Multi-carrier Transmission Techniques for Wireless Communication Systems: A Survey

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Abstract: - The next generation wireless communications systems require higher data rates transmission in order to meet the higher demand of quality services. Research in wireless digital communications techniques have been expending very rapidly in the last few decades, resulting more reliable wireless communication systems that operate at higher spectral efficiency. Since there have been an increased in demand for higher data rate transmission, the systems are incorporating the multi-carrier transmission techniques. Therefore, Orthogonal Frequency Division Multiplexing (OFDM) is one of the leading candidates for future wireless systems. The objective of the paper is to provide a survey on multi-carrier transmission techniques i.e. OFDM and the combination of OFDM with Code Division Multiple Access (CDMA). The review on this rapidly expending area of wireless communication field is carried out on research works for the past 15 years. And in this survey also we Trying to explain how to use Discrete Wavelet Transform based OFDM (DWT-OFDM) Instead of using Fast Fourier Transform based OFDM Fast Fourier Transform based OFDM (FFT-OFDM).
This study outlines the state-of-the art of OFDM novel technique as well as the methods of multi-carrier - Code Division Multiple Access (MC-CDMA) and MC- Direct Sequence-CDMA (MC-DS-CDMA).

Key-Words: - Multi-carrier-CDMA (MC-CDMA), Multi-carrier - Direct Sequence-CDMA (MC-DS-CDMA).

1 Introduction

In recent years, there have been tremendous efforts in research activities related to multi-carrier transmission techniques which have been proven to increase the application bit rates of wireless communications[1]. Multiple antennas and orthogonal frequency-division multiplexing (OFDM) are emerging as key technologies for 4G and 3G. It is increasingly believed that OFDM results in an improved downlink performance for 4G [2]. The world standard bodies such as IEEE and ETSI have selected the OFDM as their physical layer techniques for the next generation of wireless systems [3]. The growing demand for multimedia services requires high data rates communications, but this condition is significantly limited by inter-symbol interference (ISI) due to the existence of the multiple paths. Multicarrier modulation techniques, including OFDM modulation are considered as the most promising technique to combat this problem [4].

OFDM was first introduced in the late 60's, based on the multicarrier modulation techniques used in the high frequency military radio. In 1971 Weinstein [5] introduced the idea of using a Discrete Fourier Transform (DFT) for the implementation of the generation and reception of OFDM signals, eliminating the requirement for banks of analog subcarrier oscillators. This presented an opportunity for an easy implementation of OFDM, especially with the use of Fast Fourier Transform (FFT), which is an efficient implementation of DFT. This suggests the easiest implementation of OFDM is with the use of digital signal processing (DSP), which can implement FFT algorithms. The advances in integrated circuit technology have made the implementation of OFDM cost effective. The reliance on DSP prevented the wide spread use of OFDM during its early development. It wasn't until the late 1980's that work began on the development of OFDM for commercial use, with the introduction of the Digital Audio Broadcasting (DAB) systems [1].

Code Division Multiple Access (CDMA) is a spread spectrum modulation technique for digital communication was originally developed and used for military applications either to provide resistance to hostile jamming, or to hide the signal by transmitting it at low power. Thus, this makes it difficult for an unintended listener to detect its presence in noise. Today, however, spread spectrum modulation techniques are being used to provide reliable communication in a variety of commercial applications [6].

CDMA has emerged as the most important multiple access technology for second and third-generation (2-3G) wireless systems exemplified by its popularity in several major mobile cellular standards. Technical requirements in future gigabit wireless systems will be very different from 2-3G mobile cellular systems, which were developed basically for low-speed continuous traffic. Recently some emphases have been given to data applications such as stationary image transmissions and low-rate video streaming. The appreciation of CDMA technologies in the 2-3G systems is partly due to the fact that they provide on average higher bandwidth efficiency than do any other multiple access techniques.

The purpose of this paper is to provide a brief review of research activities for the last 40 years in multi-carrier transmission techniques for wireless communications. This would pave the way for the interested researchers to continue research in this area. The remainder of the paper is organized as follows. Section 2 presents background, Section 3 describes survey, Section 4 concludes the paper.

2 Back Ground

Third Generation (3G) mobile communication systems are already in deployment in several countries and this has enabled whole new ways to communicate, access information, conduct business and be entertained, liberating users from slow, cumbersome equipment and immovable points of access. In a way 3G has been the right bridge for mobile telephony and the internet. 3G services enable users to make video calls to the office and surf the internet simultaneously, or play interactive games wherever they may be. Second and third generation systems like IS-95 and WCDMA can provide nominal data rates of about 50–384 Kbps. While 3G is just transforming itself into a reality from an engineer's dream, research efforts are already on to look into systems that can provide even higher data rates and seamless connectivity [7,8].

Such systems are categorized under Fourth Generation (4G) and are predicted to provide packet data transmission rates of 5 Mbps in outdoor macro-cellular environments and up to 10 Mbps in indoor and microcellular environments. While wide-band systems could be a natural choice to provide high data rates, service providers have to pay dearly for the spectrum necessary. Hence, spectrum efficiency is always a factor on the choice of any wireless technology. Very wide-band systems usually require complex receivers as the channel is frequency selective due to the presence of large number of resolvable multipaths.

OFDM has recently gained a lot of attention and is a potential candidate for 4G systems. OFDM is very efficient in spectrum usage and is very effective in a frequency selective channel. By taking advantage of recent improvements in Digital Signal Processing (DSP) and RF technologies, OFDM can provide higher data rates and is a very good choice for service providers to compete with wire-line carriers [9].

A variation of OFDM which allows multiple accesses is MC-CDMA which is essentially an OFDM technique where the individual data symbols are spread using a spreading code in the frequency domain. The inherent processing gain due to the spreading helps in interference suppression in addition to providing high data rates. OFDM is already the technique used in Digital Audio and Video Broadcasting and Wireless LANs (802.11 family) and is believed to be the technique for future broadband wireless access [10].

In this section the background information of OFDM and CDMA is presented. The subsection begins with a brief basic description of the underlying principle of OFDM, and then the description of CDMA. Subsequently, the basic of MC-CDMA is explained at the end of section.

2.1 OFDM

OFDM is a combination technique between modulation and multiplexing. Modulation is a mapping of the information on changes in the carrier phase, frequency or amplitude or their combination. Meanwhile, multiplexing is a method of sharing a bandwidth with other independent data channel. In multiplexing, independent signals from different sources are sharing the channel spectrum. In OFDM, multiplexing is applied to independent signals but these independent signals are a sub-set of the one main signal. In OFDM the signal itself is first split into independent channels, modulated by data and then re-multiplexed to create the OFDM carrier.

The advantage of having many subcarriers for data transmission can be analogued to a transporting goods using one big truck as oppose using many small trucks as shown in Figure 1. If for example a single big truck involved in an accident, then the entire goods cannot be delivered. On the other hand, if one of the small trucks involved in an accident then there are at least three other small trucks can deliver the remaining goods [11].

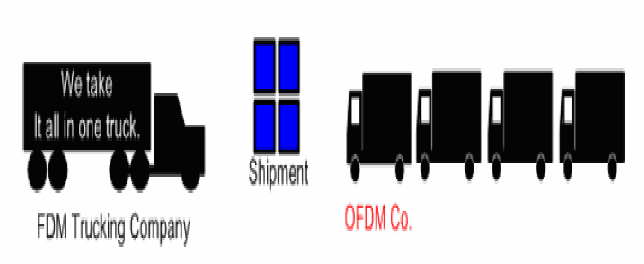


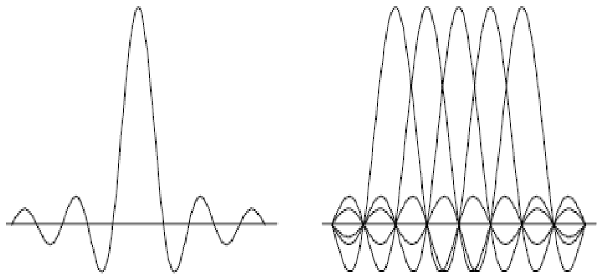
Figure 1: All cargo on one truck vs. splitting the shipment [11]

The multicarrier transmission technique uses the discrete Fourier transform. By using a DFT, the whole bandwidth will be split into N sub-channels. As a result, a high data stream will be transformed into N low rate streams, which are transmitted over different sub-channels. OFDM symbols, which contain several modulation symbols, are formed as linear combinations of mutually orthogonal complex exponentials of finite duration [12].

The splitting of high rate data stream into a number of lower rate streams results in the increase of symbol duration. Mean while a lower rate parallel subcarriers reduces the relative amount of dispersion in time caused by multipath delay spread. Therefore OFDM is an advanced modulation technique which is suitable for high-speed data transmission due to its advantages in dealing with the multipath propagation problem and bandwidth efficiency.

OFDM is a special case of traditional Frequency Division Multiplexing (FDM). As shown in Figure 2: (a), in FDM the total frequency bandwidth is divided into N non-overlapping frequency subchannels. Each subchannel is modulated with a separate symbol while N subchannels are frequency-multiplexed. This allocation method is inefficient in bandwidth utilization. In OFDM systems, as shown in Figure 2: (b), the subchannels are overlapped. The frequency spacing between subcarriers is selected carefully such that each subcarrier is located on the other subcarriers zero crossing points. In other words, the subcarriers are arranged to be orthogonal with each other. Therefore the overlapping among subcarriers will not cause interference. Thus, the bandwidth efficiency is significantly increased due to orthogonal among all subcarriers and then more subchannels can be squeezed into the same bandwidth [13].

Figure 3 (a) and (b) show the spectrum of individual subchannel and the spectrum of the entire OFDM signal, respectively. It can be noticed that there is no crosstalk from other channels at the center frequency of each subcarrier. The parallel transmission of data over multiple simultaneous carriers makes the OFDM system to be more robust against frequency selective fading or narrowband interference, some subcarriers may be degraded, others will be unaffected.



(a) (b)

Figure 3:(a) Spectra of an OFDM subchannel and (b) an OFDM signal [11]

2.2 CDMA

CDMA is a multiple access scheme, where at receiver the users are differentiated by their unique codes. Although, the users sharing the spectrum are overlapped in time and frequency, the receiver is able to shift each user's information from other users by correlating the received signal with that user's spreading code. Encoding the user information with the unique code usually leads to the spreading of the user's signal bandwidth, which is why this technique is called spread spectrum [14]. A spread spectrum system, the transmitted signal is spread over a wide frequency band, much wider, than the bandwidth of the information being sent. This is accomplished by modulating the information with a wideband encoding signal [15].A system is defined to be spread spectrum system if it fulfills the following requirements [15],[16];

i. The signal occupies a bandwidth much in excess of minimum bandwidth necessary to send the information.

ii. Spreading is accomplished by means of spreading signal, often called a *code signal,* which is independent of data.

iii. At the receiver, despreading (recovering the original data) is accomplished by the correlation of the received spread signal with a synchronized replica of the spreading signal used to spread the information.

There are two main ways of spreading a signal, spreading in time which is usually referred to as Direct Sequence Spread Spectrum (DS/SS), and spreading in frequency, also known as Frequency Hopping Spread Spectrum (FH/SS) [15],[16].

Figure 4 illustrates the basic DS/SS system. The spectrum spreading is affected by multiplying the data by the spreading code. In this case, both are assumed to be binary sequence taking on the values +1 and –1. The duration of data bit is T_b, and the duration of spreading code chip, called *chip period*, is T_c. There're usually many chips per bit, so that $T_c<<T_b$. The spreading code is chosen to have the properties of a random binary sequence. Demodulation of the DS/SS is accomplished by correlating or remodulating the received signal with a synchronized replica of the spreading signal [15],[17].

2.3 Combination of OFDM and CDMA

It is well known that the Code Division Multiple Access (CDMA) scheme is robust to frequency selective fading and has been successfully introduced in commercial cellular mobile communications systems such as IS-95 and 3G systems. On the other hand, the OFDM scheme is also inherently robust to frequency selective fading. Therefore, no one would expect any synergistic effect in combination of the OFDM and CDMA schemes.

In 1993, the MC-CDM/CDMA system, which is indeed a combination of the two schemes, was independently proposed by three different groups. So far, the MC-CDM/CDMA system has drawn a lot of attention, and the researchers have conducted intensive research on this interesting system. Now, in 2002, the MC-CDM/CDMA system is considered to be one of candidates as a physical layer protocol for 4G mobile communications, because 4G systems require high scalability and adaptability the possible transmission rate and the MC-CDMA has the potential [18,19].

3 Survey

In this section, the survey of multicarrier transmission techniques is presented. The survey of OFDM techniques evolution for the last 40 years is first presented. It follows with the survey of the combination between OFDM and CDMA techniques.

3.1 OFDM

The basic principles of OFDM have already been explained in the previous section 2.1. However, these ideas could not be implemented efficiently, because of the lack of powerful semiconductor devices availability at that time. Today, even relatively complex OFDM transmission systems with high data rates are technically feasible.

In early 1961 a code division-multiplexing scheme was proposed where sine and cosine functions were used as orthogonal signals [18]. The resulting signal could already be compared with an OFDM signal. However, the fact that this system was identical to a frequency division multiplexing, therefore it was not important for the proposal, and the benefits in frequency-selective channels were not recognized. Since 1966, FDM systems with overlapping spectra were proposed as seen in several publications [20],[21],[22]. The next proposal was to realize a FDM system with the Discrete Fourier Transform (DFT) as presented in [23].

Finally, in 1971, Weinstein and Elbert [5] proposed a complete OFDM system, which includes the generation the signals with an FFT and adding a guard interval in case of multipath channels. In further development, Cimini [24] discussed the use of OFDM for channels with both flat and frequency-selective fading. Alard and Lassalle [25], proposed OFDM for broadcast applications and mobile reception. The OFDM transmission technique eventually has become a part of the European DAP and DVB-T broadcasting standards [26].

High data rates for applications in wireless communications give rise to ISI due to multi-path fading, where such an ISI channel is called frequency-selective. On the other hand, due to mobility and/or carrier frequency offsets the received signal is subject to frequency shifts (Doppler-shifts). The Doppler shifts effect in conjunction with ISI gives rise to a so-called doubly-selective channel (frequency and time-selective). For these reasons, Barhumi *et al* [13] proposed a new equalization technique for multi-carrier systems over time and frequency-selective channels. A 1-tap time-varying filter is used to combat the time-variation of the channel. According to his work, the use of such equalization technique by transferring time-domain operations to frequency domain-operation, one can approach the performance of the purely frequency-selective channel. An important feature of that work is that no bandwidth expansion or redundancy insertion is required.

Many researchers suggested several algorithms related to the channel estimation schemes for OFDM receivers like the work presented by [27] and [28]. For example, the work presented by Barhumi *et al* [27] describes a least squares (LS) channel estimation scheme for multiple-input multiple-output (MIMO) OFDM systems based on pilot tones. First, the mean square error (MSE) of the LS channel estimate was computed. Then, the optimal pilot sequences and optimal placement of the pilot tones with respect to this MSE were derived. Also, to enhance channel estimation, a recursive LS (RLS) algorithm is proposed, for which the optimal forgetting or tracking factor was derived. This factor is found to be a function of both the noise variance and the channel Doppler spread. It is also shown that a considerable gain in signal-to-noise ratio (SNR) can be obtained by using the RLS algorithm, especially in slowly time-varying channels.

The DFT based OFDM (DFT-OFDM) has currently drawn most of attention in the area of wireless communication. In order to combat ISI, ICI, a cyclic prefix is inserted between DFT-OFDM symbols. Therefore, this additional bits use up to nearly 25 percent of bandwidth. In order to avoid this extra data that reduced bandwidth, a discrete wavelet transform (DWT) based OFDM (DWT-OFDM) has been proposed as in [29] [30]. The overall summary of OFDM developments is given in Table 1 below ;

3.1.1 System Model

The simulation Model of OFDM is shown in Fig. (5) [54,55]. The input data stream is first mapped into Qudarature Amplitude Modulation (QAM) according to the QAM constellation map, then the output complex is converted from serial to parallel into N-points IFFT to generate the OFDM symbol.

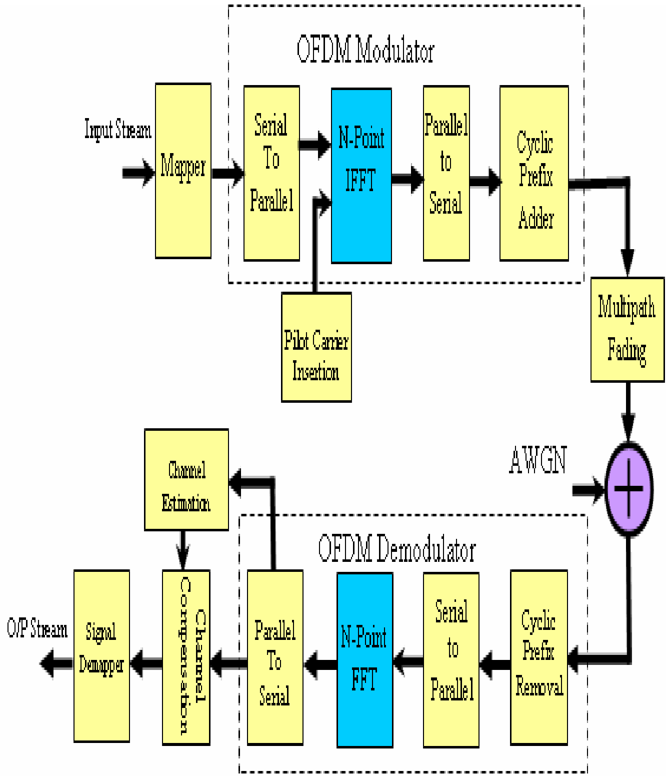


Fig. (5) Simple block diagram of OFDM transceiver based FFT [54].

The output data from the IFFT is now converted from parallel to serial and a cyclic prefix is added. The data are sent to the receiver over the channel after being converted to a frame structure (serial data stream). The frame structure consists of modulated data and the pilot signal is used for estimation and compensation. The channel consists of a multipath fading (flat fading channel or frequency selective fading channel) with AWGN, at the receiver the inverse operation is employed. The cyclic prefix is removed and a serial to parallel conversion is done for the signal. A FFT with N points is used to convert the signal from time to frequency domain. Then the effective channel is compensated after the OFDM demodulation, the signal de-mapper is used to recover the transmitted signal.

3.1.1.1 Analysis

The Performance of OFDM Based FFT

After the system for FFT-OFDM is analyzed, the simulations of its performance in Matlab version 7 are achieved. The result for such system in three types of channels will be used to compare its performance as in the table (2) which shows these parameters. The bit rate used in this simulation is 5 Mbps.

Table (2) Simulation Parameters

Modulation Type	QAM, 8 Point and 64 Point
No. of sub-carriers	31
No. of bits per Symbol	31
No. of FFT points	64
Channel model	AWGN
	Flat fading+AWGN
	Frequency selective fading+AWGN

A. BER Performance of OFDM at the AWGN Channel

A comparison was made between the FFT-OFDM at 8 and 64 constellation mapping points at the AWGN channel model, the simulation results appear in fig. (6). There are wide difference gain from 8 point over 64 point mapping at the higher values of SNR, where one can obtain more gains when the SNR increases.

B. BER Performance of OFDM in Flat Fading Channel

In this section the channel model is flat fading channel, where the bandwidth of the transmitted signal is smaller than the coherence bandwidth of the channel. Then all frequency components of the transmitted signal undergo the same attenuation and phase shift in transmission through the channel. Two values of the Doppler frequency are taken in this simulation; these are 5 Hz and 1100 Hz. The value of the $f_{d=}$1100 Hz corresponds to the relative velocity between the mobile unit and the base station of 118.8 km/h at carrier frequency 5 GHz. Where the velocity= (Doppler frequency*Speed of light)/(2*Carrier frequency).

The BER performance of FFT-OFDM system is shown in fig. (7). It shows that FFT-OFDM performs well at the lower Doppler frequency compared to its performance at the higher frequency. The performance will be reduced as the number of constellation mapping points increased from 8 to 64 point.

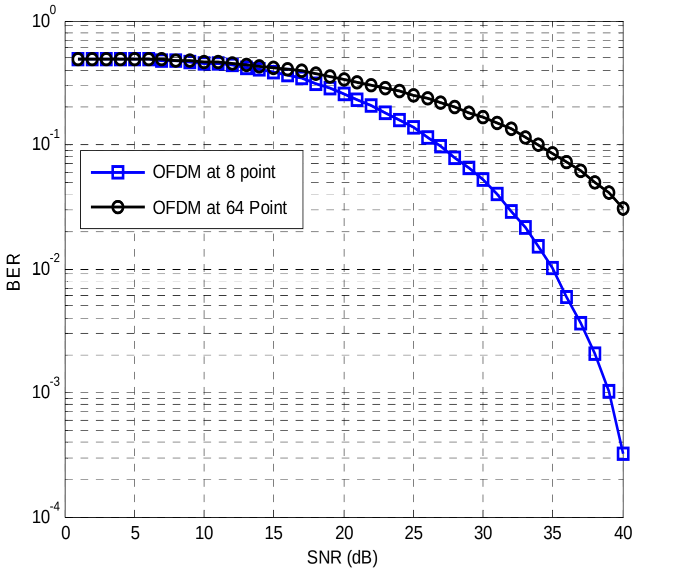


Fig. (6) BER performance of FFT-OFDM in AWGN channel.

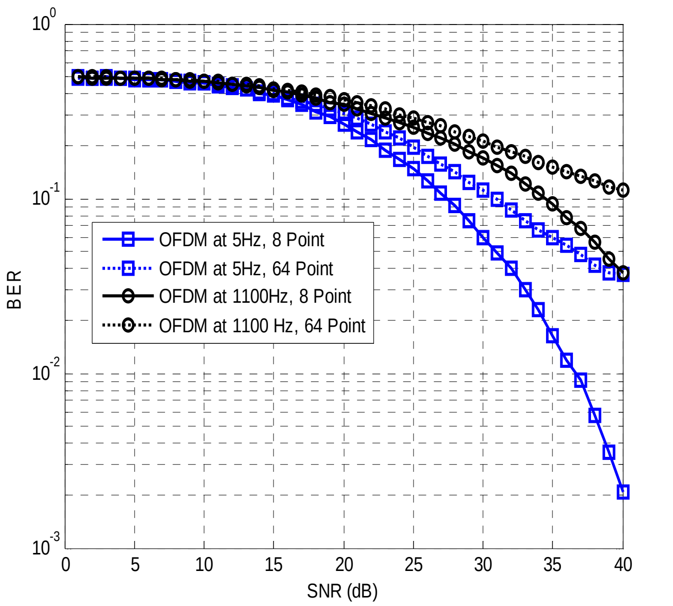


Fig. (7) BER performance of FFT-OFDM in flat fading channel.

C. BER Performance of OFDM in Selective Fading Channel

The aim of this section is to show the BER performance of the FFT-OFDM systems in the selective fading channel, where the transmitted signal has a bandwidth greater than the coherence bandwidth of the channel. The frequency components of the transmitted signal with frequency separation exceeding the coherence bandwidth are subjected to different gains and phase shifts. The path gain -8 dB and the path delay is 1 sample. Fig. (8) shows the BER performance for FFT-OFDM system. It can be seen that the BER be minimum for lower Doppler frequency and the error increases as the number of constellation points increases in the simulation range of SNR.

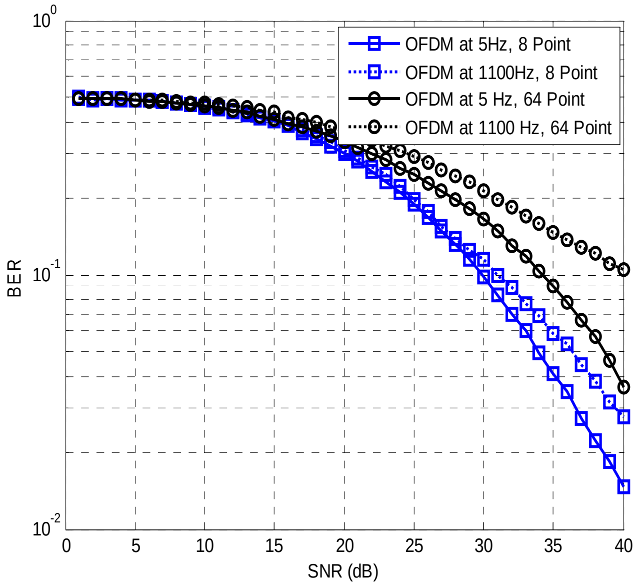


Fig. (8) BER performance of FFT-OFDM in selective fading channel.

3.1.2. OFDM System Model Based Wavelet Transform

The wavelet based OFDM modulator and demodulator used are shown in fig. (9), the block diagram of the system for DWT-OFDM is depicted in fig. (10). The overall system of OFDM is the same as in fig. (5), the only difference is in the OFDM modulator and demodulator.

The processes of the S/P converter, the signal demapper and the insertion of training sequence are the same as in the system of FFT-OFDM. Also the zeros will be added as in the FFT-OFDM model. After that the inverse discrete wavelet transform (IDWT) will be applied to the signal. The main and important difference between FFT based OFDM and DWT based OFDM is that the wavelet based OFDM will not add a cyclic prefix to OFDM symbol. Therefore, the data rates in wavelet based OFDM can surpass those of the FFT implementation. After that the P/S converter will convert the OFDM symbol to its serial version and will be sent through the channel. At the receiver, the S/P converts the OFDM symbol to parallel version. After that the DWT will be done. Also the zero pads will be removed and the other operations of the channel estimation, channel compensation, signal demapper and P/S will be performed in a similar manner to that of the FFT based OFDM.

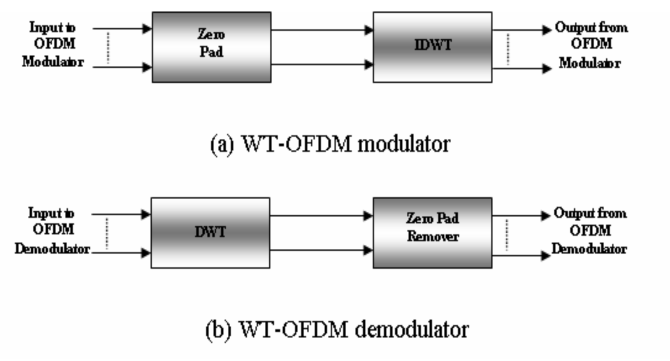


Fig. (9) WT-OFDM modem system [56].

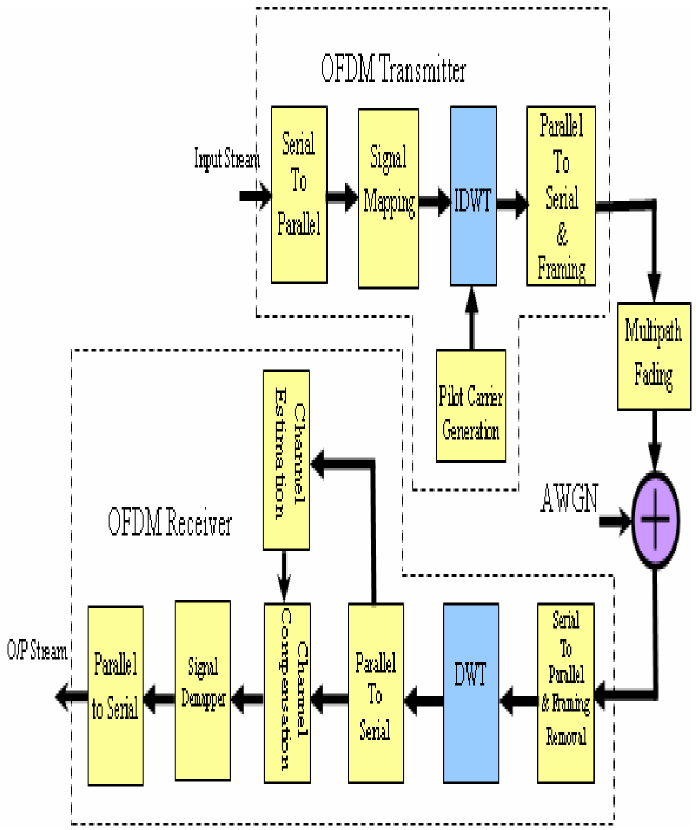


Fig. (10): Block diagram of DWT-OFDM system.

3.2 CDMA

In CDMA systems, the narrowband message signal is multiplied by a very large bandwidth signal called the spreading sequence. The spreading signal is a pseudorandom code sequence with chip rate that is an order of magnitude greater than the data rate of the message signal. All users in the CDMA system use the same carrier frequency and share the bandwidth. The data transmission may be done synchronously or asynchronously. Each user has its own pseudorandom codeword that is orthogonal to all other users.

The transmit power of users at the receiver determines the noise floor of the system after the correlation operation of the desired codeword with the received signal. If the power of each user within a cell is not controlled and the signals do not appear at the receiver base station with the same power, the near far problem occurs. This problem is particularly severe in the direct sequence systems where multiple users operate at the same frequency band simultaneously with interference with one another [40]. Figure 3.3 illustrates the CDMA system where each channel is assigned a unique orthogonal pseudorandom code sequence [57].

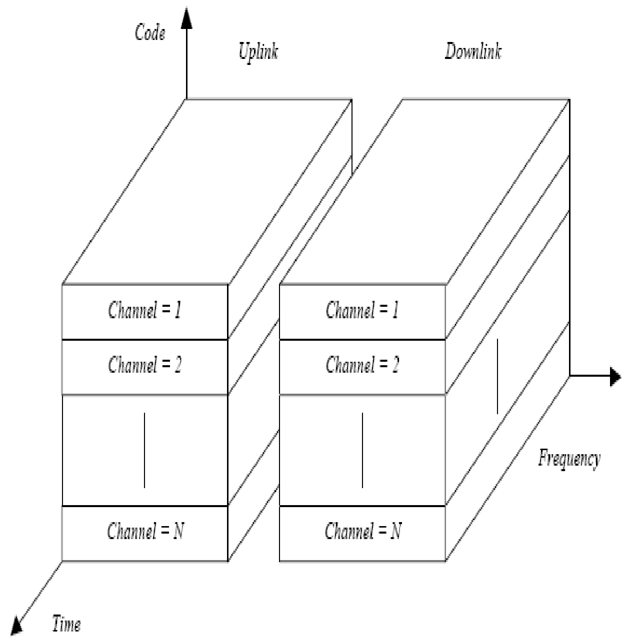


Fig. (11): Graph of the Time Domain Vs Frequency Domain and Codeword of theCDMA System[57]

In CDMA systems the stronger received signal level raises the noise floor at the base station for the weaker signals. Power control is used in CDMA system implementation to combat this problem. Each BS provides power control in a cellular system and if correctly applied, it assures

that each mobile within the same coverage of the BS offers the same signal power to the BS receiver. Power control is normally computed by rapidly sampling the signal strength at the receiver and comparing the estimated power
level to a set known threshold and then sending power control commands to the transmitter over the forward channel [57].

The second-generation CDMA cellular system is considered a narrowband CDMA system . In the narrowband CDMA system the available wideband spectrum is divided into a number of small bandwidth spectrums. Each of these sub-channels forms a narrowband CDMA system where the processing gain is lower than that for the original wideband CDMA system [57].

3.3 MC-CDMA

Table 3 summarizes the data rates of wireless communication systems. In the third generation (3G) wireless communication system, although the maximum data rates is 2Mbps, the typical data rate is around 384kbps. In order to achieve the goals of broadband cellular service, it is very appealing to leap to the fourth generation (4G) networks.

Table 3 : Summarize wireless communication system against data rate

	Data rate	such as
2G [58]	9.6 kbps – 14.4 kbps	Global System for Mobile communications (GSM)
		IS-95. 2G systems
3G [59]	64 kbps – 2 Mbps	Universal Mobile Telecommunications System (UMTS)
		CDMA2000
4G [60]	4 – 20 Mbps	High Definition Television (HDTV)
	1 - 100 Mbps	Computer network applications.

Since radio frequency spectrum is a scarce resource, future wireless radio networks need to make efficient use of the frequency spectrum by providing high capacity in term of the number of users allowed in the system. As a consequence, new communication technologies are developed to provide more efficient sharing of resources as presented in [61][14]. In 1993 that new multiple access schemes based on a combination of CDMA and multicarrier techniques were proposed, such as multicarrier-CDMA (MC-CDMA), multicarrier DS-CDMA (MC_DS_CDMA), and multi-tone CDMA (MT-CDMA) [18]. This combines the advantages of CDMA (interference rejection, and frequency reuse) with the advantages of multicarrier (robustness against multipath and impulse noise) [6].

Different users transmit over the same set of subcarriers but with a spreading code that is orthogonal to the codes of other users. The resulting signal has an orthogonal code structure in the frequency domain. MC-CDMA system solves the inter chip interference problem by transmitting the same data symbol over a large number of narrowband orthogonal carriers, without spectrum spreading per carrier, and makes it possible for multiple users to communicate through the same channel [6],[61]. In MC-DS-CDMA, the data sequence is multiplied by a spreading sequence modulates NC subcarriers. The MT-CDMA scheme uses longer spreading code in proportion to the number of subcarriers, as compared with normal DS-CDMA scheme. Therefore, the system can accommodate more users than the DS-CDMA scheme [14].

In 1993 Yee et. al. [62], examined a novel digital modulation with multiple access technique called MC-CDMA where each data symbol is transmitted at multiple narrowband subcarriers with Each subcarrier is encoded with a phase offset of 0 or π based on a spreading code. Analytical results are presented on the performance of this modulation scheme in an indoor wireless multipath radio channel. Ming and Chee [63], compared the signal model of three Hybrid OFDM-CDMA schemes which are MC/DS-CDMA, MC-CDMA and OFCDM in order to benefit from the frequency diversity of these hybrid schemes. In [64] a comparison was made of the sensitivities of MC-CDMA and MC-DS-CDMA to carrier frequency offset, which are both a combination of the multicarrier transmission technique and the CDMA multiple access. In [65] the utilization of MC-CDMA as a digital modulation and multiple access technique was discussed in wireless environment. Different Users transmit at the same set of sub-carriers but with a different spreading code in the frequency domain. It has significantly increased the number of simultaneously supportable users in CDMA systems. In 2003 Venkatasubramanian [7] analyzed the concepts of MC-CDMA systems. The research work investigates multi antenna receivers for OFDM and MC-CDMA systems and specifically adaptive antenna algorithms for MC-CDMA for different channel conditions. Table 4 below summarizes of the development of MC-CDMA systems.

4 Conclusion

This paper presents the analysis and review of OFDM and CDMA techniques as well as the combination of both. The combination of OFDM and CDMA schemes offers great advantage which can lower the symbol rate in each subcarrier. The longer symbol duration makes it easier to synchronize the transmission.

Direct sequence spread spectrum transmission has received considerable attention for applications in mobile and personal communications networks due to its ability to provide higher spectral efficiencies in comparison with other conventional modulation schemes. A multi-carrier (MC) orthogonal CDMA signaling scheme was introduced as a mean to reduce interference in multi-point to point CDMA network. It presents a class of spreading codes that enables a simple de-spreading combining receiver to achieve the performance of optimum multi-user linear receiver. These codes were shown to be optimum for independent fading channels under a code design criterion derived. Also it shows that both systems are strongly degraded in the presence of a carrier frequency offset.

The main advantages of the Multicarrier Modulation are; firstly to solve the multipath propagation problem using simple equalization at the receiver (CP case). Secondly, the system offers computation efficiency i.e. more efficient than single carrier transmission. Finally, the system provides support to several multiple access schemes (TDMA, FDMA, MC-CDMA) as well as, various modulation schemes.

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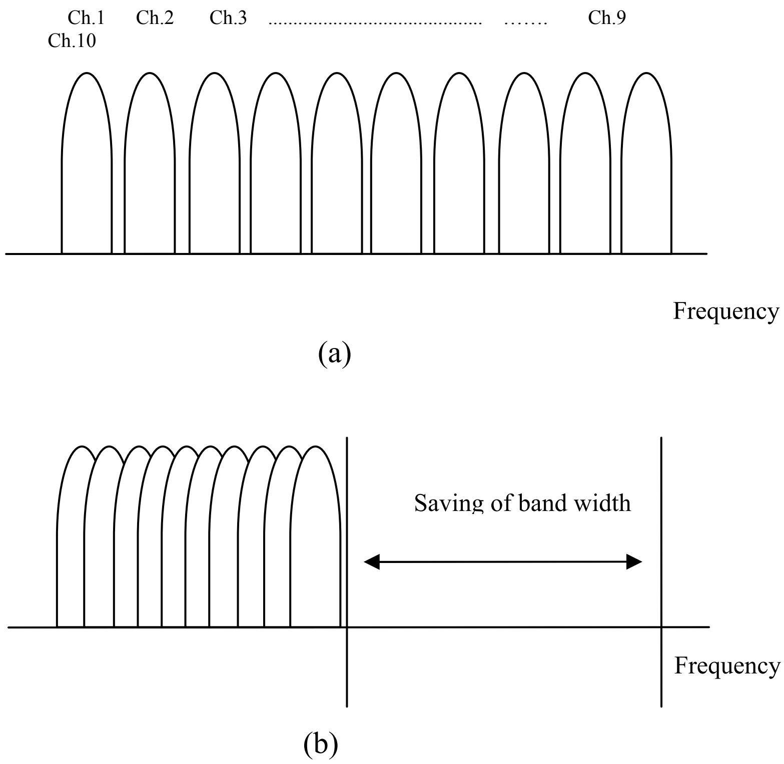

Figure 2:(a) Conventional multicarrier and (b) Orthogonal multicarrier modulation technique

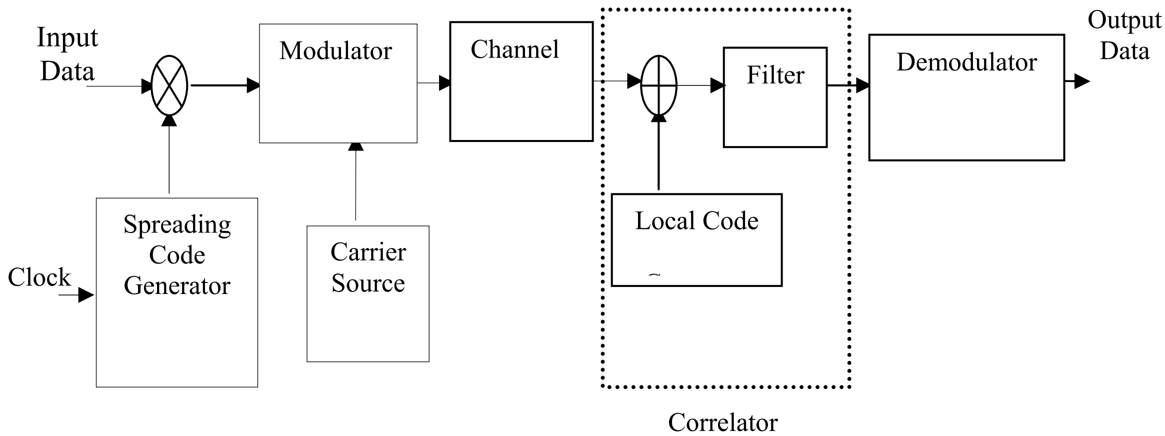

Figure 4: Basic direct sequence spread spectrum (DS/SS) system [15].

Table 1: Summary (Milestones in the history) OFDM development.

1991	J. M. Cioffi	ANSI ADSL standard [31].
1994	ANSI Committee	ANSI HDSL standard [32].
1995	ETSI	ETSI DAB standard [33]: the first OFDM-based standard for digital broadcasting systems.
1996	ETSI	ETSI WLAN standard [34].
1997	ETSI	ETSI DVB-T standard [35].
1998	ETSI	ANSI VDSL and ETSI VDSL standards [36][37].
1998	ETSI	ETSI BRAN standard [38].
1999	IEEE	IEEE 802.11a WLAN standard [39].
2002	IEEE	IEEE 802.11g WLAN standard [40].
2004	ETSI	ETSI DVB-H standard [41].
2004	IEEE	IEEE 802.16 WMAN standard [42].
2004	IEEE	Candidate for IEEE 802.11n standard for next generation WLAN [43].
2004	IEEE	Candidate for IEEE 802.15.3a standard for WPAN (using MB-OFDM) [44].
2005	M. Yabusaki	Candidate for 4G standards in China, Japan and South Korea (CJK) [45].
2006	A. Sang et al	Discussed OFDM for channels with both flat and frequency-selective fading [46].
2006	C.D. Chung	The linear combinations of rectangularly pulsed multicarrier basis signals, and thereby allow for the efficient realization of FFT[47].
2007	Yu Fu, et al	The ICI coefficient matrix is approximately unitary and exploit this property to design a nonlinear Tomlinson-Harashima precoder for the reduction of ICI in closed-loop SISO OFDM and orthogonal space-time block-coded (OSTBC) MIMO OFDM[48].
2007	Tilde Fusco, et al	Consider a semiblind carrier frequency offset (CFO) synchronization scheme based on the insertion of pilot tones and exploiting the statistical redundancy of the OFDM signal due to the CP and/or to virtual subcarriers[49].
2008	S. F. A. Shah, A. H. Tewfik,	Design and analysis of post coded OFDM (PC-OFDM) systems[50].
2009	E. Saberinia, et al	Describe a novel approach for reducing the power consumption and complexity of a multiband-OFDM UWB system by applying ideas from pulsed UWB systems[51].
2009	S. U. H. , J. H. Lee, and J. Seo	Low complexity iterative ICI cancellation and equalization technique is proposed for use in OFDM systems over doubly selective channels[52].
2009	S. Wang and J.H. Manton	The proposed algorithm is able to identify the channels using a single received OFDM data block[53].

Table 4: Glimpses of MC-CDMA systems

1993	Yee et al,	Examined a novel digital modulation/multiple access technique called Multi-Carrier Code Division Multiple Access (MC-CDMA) where each data symbol is transmitted at multiple narrowband subcarriers [62].
1993	Fazel and Papke	had investigated convolutional coding in conjunction with OFDM/CDMA [66].
1995	Rowttch and Milstein	Presented a multicarrier asynchronous Direct Sequence Code Division Multiple Access (MC-DS-CDMA) system which, through use of convolutional codes, achieves frequency diversity of an order above and beyond that realized by path diversity in a conventional RAKE DS-CDMA system[67].
1999	B. Popovic	Analyzed the basic criteria for the selection of spreading sequences of the Muilticarrier CDMA (MC-CDMA) systems with spectrum spreading in frequency domain. It is shown that, the time-domain cross-correlation function between the spreading sequences is not a proper interference measure for the asynchronous MC-CDMA users [68].
1999	Lee and Milstein	Analyzed the performance of a MC-DS-CDMA system employed in the forward link of a cellular system operating over a Rayleigh fading channel, and compared it with the performance of both single carrier CDMA and hybrid multicarrier CDMA/ frequency division multiplexing systems [69].
1999	S. Hara and R. Prasad	Presented the advantages and disadvantages of MC-CDMA system. The transmitter/receiver structure and the bandwidth of transmitted signal spectrum are compared with those of a conventional DS-CDMA system, and a MC-CDMA design method, how to determine the number of subcarriers and the length of guard interval [70].
2000	Mottier, and	Proposed and investigated a novel spreading sequence allocation procedure for MC-CDMA

	Castelain	systems. This technique, which relies on an analytical evaluation of the Multiple Access Interference (MAI), mitigates the interference between different users by optimizing the spreading sequence selection within a given spreading sequence family [71].
2001	H. Steendam and M. Moeneclaey	Considered the effect of a carrier frequency offset on the performance of MC-CDMA and MC-DS-CDMA, which are both a combination of the multi-carrier transmission technique and the CDMA multiple access technique. Also it showed that both systems are strongly degraded in the presence of a carrier frequency offset. Furthermore, for given spreading factor, the MC-DS-CDMA system is less (more) sensitive to carrier frequency offset than MC-CDMA when the number of modulated carriers in the former system is smaller (larger) than the spreading factor [72].
2003	R. V.	Analyzed the concepts of MC-CDMA systems. The research work investigates multi antenna receivers for OFDM and MC-CDMA systems and specifically adaptive antenna algorithms for MC-CDMA for different channel conditions [7].
2003	L. Hanzo, et al	a novel approaches based on Genetic Algorithms (GA) were suggested in the multi-user detection of MC-CDMA systems [73].
2003	Chatterjee, et al	Proposed an adaptive modulation based MC-CDMA systems can play a vital role in future generation consumer communication electronics. Adaptive modulation, combined with MC-CDMA based transmission technology, is a promising way to increase the data rate that can be reliably transmitted over the wireless radio channels [74].
2004	Hongbing Zhang	Developed and evaluated a wavelet packet based MC-CDMA wireless communication system. In this system design a set of wavelet packets are used as the modulation waveforms in a MC-CDMA system [30].
2004	G. J. and H. Teresa	Developed and analyzed a high capacity, low complexity, and robust system design for a Successive Interference Cancellation (SIC) in MC-CDMA system [75].
2005	F. Sanzi	Investigate four different detection methods for OFDM-CDM[76].
2006	K. Ko, M. Park, and D. Hong	Analysis of asynchronous MC-CDMA systems with a guard period (GP) in the form of a CP over frequency selective multipath fading channels, which results in closed-form bit-error rate performance[77].
2006	P. Ting, et al	Analyze the BER performance of the optimum MUD with channel mismatch in MC-CDMA systems[78].
2006	Z. Li and M. L.aho	Novel space-frequency multiuser detection scheme for multirate uplink MC-CDMA systems with multiple receive antennas is proposed[79].
2007	J. Zhan, G. Liao and G. Li	The proposed method is based on a three-level design of user codes: the top level (based on OFDMA) deals with group interference and ISI, the middle level (based on space-frequency block coding) results in space-frequency diversity, and the lower level (based on CDMA) handles multiuser interference[80].
2007	M. Guenach and H. Stee.	Investigate the sensitivity of downlink MC-CDMA performance to parameters in different environments[81].
2007	M. El-Hajjar, et al	The MC DSCDMA transmitter employs an Antenna Array (AA) and Steered Space-Time Spreading (SSTS) [82].
2008	T. Hwang, Ye. L. Yi Y.Wu	Apply recently developed energy spreading transform (EST) technique to down-link MC-CDMA systems for frequency and spatial diversity[83] .
2008	W. M. Jang, et al	Analyze the performance of random spreading CDMA systems with a multicarrier in asynchronous uplink channels[84].
2009	A. B. Djebbar,et al	New blind time domain equalization (TEQ) techniques for downlink MC-CDMA systems[85].