig. 1 Difference between FDM and OFDM. Fig 1 (a) shows the frequency spectrum of five channels in which guard bands are placed between subcarriers utilizing the FDM. Fig 1(b) shows the frequency spectrum of OFDM where sub channel are orthogonal to the adjacent channel.

In this paper we focus on the overview of the evolution of OFDM and discuss why and how to apply OFDM in the next generation mobile communication. The organization of this paper is as follows. Section II outlines the history of OFDM. Section III shows the typical OFDM system for wireless communication. In the Section IV, we briefly introduce the overview of wireless LAN standards. Finally, we present our concluding remarks in Section V.

2. HISTORICAL BACKGROUND OF OFDM

The first proposal to use orthogonal frequencies for transmission appears in a 1966 by Chang of Bell Labs. [2] He published his work on the Synthesis of Band-limited Orthogonal Signals for multichannel Data Transmission. He introduced the concept of using parallel data transmission by means of frequency division multiplexing (FDM) with overlapping subcarriers. This was an efficient way to avoid the use of high-speed equalization and to combat impulsive noise, and multipath distortion as well as to fully use the available bandwidth. In his scheme the orthogonal signals are transmitted through a band limited transmission medium at a maximum data rate without Inter channel interference and Intersymbol interferences. In this method frequency selective channel is divided into parallel flat sub channel. So the channel becomes narrow band and individual channels experiences flat fading. The use of narrow band sub channel makes the receiver design so simple. Due to this Orthogonality individual channel have a data rate equal to the channel bandwidth.

Soon after the Chang's paper Burton R. Saltzberg analysed the performance of efficient parallel data transmission system in 1967. [3] He concluded that ISI is eliminated when adjacent channels are in phase quardrature. He extended the idea and showed how the Chang's method could be modified for transmission of quardrature amplitude modulated (QAM) symbols, in a double side-band modulated format. The Designing of the efficient parallel system should have to remove the interference and crosstalk between adjacent sub channels rather than on perfecting the individual channel themselves. He also proved that the use of a large number of narrow channels is effective in reducing the delay and amplitude distortions of the transmission medium.

In 1968 Chang and Gibby presented a theoretical analysis on the performance of orthogonally multiplexed data transmission. The analysis of OFDM subject to a number of degrading factors normally encountered by a practical operating system was also studied. [4] The factors considered jointly were sampling time error, carrier phase offset, and imperfect phase characteristics of transmitting and receiving filters. In 1966 a U.S. patent was filed for Chang's research and then in 1970 patent was issued for his work. [5]

In a conventional parallel system the large number of sinusoidal generators and coherent demodulators required for a large number of subcarriers. So the system becomes expensively, complex and bulky. At the receiver there is a need of precise phasing of the demodulating subcarriers and sampling times so that the crosstalk between subcarriers can be acceptable. FDM made more practical through DFT was proposed by Weinstein and Ebert in 1971. [6] He proposed the use of Discrete Fourier transform for eliminating the banks of subcarrier oscillator and coherent demodulators. Thus it reduces the system complexity. This evolution makes the modern low-cost OFDM systems possible today. DFT-based OFDM can be completely implemented in the digital baseband for efficient processing, eliminating band pass filtering. All subcarriers still overlap in the frequency domain while the DFT ensures Orthogonality. He also added a guard interval to improve the performance in multipath Channel to remove the ICI and ISI. However, they didn't obtain perfect Orthogonality between subcarriers in multipath channels.

In DFT based OFDM, Orthogonality was a main problem, so to maintain the Orthogonality between sub carriers, Peled and Ruiz introduced the cyclic extension (CE) in 1980. This is another important contribution. It is also called cyclic prefix (CP). [7] The cyclic prefix (CP), which is an important aspect of almost all practical OFDM implementations. A cyclic prefix is inserted in front of each OFDM block. In the time dispersive channel the use of cyclic extension converts the linear convolution to cyclic convolution for ensuring the Orthogonality. It also reduces the ISI between the subcarriers. The length of the cyclic prefix is greater than the expected delay spread. In CE there is an additional bits are added so there is a loss in effective data rate but zero ISI compensates for reduction.

In the mid 1980 OFDM was ready to be considered for practical wireless applications. Cimini of Bell Labs published a paper on OFDM for mobile radio channels in 1985. [8] He introduced OFDM in the wireless market place. He introduced a pilot-based method to reduce interference from multipath and co-channels. Pilot-based correction provides an amplitude and phase reference which can be used to counteract the unwanted effects of multipath propagation. The magnitude and phase of these carriers are known to the receiver and they are used for channel estimation. This technique also provides the protection against delay spread and enhance the behavior of system in heavily frequency selective environment.

3. OFDM SYSTEM ARCHITECTURE

Orthogonal frequency division multiplexing (OFDM) is broadly considered as an effective approach for the future

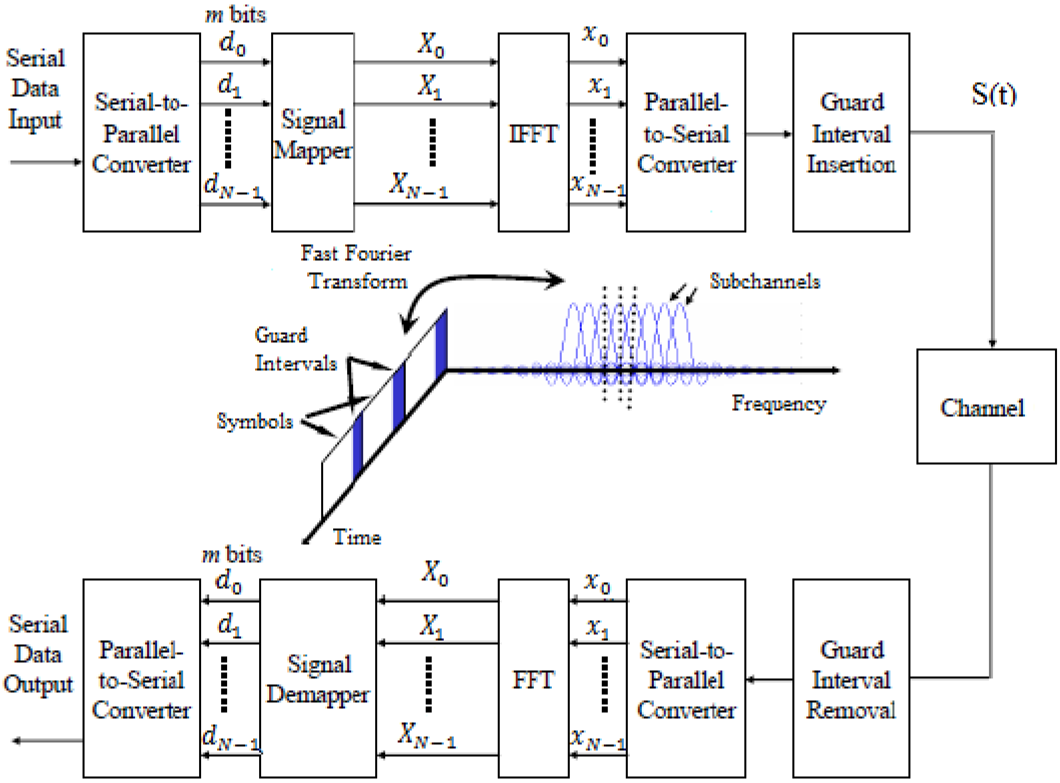

Fig. 2 Block diagram of an OFDM communication system for wireless applications.

high speed wireless multimedia communication systems. In OFDM high rate data stream is split into a number of lower rate streams that are transmitted simultaneously over a number of subcarrier. In this section we described the basic function of typical OFDM system for wireless applications. Spectral efficiency is achieved by making all the OFDM subcarriers orthogonal, i.e. it is possible to arrange OFDM subcarriers such that the signals can still be received without adjacent carrier interference. In order to do this, all subcarriers must be mathematically orthogonal. The "orthogonal" part of the OFDM name indicates that there is a precise mathematical relationship between the frequencies of the carriers in the system. Figure 2 shows the block diagram of an OFDM system for wireless applications.

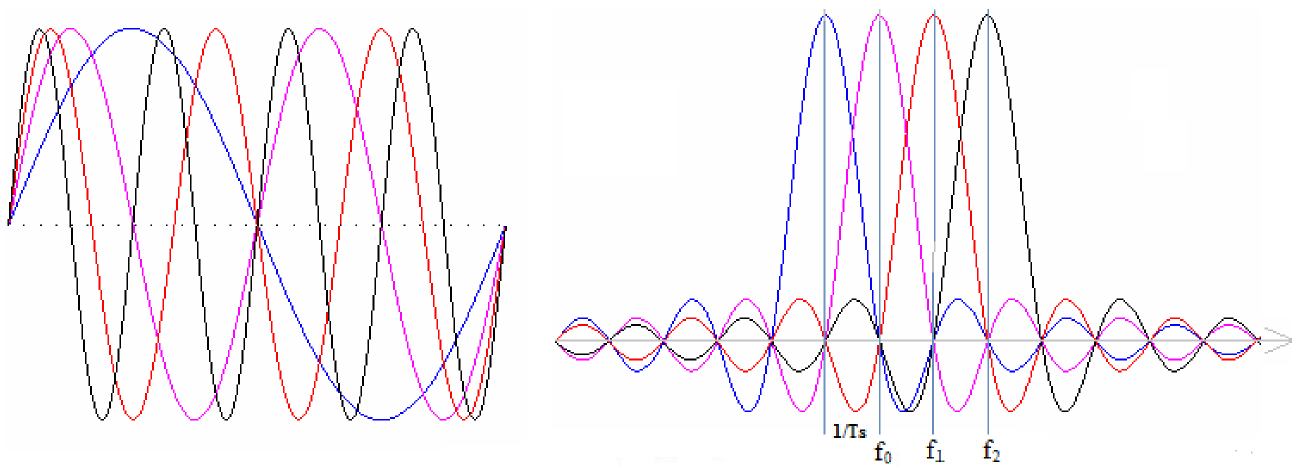

Fig. 3(a) OFDM signal in time domain 3(b) OFDM signal in frequency domain of 4 carriers

The Orthogonality allows simultaneous transmission on a lot of sub-carriers in a tight frequency space without interference from each other as shown in Figure 3. If the given bandwidth has to be divided among n carriers (say $f_1, f_2, f_3, f_4 ...... f_n$). If the carriers are harmonics like $f_2 = 2f_1, f_3 = 3f_1 ...... f_n = nf_1$ integral multiple of fundamental frequency f_1, than they become orthogonal to each other or we can say that carriers are orthogonal if the carrier spacing is the multiple of 1/ Ts, Where Ts is the symbol duration. When added together, they do not interface with each other.

The first step in the OFDM system is to convert a serial data stream into a parallel stream and then modulate the symbols, using the quardrature amplitude modulation (QAM) or the phase shift keying (PSK) modulation depending on the number of subcarriers N. The number of bits in a symbol is given as the $log_2 M$bits, where M is the alphabet of size of the the digital modulation scheme employed on each sub-carrier. A total of N such symbol d_0 to d_N be created. The OFDM modulated signal can be expressed as

$$s(t) = \sum_{k=0}^{N-1} s_k \, e^{j\,2\pi\, f_k t} \quad (1)$$

Where s_k be the complex symbol to be transmitted by OFDM modulation and $f_k = f_0 + k \Delta f$ and Δf = Sub channel spacing of OFDM. The Orthogonality among the carriers can be maintained if the OFDM signal is defined by using Fourier transform procedures.

3.1 FFT and IFFT

IFFT block is the main component in the transmitter and FFT in the receiver. It was a complicated process to achieve N subcarrier oscillators, especially when the N was large. They overcome the complexity of number of modulator and demodulator. The input bit stream is multiplexed into N symbol streams, each with symbol period Ts, and each symbol stream is used to modulate parallel, synchronous sub-carriers. The sub-carriers are spaced by 1/NTs in frequency, thus they are orthogonal over the interval (0, Ts).

The input to the IFFT is the complex vector $[X_0\, X_1\, X_2 \ldots \ldots X_{N-1}]^T$; N is the size of FFT. X represents the data to be carried on the corresponding subcarrier so X_k represents the data to be carried on the K_{th} subcarrier. X is the complex number representing a modulating (QAM or PSK) constellation point which can be given as $X_k = A_k + jB_k$. So this signal is passing through the IFFT block and output of this block is vector $x = [x_0\, x_1\, x_2 \ldots \ldots x_{N-1}]^T$

The inverse discrete Fourier transform can be represented as

$$x_m = \frac{1}{\sqrt{N}} \sum_{k=0}^{N-1} \mathrm{X_k} \exp\left(\frac{j2\pi km}{N}\right) for\ 0 \le m \le N-1 \quad (2)$$

The discrete Fourier transform can be represented as

$$X_k = \frac{1}{\sqrt{N}} \sum_{m=0}^{N-1} \mathrm{x_m} \exp\left(\frac{-j2\pi km}{N}\right) for\ 0 \le m \le N-1 \quad (3)$$

Consider an example for 4 QAM modulation and N= 16 the given data is $d = [0,0,0,1,1,0,1,1 \ldots\ldots]$. Then the output of serial to parallel converter is $d_0 = [0,0]$ $d_1 = [0,1]$ $d_2 = [1,0]$ $d_4 = [1,1]$. After modulation the values of X vector from 4QAM constellations is $X_0 = 1 + j$, $X_1 = 1 - j$, $X_2 = -1 + j$, $X_3 = -1 - j$. The output of IFFT is the corresponding time domain vector x. At the receiver reverse operation is performed to obtain the data. The FFT algorithm provides an efficient way to implement the DFT and the IDFT. It reduces the number of complex multiplications from N^2 to $\frac{N}{2} log_2$N for an N-point DFT or IDFT. Hence, with the help of the FFT algorithm, the implementation of OFDM is very simple. The operation of FFT and IDFT is shown by the following figure 4.

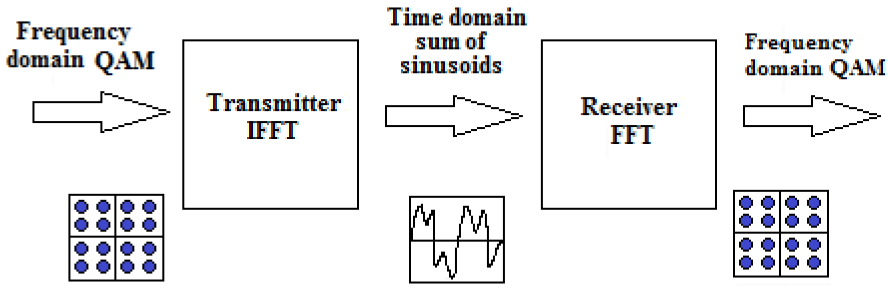

Fig. 4 IFFT and FFT operation of OFDM system

3.2 Cyclic Prefix

To remove the intersymbol interference cyclic prefix is added in which a number of samples from the end of the symbol are appended to the start of the symbol. This results in a longer symbol time. This Fig 4 shows the insertion of cyclic prefix.

The total length of the symbol is $T_s = T + T_{cp}$ where T_s is the total length of the symbol in samples. T_{cp} is the length of the guard period in samples, and T is the size of the IFFT used to generate the OFDM signal. Output of parallel to serial converter is given as $x = [x_0\, x_1\, x_2 \dots \dots x_{N-1}]$ so instead of transmitting $x = [x_0\, x_1\, x_2 \dots \dots x_{N-1}]$, the transmitted sequence is $x_{cp} = [x_{N-L}\, x_{N-L-1} \dots x_{N-1}\, x_0\; x_1\; x_2 \dots \dots x_{N-1}]$. L is the length of cyclic prefix. Although the CP introduces some redundancy, and reduces the overall data rate, but the use of the CP eliminates both ISI and intercarrier interference (ICI) from the received signal and is the key to simple equalization in OFDM.

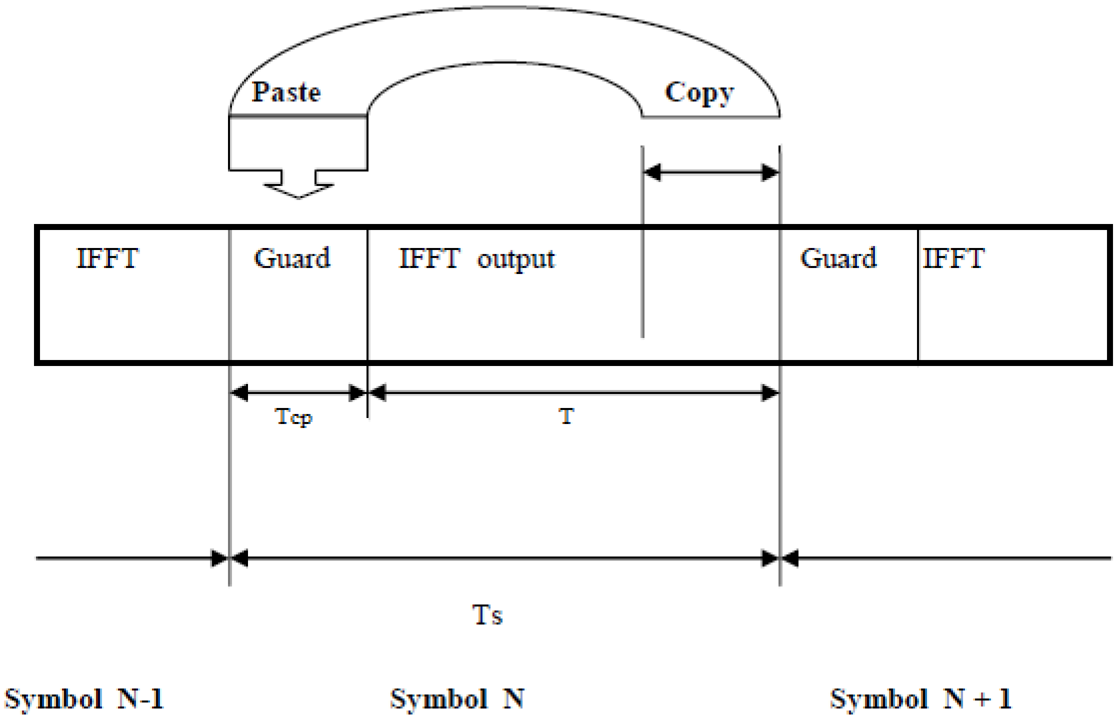

Fig. 5 cyclic prefix insertion in OFDM

4. HISTORY OF WLAN STANDARD

Wireless system that offers high data rate is of great demand besides that the ability to deal with multipath propagation is necessary for a wireless system. Among all the techniques orthogonal frequency division multiplexing (OFDM) is a tremendous technique that capable to reduce the frequency-selective fading into flat fading by separating the available spectra into multiple subcarriers. During the past decade, OFDM has been adopted in many wireless communication standards. The first ones to use OFDM were asymmetric digital subscriber loop (ADSL) and digital audio broadcasting (DAB) in the 90s. OFDM was chosen for the European and Japanese standards for digital terrestrial video broadcasting (DTVB) in 1995 and later on, it has also been assigned to the wireless local area network, Hiperlan/2. OFDM is also being pursued for dedicated short-range communications (DSRC) for road side to vehicle communications and after that, multiple IEEE standards based on OFDM was developed and applied, OFDM is also regarded as one of the key technologies in the fourth generation mobile communications.

WLAN standards are been created by the Institute of Electrical and Electronics Engineers (IEEE). The IEEE extended the 802.3 wired Ethernet standards to wireless domain. For the first time in June 1997, IEEE created the standard for the WLAN as 802.11 which are named after the group formed to oversee its development. IEEE 802.11's family has become very popular in every different environment due to their simplicity, low cost, easy installation, location freedom and high data rate. It provides easy way to configuration of computer network using without wiring complexity. This initial standard specifies a 2.4 GHz operating frequency with data rates of 1 and 2 Mbps [9]. The original standard defined the basics of the MAC and PHY layers of the protocol which provide the physical and data link layers of the OSI layer model. With this standard, one could choose to use either frequency hopping or direct sequence (two non compatible forms of spread spectrum modulation). Because of relatively low data rates (as compared to Ethernet) products based on the initial standard did not flourish as many had hoped.

802.11 standards consist of 3 layers: Logical Link control (LLC), Media Access Control (MAC) and Physical Layer (PHY). In 1997 B.P.Crow explained the IEEE802.11 protocol, with particular emphasis on the medium access control sub layer. He showed that MAC layer is responsible for channel allocation procedures, protocol data unit addressing, frame formatting, error checking and fragmentation [10]. For further enhancement in 802.11 standard Cali analysed that the medium access control (MAC) protocol is the main element for determining the efficiency in sharing the limited communication bandwidth of the wireless channel in WLAN. He proposed that MAC protocol capacity can be improved significantly by suitably setting of its parameter by using the analytical formula [11]. In late 1999, the IEEE published two supplements to the initial 802.11 standard: 802.11a and 802.11b (Wi-Fi).

IEEE 802.11a is a physical layer (PHY) standard specifies operation in the 5 GHz spectrum. This is the standard which is derived while the development of the 802.11b is in the process. It was approved as a standard earlier than 802.11b. The 802.11a standard was designed for better scalability and higher bandwidth application rather than 802.11b include with the data rates of 6, 9, 12, 18, 24, 36, 48, 54 Mbps using orthogonal frequency division multiplexing (OFDM) modulation. [12] The advantages of this standard (compared to 802.11b.Higher Speed Physical Layer Extension in the 2.4 GHz Band) include having much higher capacity and less RF (radio frequency) interference with other types of devices (e.g., Bluetooth), and products are just now becoming available throughout 2002.

In the late 1999 IEEE 802.11b standard is specified by the task group by extending the WLAN standard 802.11 for the first time. As with the initial standard 802.11b operates in the 2.4 GHz band, but it includes 5.5 and 11 Mb/s in addition to the initial 1 and 2 Mb/s. [13] To provide higher data rates 802.11b uses Complementary Code Keying modulation technique that makes efficient use of the ratio spectrum. This is first time to be more popular as WLAN standard which is adapted many organizations and many products supporting it are also been manufactured. The main disadvantage of the 802.11b is the frequency band is common and interference from the other networking technology such as Bluetooth, 2.04GHz cordless phone and so on.

IEEE 802.11b standard has the low data rate in 2.4 GHz so 802.11 working group extended the 802.11b physical layer with higher speed extension up to 54Mbps. In June 2003 IEEE standard released 802.11g which is backward-compatible to the 802.11b at 2.4GHz radio frequency. [14] At 6, 9, 12, 18, 24, 36, 48, and 54 Mbps it uses OFDM which is compatible to 802.11a. At 5.5Mbps and 11Mbps it uses Complementary Code Keying (CCK) which is compatible to 802.11b and at 1Mbps, 2Mbps, it reverts to DSSS and Binary Phase Shift-Keying (BPSK) which is compatible to 802.11a specification. The advantage of this standard is good signal strength, large range, and high speed and not easily obstructed. The drawback of this standard is costs more than 802.11b.

802.11b standard provides the 11Mbps data rate so Chirs and John proposed the method to extend the transmission rate of 22 Mbps in 2001. [15] In 2002 Steve Kapp examined the IEEE 802.11a standard and its networking in depth. 802.11a standard is the third generation wireless networking standard. He compared the 802.11a and b standard and showed that 802.11a provides the improved performance over short distances and less frequency band interferences [16]. In 2005 Abu Nasser and his team analysed the performance of 802.11a standard. He investigated the effect of topology in packet drop, change in delay, throughput and the effect of node movement [17]. He showed the performance and scalability of IEEE802.11a standard sustains good throughput even in adverse network condition. In 2003 the Ming ju Ho analysed the throughput performance of 802.11g OFDM WLAN. He gave the required SNR under an AWGN channel and Rayleigh Fading channel. He showed that 802.11g standard experienced reduced propagation loss compared with 5GHz 802.11a [18].

In January 2004 IEEE announced that it had formed a new 802.11 Task Group (TGn) to develop a new amendment to the 802.11 standard for local-area wireless networks. The real data throughput will be at least 100 Mb/s (which may require an even higher raw data rate at the physical layer), and so up to 4–5 times faster than 802.11a or 802.11g, and perhaps 20 times faster than 802.11b and also offer a better operating distance than the current networks. In 2005 the first paper was published by Yang Xiao on a new emerging standard named as 802.11n [19]. He showed the current status of IEEE 802.11n. He analysed the overhead is the main problem of MAC layer efficiency so he proposed the frame aggregation method to reduce the overhead problem.

In 2006 Josip Lorincz analysed the Physical layer of emerging 802.11n standard [20]. He emphasized on some new concepts, features and technical solutions on PHY that will be implemented in 802.11n standard. He proposed that using of multiple input multiple output technology in 802.11n standard can improve the data rate. The additional transmitter and receiver antennas allow for increased data throughput through spatial multiplexing and increased range. The medium access control layer is the main bottleneck in 802.11 standards. Saida and his team investigated the new method to remove the overhead in MAC layer named Aggregation with Fragment Retransmission (AFR) in 2007. Overhead refers to back-off delays, distributed inter-frame space (DIFS), short inter-frame space (SIFS), acknowledgment, delivery delay and PHY layer header. In this scheme, multiple packets are aggregated and transmitted in a single large frame reducing the access overheads and hence increasing the data rate [21].

In 2007 the first draft was published, and then it was ratified and finally approved in 2009. [22] 802.11n is the newest Wi-Fi LAN technology and the most commonly used now one among others. The technology offers quadruple transfer rates of data with the fastest Wi-Fi technology. Unlike the 802.11a which works in the 5GHz and requires line-of-sight availability, the 802.11n does not need that. Using the MIMO communication techniques together with OFDM digital modulation provides extremely high data rates over large distances in a wireless communications. It provides the throughput up to 600 Mbps. This standard also operates in both the 2.4 GHz and 5 GHz band using 20 MHz band channels. In addition to 20 MHz channels one can use 40 MHz channels which could allow for a higher capacity channel.

5. CONCLUSION

OFDM technique is used in many wireless systems and proven as a reliable and effective transmission method. In this paper we described the OFDM for wireless communication. We also depicted the OFDM transmitter and receiver and the roles of each block explained. The DFT -IDFT block and role of cyclic prefix to remove the intersymbol interference was summarized. Although the theoretical basis for OFDM was laid several decades ago and OFDM became the basis of many communication standard for wireless and wired standard. Wireless LAN is a very important application for OFDM. We summarized the tutorial introduction IEEE 802.11 WLAN standard that how different standard like a/b/g/n come into existence.

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