OFDM: Comparison with Multicarrier Techniques and Applications

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Abstract –*Orthogonal Frequency Division Multiplexing (OFDM)is the promising candidate of a multiple carrier modulation technique because it does not require equalizers. OFDM is robust in adverse channel conditions and allows a high level of spectral efficiency. It effectively mitigates performance degradations due to multipath and is capable of combating deep fades in part of the spectrum. Orthogonal Frequency Division Multiplexing (OFDM) is an emerging multi-carrier modulation scheme, which has been adopted for several wireless standards such as IEEE 802.11a and HiperLAN2.In this paper, the comparison between other carriertechniques like single carrier transmission, multi carrier transmission, conventional multi carrier technique, CDMA, TDMA, FDMA. The wireless communication broadcasting, WLAN, WMAN who are implemented OFDM are detailedand compared here. The advantages and disadvantages of OFDM are discussed in this paper.*

Key Words:OFDM, CDMA, FDMA,TDMA, Broadcasting, WLAN, WMAN.

1. INTRODUCTION

The demand for high data rate services has been increasing very rapidly and there is no slowdown in sight. Currently Global System for Mobile telecommunications (GSM) technology is being applied to wireless phone systems. But, GSM uses time division multiple access (TDMA), which has a high symbol rate leading to problems with multipath causing inter-symbol interference. Several techniques are under consideration for the next generation of digital phone systems, with the aim of improving cell capacity, multipath immunity, and flexibility.[1,2] These include CDMA and OFDM. In the beginning of 3G (Third Generation) era, CDMA technique was widely employed for most systems. Buttheir capability of supporting much higher data rate is limited. This is because they use multiple codes simultaneously, which may result in self-interference. So B3G (Beyond 3G), OFDM is used instead of CDMA. In IEEE802.11 series, the low date rate is working on CDMA (802.11b) but high date rate uses OFDM (802.11g and 802.11a). WiMAX is also using OFDM. OFDM is currently being used in several new radio broadcast systems including high definition digital television (HDTV) and digital audio broadcasting (DAB). A research has been done into the use of OFDM as a transmission method for mobile telecommunications systems. [5]

2. COMPARISON BETWEEN OTHER TECHNIQUES

2.1. Single carrier transmission

In single carrier transmission, all data is sending on a single channel with very high data rate. The transmitted symbols are pulse formed by a transmitter filter. After passing the multipath channel in the receiver a matched filter is used to maximize signal to noise ratio.

The system is characterized by the following conditions:

- Transmission Rate: R= 1/T
- Maximum channel delay: T_d

For the single carrier system this results in an ISI of: T_d / T. The complexity involved in removing this interference in the receiver is tremendous. This is the main reason why the multi carrier approach has become so popular. [4]

Fig-1: Basic structure of a single carrier system[4]

2.2. Multi carrier transmission

The original data stream of rate R is multiplexed into N parallel data streams of rate R/N each of the data streams is modulated with a different frequency and the resulting signals are transmitted together in the same band. Correspondingly the receiver consists of N parallel receiver paths. Due to the prolonged distance in between transmitted symbols the ISI for each sub system reduces to $T_d/(N*T)$

Such little ISI can often be tolerated and no extra counter measure such as an equalizer is needed. But as far as the complexity of a receiver is concerned a system with large parallel paths are not feasible. This leads to the concept of OFDM. [4]

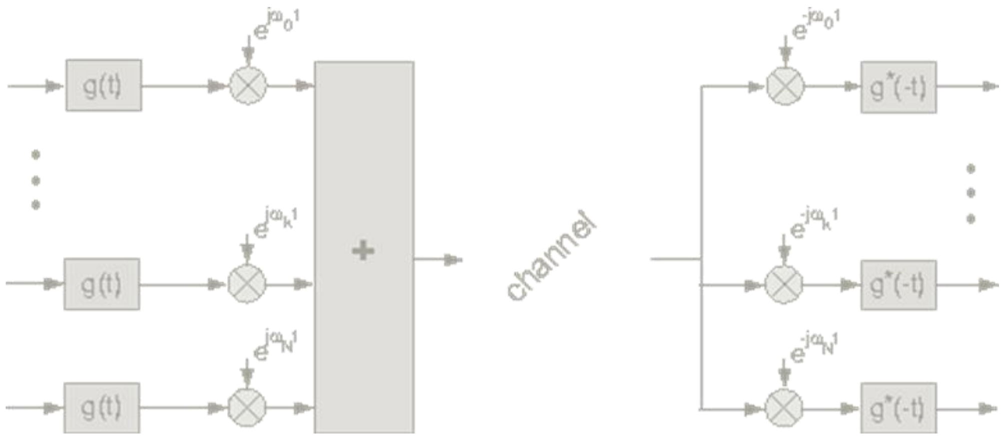

Fig-2: Basic structure of a multicarrier system [4]

2.3. Conventional multi carrier technique

In a classical parallel data system, the total signal frequency band is divided into N non overlapping frequency subchannels. Each subchannel is modulated with a separate symbol and then the N subchannels are frequency-multiplexed. It seems good to avoid spectral overlap of channels to eliminate interchannel interference. But, this leads to inefficient use of available spectrum

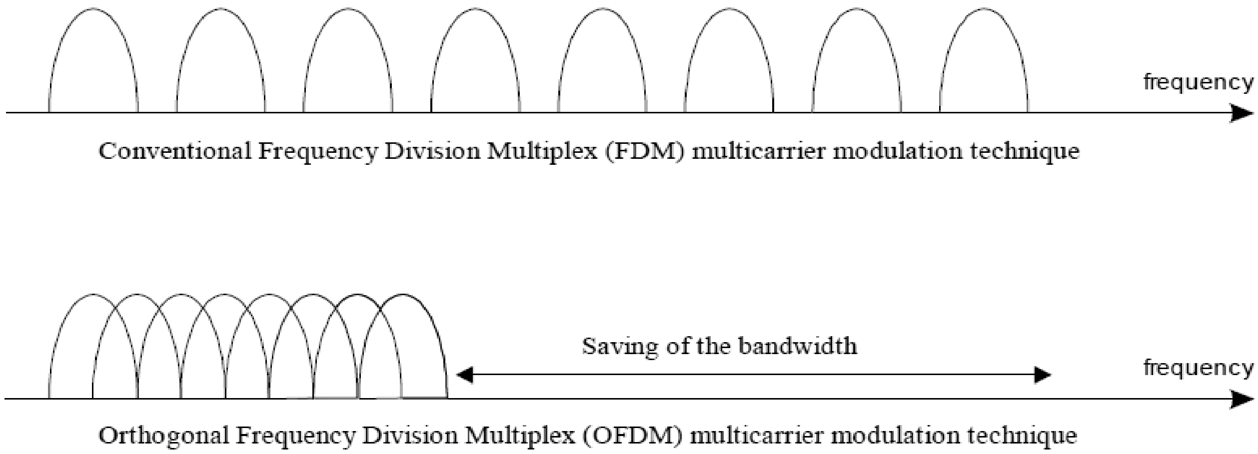

Fig-3: Comparison of conventional FDM and OFDM [5]

The difference between the conventional non-overlapping multicarrier technique and the overlapping multicarrier modulation technique is that by using the overlapping multicarrier modulation technique, we save almost 50% of bandwidth. To realize the overlapping multicarrier technique, however we need to reduce crosstalk between subcarriers, which means that we want orthogonality between the different modulated carriers.

2.4. CDMA

CDMA is achieved by modulating the data signal by orthogonal pseudo random noise (PN code), called Walsh code by modular-2 adder. But for Walsh codes, all users must be synchronized. If the Walsh code used by one user is shifted in time by more than about 1/10 of chip period, with respect to all the other Walsh codes, it loses its orthogonal nature .This results in inter-user interference. For the forward link signals for all the users originate from the base station, allowing the signals to be easily synchronized.

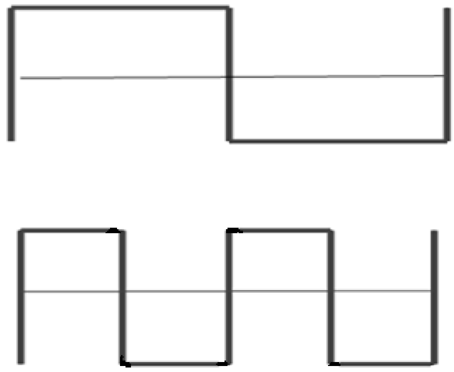

Fig- 4: Orthogonal walsh codes in CDMA

But during reverse link, the transmission from each user will arrive at a different time, due to propagation delay, and there are synchronization errors. The reverse link is not orthogonal, resulting in significant inter-user interference. For this reason the reverse channel sets the capacity of the system. [1]
Direct Sequence Code Division Multiple Access (DS-CDMA) became commercial only in the mid 90's IS-95, CDMA-2000 (3GPP2), W-CDMA (3GPP).

2.5. FDMA

In FDMA each user is typically allocated a single channel, which is used to transmit all the user information. The bandwidth of each channel is typically 10 kHz-30 kHz for voice communications. However, the minimum required bandwidth for speech is only 3 kHz. The allocated bandwidth is made wider than the minimum amount required preventing channels from interfering with one another. This extra bandwidth is to allow for signals from neighbouring channels to be filtered out, and to allow for any drift in the centre frequency of the transmitter or receiver. In a typical system up to 50% of the total spectrum is wasted due to the extra spacing between channels.
This problem becomes worse as the channel bandwidth becomes narrower, and the frequency band increases. [1]

2.6. TDMA

Time Division Multiple Access (TDMA) is the most prevalent wireless access system to dateGSM, EDGE, DECT TDMA partly overcomes this problem by using wider bandwidth channels, which are used by several users. Multiple users access the same channel by transmitting their data in time slots. Thus, many low data rate users can be combined together to transmit over a single channel which has a bandwidth sufficient so that the spectrum can be used efficiently.
But there are two main problems with TDMA. There is an overhead associated with the changeover between users due to time slotting on the channel. A change over time must be allocated to allow for any tolerance in the start time of each user, due to propagation delay variations and synchronization errors. This limits the number of users that can be sent efficiently in each channel [1]

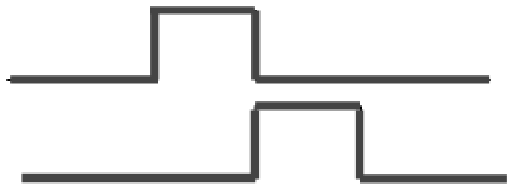

Fig-5: Orthogonal data in time slots in TDMA

2.7. OFDM

TDMA is not normally considered an orthogonal coding scheme, by considering the time interval to be the burst width. Over that interval, the other signal is zero, so the dot product is zero.
Walsh codes which are used in CDMA systems are orthogonal, and the most common form of orthogonal signalling. For example in IS-95, length 64 Walsh codes provide 64 possible code channels.

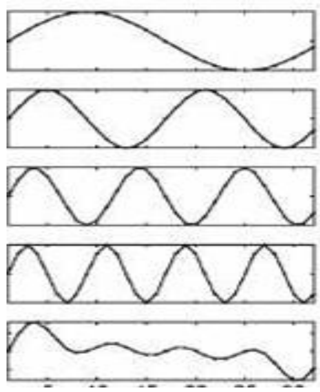

Fig-6: Orthogonal signals in OFDM [6]

OFDM is actually very closely related to CDMA. Instead of Walsh codes, the basic functions are sinusoids. In a given period, the sinusoids will be orthogonal provided there are an integral number of cycles. The amplitude and phase of the sinusoid, which will be used to represent symbols, does not affect the orthogonality property. Using sinusoids instead of Walsh codes produces a spectrum where it is possible to associate a carrier frequency with a code channel. [2]

Orthogonal Frequency Division Multiplexing (OFDM) is perhaps the least well known can be viewed as a spectrally efficient FDMA technique IEEE 802.11A, .11G, HiperLAN, IEEE 802.16 OFDM/OFDMA options

For narrowband applications (up to 5 MHz), CDMA technologies can achieve some of the highest data throughputs possible, while OFDM technologies can offer a simpler implementation within wider radio channels (more than 10 MHz). Outside of high traffic metro areas, OFDM-based systems are not economical since the spectrum and network will most likely remain underutilized.

3. OFDM APPLICATIONS

In the 1990s, OFDM was exploited for wideband data communications over mobile radio FM channels, high-bit-rate digital subscriber lines (HDSL; 1.6 Mbps), asymmetric digital subscriber lines (ADSL; up to 6 Mbps), very-high-speed digital subscriber lines (VDSL; 100 Mbps), digital audio broadcasting (DAB), and high-definition television (HDTV) terrestrial broadcasting[3]

3.1. Broadcasting

3.1.1. DAB (Digital Audio Broadcasting)

DAB can carry text and images as well as sound.DAB combines two advanced digital technologies to achieve robust and spectrum-efficient transmission of high-quality audio and other data. In DAB, staggered quadrature phase shift keying is used, with differential coding. Main channel code is convolutional error correcting code, with a Viterbi decoder. Some of the higher priority data is precoded with a block code for additional security. The data is interleaved, both in frequency and time. The error correction process works best if the errors in the incoming data are random.

Table -1: Parameters of various OFDM applications [3]

Transform Size	System	**Number Carriers**	**Channel Spacing kHz**	**Bandwidth MHz**	**Sample Rate MHz**	**Symbol Duration μsec**	**Data Rate Mbits/s**
64	HyperLAN/2	52 4	312.5	16.25	20	3.2 0.8	6-54
64	802.11a	52 4	312.5	16.56	20	3.2 0.8	6-54
2048 1024	DVB-T	1712 842	4.464	7.643	9.174	224	0.68- 14.92
2048 8192	DAB	1536	1.00	1.536	2.048	24/48/96 msec	3.072
256 (down) 64 (up)	ADSL	36-127 7-28	4.3125	1.104	1.104	231.9	0.64- 8.192

3.1.2. DVB (Digital Video Broadcasting)

Digital Video Broadcasting (DVB) is a suite of internationally accepted open standards for digital television. The areas include DVB-S (the first generation version of the digital satellite system), DVB-C (the digital cable system), DVB-T (the digital terrestrial broadcasting system), DVB-H (bringing digital terrestrial broadcasting to battery-powered handheld receivers), DVB-DATA (the cyclical data delivery system), DVB-SI (the service information system), and DVB-MHP (middleware for interactive television). All data is transmitted in MPEG transport streams with some additional constraints (DVB-MPEG). These distribution systems differ mainly in the modulation schemes used and error correcting codes used, due to the different technical constraints.

3.2. WLAN (Wireless Local Area Networks)

3.2.1. IEEE 802.11a

The IEEE 802.11 specification is a wireless LAN (WLAN) standard that 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 - IEEE 802.11b for 2.4-GHz operation and IEEE 802.11a for 5-GHz operation. The IEEE 802.11a standard is designed to serve applications that require data rates higher than 11 Mbps in the 5-GHz frequency band.

Table -2: Physical layer Parameters of IEEE 802.11a [3]

Parameters	Values
Sampling rate	20MHz
Number of FFT points	64
Total number of sub-carriers available	52
Number of data sub-carriers	48
Number of pilot sub-carriers	4
Subcarrier frequency spacing	0.3125 MHz
FFT symbol period	3.2μs
Cyclic prefix	0.8μs (1/4)
OFDM symbol period	4μs

3.2.2. Hiperlan2

For the most part, the PHY for 802.11a is similar to Hiperlan2. The differences between the two standards are minimal and reside in the method by which convolution encoding is used to generate the OFDM symbols and data rates.

Table-3 : Comparison of 802.11b and HIPERLAN2 [3]

Standard	802.11 b	HIPERLAN2
Spectrum	5.2 GHz	5.2 GHz
Modulation Technique	OFDM	OFDM
Medium access control	---------	TDMA/TDD
Connection	Connection less. Less	connection oriented

3.3. Wireless MAN (Wireless Metropolitan Area Networks)

3.3.1. IEEE 802.16 (WiMAX)

WiMAX (Worldwide Interoperability for Microwave Access) is a telecommunications protocol that provides fixed and fully mobile internet access. Fixed FFT size (256 carriers), variable subcarrier spacing to support multiple defined bandwidths .Adaptive modulation with BPSK, QPSK, 16-QAM and 64-QAM defined. Coding includes concatenated Reed-Solomon-convolutional code (mandatory), Block Turbo coding (optional) or convolutional turbo codes (optional).

Table - 4: Parameters of WIMAX [3]

Parameters	Values
Number of FFT points	256
Number of null sub carriers	56
Number of data sub-carriers	192
Number of pilot sub-carriers	8
Subcarrier frequency spacing	0.3125 MHz
FFT symbol period	3.2μs
Cyclic prefix	0.8μs

4. ADVANTAGES OF OFDM

- **Reduced computational complexity:** OFDM can be easily implemented using FFT/ IFFT, and the processing requirements grow only slightly faster than linearly with data rate or bandwidth..
- **Graceful degradation of performance under excess delay:** The performance of an OFDM system degrades gracefully as the delay spread exceeds the value designed for system .Greater coding and low constellation sizes can be used to provide fallback rates that are significantly more robust against delay spread.
- **OFDM is spectrally efficient.**
- **OFDM has excellent robustness in multi-path environments:** Cyclic prefix preserves orthogonality between sub-carriers. Cyclic prefix allows the receiver to capture multi- path energy more efficiently.
- **Exploitation of frequency diversity:** OFDM facilitates coding and interleaving across subcarriers in the frequency domain, which can provide robustness against burst errors caused by portions of the transmitted spectrum undergoing deep fades.
- **Use as a multiaccess scheme:** OFDM can be used as a multiaccess scheme, where different tones are partitioned among multiple users. This scheme is referred to as OFDMA and is exploited in mobile WiMAX. This scheme also offers the ability to provide fine granularity in channel allocation.
- **Robust against narrowband interference:** OFDM is relatively robust against narrowband interference, since such interference affects only a fraction of the subcarriers.
- **Suitable for coherent demodulation:** It is relatively easy to do pilot-based channel estimation in OFDM systems , which renders them suitable for coherent demodulation
  schemes which are more power efficient.
- **Now possible because of advances in digital signal processing.**
- **Ability to comply with world-wide regulations:** Bands and tones can be dynamically turned on/off to comply with changing regulations.
- **Coexistence with current and future systems:** Bands and tones can be dynamically turned on/off for enhanced coexistence with the other devices. [9], [11].

5. DISADVANTAGES OF OFDM

There are two main limitations of OFDM –sensitivity to synchronization, high peak to average value

- **High sensitivity to synchronization errors**: OFDM is very sensitive to frequency errors caused by frequency differences between the local oscillators of the transmitter and the receiver. Carrier frequency offset causes a number of impairments including attenuation and rotation of each of the sub carriers and carrier interference (ICI) between sub carriers. In the mobile radio environment, relative movement between transmitter and receiver causes Doppler frequency shifts; in addition, the carriers can never be perfectly synchronized. These random frequency errors in OFDM system distort orthogonality between sub carriers and thus inter-carrier interference (ICI) occurs .It is more sensitive to carrier frequency offset and drift than single carrier systems are due to leakage of the DFT. The phase noise is an additional modulation which will modify the sin(x)/x spectrum, reducing the depth of the nulls, and creating interference to other carriers.

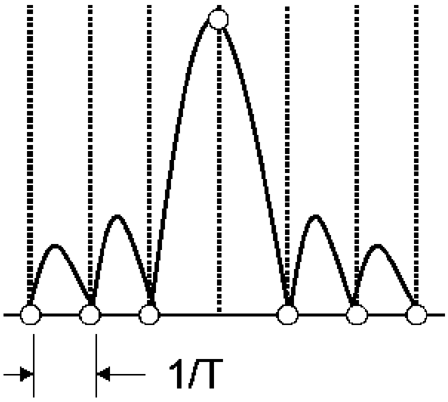

Fig-7: For FFT, Nulls are On Bin if the Tone is On Bin [2]

- If the receiver is off frequency, then the nulls in each carrier won't land on an FFT bin. In FFT terminology this is called leakage. For OFDM, the result is inter-carrier interference. [6]

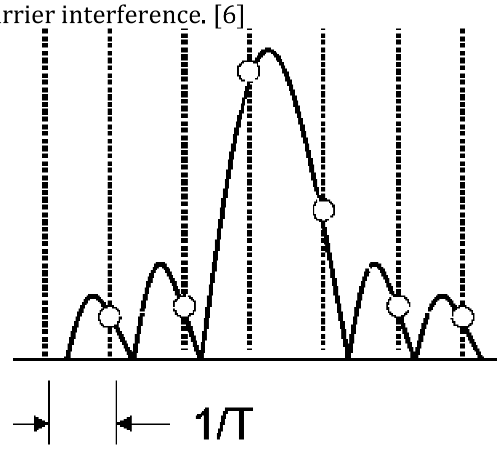

Fig -8: Frequency Errors and Phase Noise Cause Leakage [2]

- **Higher Peak-to-average:** The OFDM time-domain signal has a relatively large peak-to-average ratio.It tends to reduce the power efficiency of the RF amplifier. The non-linear amplification destroys the orthogonality of the OFDM signal and introduced out-of-band radiation.

  The OFDM signal has a noise like amplitude with a very large dynamic range, therefore it requires RF power amplifiers with a high peak to average power ratio.OFDM signal has varying amplitude. If the amplitude is clipped or modified, then an FFT of the signal would no longer result in original frequency characteristics, and the modulation may be lost. In addition, very large amplitude peaks may occur depending on how the sinusoids line up, so the peak-to-average power ratio is high. This means that the linear amplifier has to have a large dynamic range to avoid distorting the peaks. The result is a linear amplifier with a constant, high bias current resulting in very poor power efficiency. This high PAR is one of the most important implementation challenges that face OFDM, because it reduces the efficiency and hence increases the cost of the RF power amplifier, which is one of the most expensive components in the radio.
- **More expensive transmitters and receivers**
- **Efficiency gains reduced by requirement for guard interval.**
- **OFDM-based systems are not economical**: For narrowband deployments (up to 5 MHz), CDMA technologies can achieve some of the highest data throughputs possible, while OFDM technologies can offer a simpler implementation within wider radio channels (more than 10 MHz). Outside of high traffic metro areas, OFDM-based systems are not economical since the spectrum and network do not remain under utilization.[20]

6. CONCLUSIONS

Now WLAN standards such as IEEE802.11a and HiperLAN2 are based on OFDM technology provide a much higher data rate of 54 Mbps. But systems of the near future will require WLANs with data rates of greater than 100 Mbps.

OFDM alone is not able to fully satisfy the development of subsequent wireless communications. For example, the study of technologies such as multi-antenna processing, wireless resource allocation, adaptive modulation of codes (AMC), channel assessment, and adaptive frequency hopping in relation to OFDM technology, have currently become hot topics, and under research.

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