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A Review on Various OFDM Techniques and Their Applications

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Abstract: ***Orthogonal frequency-division multiplexing (OFDM) effectively mitigates intersymbol interference (ISI) caused by the delay spread of wireless channels. Therefore, it has been used in many wireless systems and adopted by various standards. In this paper, we present a comprehensive survey on OFDM for wireless communications. We address basic OFDM and related modulations, as well as techniques to improve the performance of OFDM for wireless communications, including channel estimation and signal detection, time-and frequency-offset estimation and correction, peak-to-average power ratio reduction PAPR, intercarrier interference (ICI) and multiple-input–multiple-output (MIMO) techniques. We also describe the applications of OFDM in current systems and standards.***

Keywords: Channel estimation , frequency-offset estimation, intercarrier interference (ICI), multicarrier (MC), multiple input–multiple-output (MIMO) orthogonal frequency-division multiplexing (OFDM), peak-to-average power reduction, timeoffset estimation, wireless standards.

1. Introduction

With the rapid growth of digital communication in recent years, the need for high speed data transmission is increased. Moreover, future wireless systems are expected to support a wide range of services which includes video, data and voice. Orthogonal Frequency Division Multiplexing (OFDM) is a promising candidate for achieving high data rates in mobile environment because of its multicarrier modulation technique [1]. Due to its high capacity transmission, and multi carrier modulation technique it was chosen for digital audio broadcasting (DAB), terrestrial digital video broadcasting TV (DVB-T), asymmetric digital Subscriber Lines (ADSL), ultra-wideband system. The IEEE 802.11a standard for wireless local area networks (WLAN) and IEEE 802.16 standard is also based on OFDM [2].

2. What is OFDM?

Orthogonal frequency division multiplexing (OFDM) is a widely used modulation and multiplexing technology, which has become the basis of many telecommunications standards including wireless local area networks (LANs), digital terrestrial television (DTT) and digital radio broadcasting in much of the world. In the past, as well as in the present, the OFDM is referred in the literature as Multi-carrier, Multi-tone and Fourier Transform. The OFDM concept is based on spreading the data to be transmitted over a large number of carriers, each being modulated at a low rate. The carriers are made orthogonal to each other by appropriately choosing the frequency spacing between them. A multicarrier system, such as FDM (aka: Frequency Division Multiplexing), divides the total available bandwidth in the spectrum into sub-bands for multiple carriers to transmit in parallel.[2] It combines a large number of low data rate carriers to construct a composite high data rate communication system. Orthogonality gives the carriers a valid reason to be closely spaced with overlapping without ICI. [3]

The flexibility of OFDM provides opportunities to use advanced techniques, such as adaptive loading, transmit diversity, and receiver diversity, to improve transmission efficiency. Shannon's classical paper in 1948 [27] suggested that the highest data rate can be achieved for frequency-selective channels by using an MC system with an *infinitely dense* set of subchannels and adapting transmission powers and data rates according to the signal-to-noise ratio (SNR) at different subchannels. Based on his theory, a *water-filling* principle has been derived [28]. Cioffi and his group have extensively investigated OFDM with performance optimization for asymmetric digital subscriber line, which they more often called discrete multiple tone (DMT). Some of their earlier inventions on practical loading algorithms for OFDM or DMT systems were in [6].

More results on this topic can be found in [9]–[10]. The capacity of a wireless system can significantly be improved if multiple transmit and receive antennas are used to form multiple-input–multiple-output (MIMO) channels [11]–[3]. It is proved in [6] that, compared with a single input– single-output (SISO) system, a MIMO system can improve the capacity by a factor of the minimum number of transmit and receive antennas for flat fading or narrow-band channels. For wideband transmission, it is natural to combine OFDM with space–time coding (STC) or spatial–temporal processing to deal with frequency selectivity of wireless channels and to obtain diversity and/or capacity gains. Therefore, MIMO-OFDM has widely been used in various wireless systems and standards.

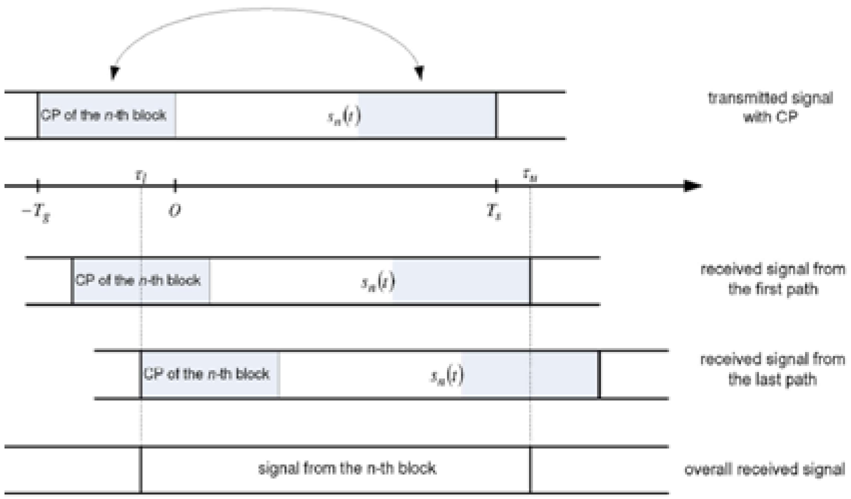

Figure: Function of CP

3. Why OFDM?

In contrast to conventional Frequency Division Multiplexing, the spectral overlapping among subcarriers are allowed in OFDM since orthogonality will ensure the subcarrier separation at the receiver, providing better spectral efficiency and the use of steep band pass filter was eliminated. OFDM transmission system offers possibilities for alleviating many of the problems encountered with single carrier systems. It has the advantage of spreading out a frequency selective fade over many symbols. This effectively randomizes burst errors caused by fading or impulse interference so that instead of several adjacent symbols being completely destroyed; many symbols are only slightly distorted. This allows successful reconstruction of majority of them even without forward error correction. Because of dividing an entire signal bandwidth into many narrow subbands, the frequency response over individual subbands is relatively flat due to subband are smaller than coherence bandwidth of the channel. Thus, equalization is potentially simpler than in a single carrier system and even equalization may be avoided altogether if Differential encoding is implemented.

4. Principle of OFDM

The basic principle of OFDM is to split a high rate data-stream into multiple lower rate data streams that are transmitted simultaneously over a number of sub carriers. OFDM sends multiple high-speed signals concurrently on orthogonal carrier frequencies. This results much more efficient use of bandwidth as well as robust communications during noise and other interferences. With OFDM, it is possible to have overlapping sub channels in the frequency domain, thus increasing the transmission rate. Inorder to avoid a large number of modulators and filters at the transmitter and complementary filters and demodulators at the receiver, it is desirable to be able to use modern digital signal processing techniques, such as fast Fourier transform (FFT). Aftermore than forty years of research and development carried out in different places, OFDM is now being widely implemented inhigh-speed digital communications. In a basic communication system, the data are modulated onto a single carrier frequency. The available bandwidth is then totally occupied by each symbol. This kind of system can lead to inter-symbol-interference (ISI) in case of frequency selective channel. The basic idea of OFDM is to divide the available spectrum into several orthogonalsub channels so that each narrowband sub channels experiences almost flat fading. The major advantages of OFDM are its ability to convert a frequency selective fading channel into several nearly flat fading channels and high spectral efficiency.

5. Basic OFDM System

The OFDM signal generated by the system in Figure 1 & 2 is at baseband ; in order to generate a radio frequency (RF) signal at the desired transmit frequency filtering and mixing is required. OFDM allows for a high spectral efficiency as the carrier power and modulation scheme can be individually controlled for each carrier. However in broadcast systems these are fixed due to the one-way communication. The basic principle of OFDM is to split a high-rate datastream into a number of lower rate streams that are transmitted simultaneously over a number of subcarriers. The block diagram showing a simplified configuration for an OFDM transmitter and receiver is given in Fig.1 & Fig. 2.

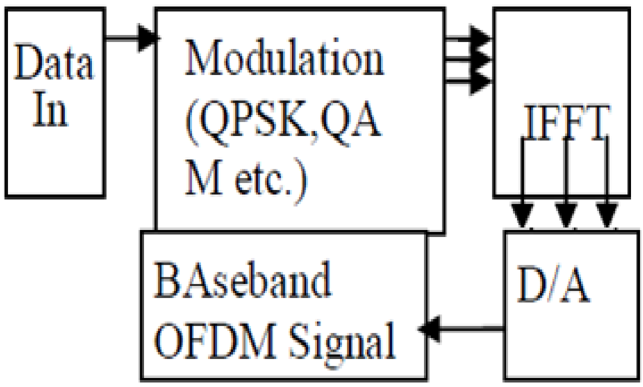

Figure: Transmitter

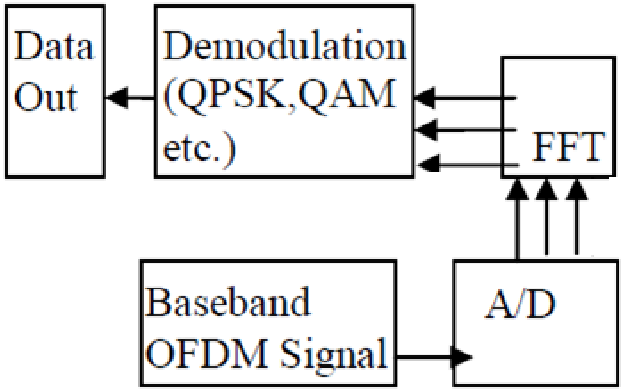

Figure: Receiver

OFDM Parameters and Characteristics

The number of carriers in an OFDM system is not only limited by the available spectral bandwidth, but also by the IFFT size (the relationship is described by: number of carriers < ((ifft – size)/2 - 2), which is determined by the complexity of thesystem [5]. The more complex (also more costly) the OFDM system is, the higher IFFT size it has; thus a higher number of carriers can be used, and higher data transmission rate achieved. The choice of M-PSK modulation varies the data rate and Bit Error Rate (BER). The higher order of PSK leads to larger symbol size, thus less number of symbols needed to be transmitted, and higher data rate is achieved. But this results in a higher BER since the range of 0-360 degrees of phases will be divided into more sub-regions, and the smaller size of sub-regions is required, thereby received phases have higher chances to be decoded incorrectly. OFDM signals have high peak-to-average ratio, therefore it has a relatively high tolerance of peak power clipping due to transmission limitations.

Orthogonality

The main aspect in OFDM is maintaining orthogonality of the carriers. If the integral of the product of two signals is zero over a time period, then these two signals are said to be orthogonal to each other. Two sinusoids with frequencies that are integer multiples of a common frequency can satisfy this criterion. Therefore, orthogonality is defined by:

$$\int_0^T \cos(2\pi n f_o t)\cos(2\pi m f_o t)dt = 0 \quad (n \neq m)$$

Where n and *m* are two unequal integers; *f*o is the fundamental frequency; *T* is the period over which the integration is taken. For OFDM, *T* is one symbol period and *f*o set to 1/*T* for optimal effectiveness [6and 7].

6. Advantages of OFDM

OFDM has several advantages over single carrier modulation systems and these make it a viable for CDMA in future wireless networks. In this section, I will discuss some of these advantages.

a) Multipath delay spread tolerance:
   OFDM is highly immune to multipath delay spread that causes inter-symbol interference in wireless channels. Since the symbol duration is made larger (by converting a high data rate signal into N„low rate signals), the effect of delay spread is reduced by the same factor. Also by introducing the concepts of guard time and cyclic extension, the effects of inter-symbol interference (ISI) and inter-carrier interference (ICI) can be removed completely.

b) Immunity to frequency selective fading channels**:**
   If the channel undergoes frequency selective fading, then complex equalization techniques are required at the receiver for single carrier modulation techniques. But in the case of OFDM the available bandwidth is split among many orthogonal narrowly spaced sub-carriers. Thus the available channel bandwidth is converted into many narrow flat- fading sub-channels. Hence it can be assumed that the subcarriers experience flat fading only, though the channel gain/phase associated with the sub-carriers may vary. In the receiver, each sub-carrier just needs to be weighted according to the channel gain/phase encountered by it. Even if some sub-carriers are completely lost due to fading, proper coding and interleaving at the transmitter can recover the user data.

c) Efficient modulation and demodulation:

Modulation and Demodulation of the sub-carriers is done using IFFT and FFT methods respectively, which are computationally efficient. By performing the modulation and demodulation in the digital domain, the need for highly frequency stable oscillators is avoided. OFDM makes efficient use of the spectrum by allowing overlap.

- High transmission bitrates
- Chance to cancel any cannel if is affected by fading
- Flexibility: each transceiver has access to all subcarriers within a cell layer.
- Easy equalization: OFDM symbols are longer than the maximum delay spread resulting in flat fading channel which can be easily equalized.
- High spectral efficiency,
- Resiliency to RF interference.
- Lower multi-path distortion.

7. Disadvantages of OFDM

- High synchronism accuracy.
- Multipath propagation must be avoided in other orthogonally not be affected
- Large peak-to-mean power ratio due to the superposition of all subcarrier signals, this can become a distortion problem.
- More complex than single-carrier Modulation.
- Requires a more linear power amplifier.
- 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.
- It is more sensitive to carrier frequency offset and drift than single carrier systems are due to leakage of the DFT.
- Peak to average power ratio (PAPR) is high.
- High power transmitter amplifiers need linearization.
- Low noise receiver amplifiers need large dynamic range.
- Capacity and power loss due to guard interval.
- Bandwidth and power loss due to the guard interval can be significant.

8. Limitations of OFDM

There are some obstacles in using OFDM which are as given

- OFDM signal exhibits very high Peak to Average Power

Ratio (PAPR).
- Very sensitive to frequency errors (Tx. & Rx. offset)
- Intercarrier Interference (ICI) between the subcarriers.

9. OFDM Applications

OFDM technique is the most prominent technique of this era .Some of its applications is given below.
- DAB: DAB - OFDM forms the basis for the Digital Audio Broadcasting (DAB) standard in the European market [8]. Digital Audio Broadcasting (DAB) using OFDM has been standardized in Europe [9] and is the next step in evolution beyond FM radio broadcasting providing interference free transmission.
- HDTV
- Wireless LAN Networks
- 5.3.1 HIPERLAN/2
- IEEE 802.11g
- IEEE 802.16 Broadband Wireless Access System.
- Wireless ATM transmission system
- IEEE 802.11a

10. Conclusion

The demand for high data rate wireless communication has been increasing drastically over the last decade. One way to transmit this high data rate information is to employ well-known conventional single carrier systems. Since the transmission bandwidth is much larger than the coherence bandwidth of the channel; highly complex equalizers are needed at the receiver for accurately recovering the transmitted information. Multi-carrier techniques can solve this problem significantly. In this paper we have discussed about the basic idea behind the ofdm, the most emerging technology of this era. Here we take a review on its concept, its properties in terms of its advantages and disadvantages, its limitations and also its applications in different fields. This paper has explored the role of OFDM in the wireless communication and its advantages over single carrier transmission. There are also some limitations of this technique which can be removed with the help of suitable techniques.

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