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Transmission Technology OFDM: Concept, Scope & its Applications

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Abstract: This OFDM concept lies on the two-dimensional distribution of modulated symbols. In time, the symbol spacing allows for guard intervals that protects against the delay spread. In frequency, the symbols are overlapping one another such that each symbol's peak amplitude occurs at a zero crossing for all other symbols.[11] Hence, the system characteristically has high spectrum efficiency because the OFDM symbols only require guard intervals in the time domain. This new standard is the first one to use OFDM in packet-based communications. In wireless communication, concept of parallel transmission of symbols is used to achieve high throughput and better transmission quality. Orthogonal Frequency Division Multiplexing (OFDM) is one of the techniques for parallel transmission OFDM converts frequency selective fading channel into N flat fading channels, where N is the number of sub-carriers. Orthogonality is maintained by keeping the carrier spacing multiple of 1/Ts by using Fourier transform methods, where Ts is the symbol duration. In this paper we will discuss the basics of OFDM techniques, role of OFDM in this era, its benefits and losses and also some of its application.

Keywords: Orthogonal Frequency Division Multiplexing (OFDM) ,BER , ISI, PAPR , DVB, DAB.

I. Introduction

Multi-carrier, or orthogonal frequency-division multiplexing (OFDM), systems have gained in interest during the last years. It is used in the European digital broadcast radio system, and its use in wireless applications such as digital broadcast television and mobile communication systems is currently being investigated. By the name of discrete multi-tone (DMT) modulation, OFDM is also being examined for broadband digital communication on existing copper networks. The OFDM technique has been proposed for high bit-rate digital subscriber lines (HDSL) and for asymmetric digital subscriber lines (ADSL).OFDM has also been standardized as the physical layer for the wireless networking standar, HIPERLAN2‟ in Europe and as the IEEE 802.11a, g standard in the US, promising raw data rates of between 6 and 54Mbps .Orthogonal Frequency Division Multiplexing (OFDM) is a digital transmission Method developed to meet the increasing demand for higher data rates in communications which can be used in both wired and wireless environments.[2]

1. Definition of OFDM:

The COFDM, commonly referred to as OFDM, is a multicarrier scheme that takes the total signal and subdivides it into bit stream each with a lower bit rate. This allows for symbols to have a longer duration than the expected delay spread for the transmission channel. In addition Interleaving and coding procedures are using to mitigate the effect of frequency selective fading. This combined process produces a signal that is less sensitive to multipath propagation.[3] 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.[4] 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. [5]

2. Need of OFDM :

Frequency Division Multiplexing (FDM) was used for a long time to carry more than one signal over a telephone line.

FDM divides the channel bandwidth into sub channels and transmits multiple relatively low rate signals by carrying each signal on a separate carrier frequency. To ensure that the signal of one sub channel did not overlap with the signal from an adjacent one, some guard-band was necessary which an obvious loss of spectrum is and hence bandwidth In order to overcome the problem of multipath fading environment and bandwidth efficiency OFDM technology was proposed. OFDM stands for Orthogonal Frequency Division. 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.

3. Principle of OFDM

OFDM is a combination of modulation and multiplexing. OFDM is based on a parallel data transmission scheme that reduces the effect of multipath fading and makes the use of complex equalizers unnecessary. The Eureka 147 DAB signal is transmitted in a frame structure. Each frame is divided into a integral number of modulated carriers dependent on transmission mode. These carriers are modulated using Differential Quadrature Phase Shift Keying (D-QPSK). "The modulation carriers are derived from the orthogonal base of the discrete Fourier Transform by using a vector of complex coefficient defining the I and Q components of each element of the base. [2] This procedure is done by the block partitioner and QPSK symbol mapper. The differential modulation is applied after the frequency interleaving. It is applied to facilitate bit recovery at the receiver. Each OFDM carrier contains two bits of Gray-coded QPSK data.[1] Therefore, determining the parameters for the convolutional coding, modulation technique, frequency interleaving, guard interval and bandwidth consequently defines a COFDM signaling procedure. The features of OFDM system are as following:

- Some processing is done on the source data, such as coding for correcting errors, interleaving and mapping of bits onto symbols. An example of mapping used is QAM.
- The symbols are modulated onto orthogonal sub-carriers. This is done by using IFFT.
- Orthogonality is maintained during channel transmission. This can be achieved by adding a cyclic prefix to the OFDM frame to be sent. The cyclic prefix consists of the L last samples of the frame, which are copied and placed in the beginning of the frame. It must be longer than the channel impulse response.
- Synchronization: cyclic prefix can be used to detect the start of each frame. This is done by using the fact that the L first and last samples are the same and therefore correlated.
- Demodulation of the received signal by using FFT.
- Channel equalization: the channel can be estimated either by using a training sequence or sending known so-called pilot symbols at predefined sub-carriers.
- Decoding and de-interleaving

4. Basic OFDM system:

The OFDM signal generated by the system in Figure 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 data stream into a number of lower rate streams that are transmitted simultaneously over a number of subcarriers. OFDM signals also allow the possibility of single-frequency network (SFN) operation. This is due to OFDM multi-path immunity. SFN operation is possible when exactly the same signal, in time and frequency, is radiated from multiple transmitters. In this case at any reception point in the coverage overlap between transmitters, the weakest received signals will act as post- or pre-echoes to the strongest signal. However, if the transmitters are far apart the time delay between the received signals will be large and the system will need a large guard interval.

While the use of the guard interval (or cyclic prefix) removes the effects of inter-symbol interference under multi-path conditions, it cannot remove the effects of frequency selective fading. Under these conditions the amplitude and phase of each subcarrier is distorted. If the OFDM receiver is to coherently demodulate the signal it must equalize the phase and amplitude of each carrier; this can be done after the FFT using a simple equalizer. This process is known as channel estimation and equalization. The block diagram of a basic OFDM system is shown in the following figure:

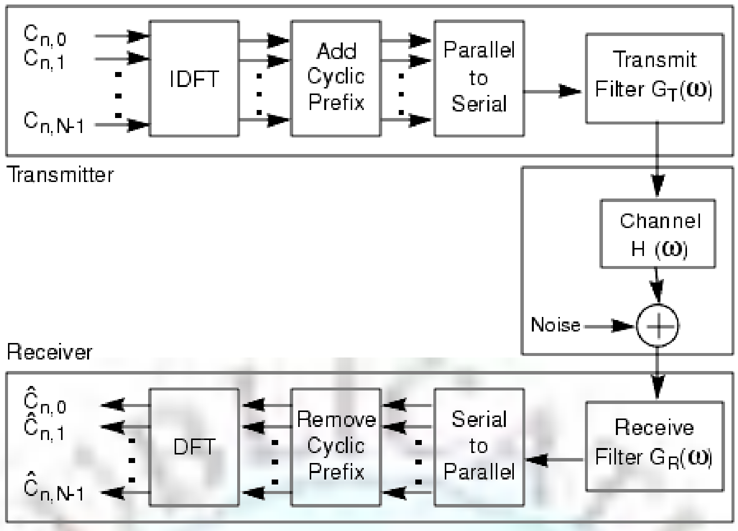

Figure: Basic OFDM Communication System

5. Parameters and Characteristics of OFDM System:

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 the system [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.

6. Concept of Orthogonality:

Basically, OFDM is a specialized FDM, with all the carrier signals are orthogonal to each other. In OFDM, the sub-carrier frequencies are chosen so that the sub-carriers are orthogonal to each other, meaning that cross-talk between the sub-channels is eliminated and inter-carrier guard bands are not required. This greatly simplifies the design of both the transmitter and the receiver; unlike conventional FDM, a separate filter for each sub-channel is not required.

The orthogonality requires that the sub-carrier spacing is $\Delta f = \frac{k}{T_U}$ Hertz, where T_U seconds is the useful symbol duration (the receiver side window size), and k is a positive integer, typically equal to 1. Therefore, with N sub-carriers, the total passband bandwidth will be $B \approx N \cdot \Delta f$ (Hz).

II ADVANTAGES OF OFDM TECHNOLOGY

1. Features of OFDM Technology:

OFDM has been used in many high data rate wireless systems because of the many advantages it provides:

- **Immunity to selective fading:** One of the main advantages of OFDM is that is more resistant to frequency selective fading than single carrier systems because it divides the overall channel into multiple narrowband signals that are affected individually as flat fading sub-channels.

- **Resilience to interference:** Interference appearing on a channel may be bandwidth limited and in this way will not affect all the sub-channels. This means that not all the data is lost.
- **Spectrum efficiency:** Using close-spaced overlapping sub-carriers, a significant OFDM advantage is that it makes efficient use of the available spectrum.
- **Resilient to ISI:** Another advantage of OFDM is that it is very resilient to inter-symbol and inter-frame interference. This results from the low data rate on each of the sub-channels.
- **Resilient to narrow-band effects:** Using adequate channel coding and interleaving it is possible to recover symbols lost due to the frequency selectivity of the channel and narrow band interference. Not all the data is lost.
- **Simpler channel equalisation:** One of the issues with CDMA systems was the complexity of the channel equalisation which had to be applied across the whole channel. An advantage of OFDM is that using multiple sub-channels, the channel equalization becomes much simpler.

III DISADVANTAGES OF OFDM TECHNOLOGY:

As OFDM has been widely used; but still exhibits some disadvantages which are necessary to address before its use .

- **High peak to average power ratio:** An OFDM signal has a noise like amplitude variation and has a relatively high large dynamic range, or peak to average power ratio. This impacts the RF amplifier efficiency as the amplifiers need to be linear and accommodate the large amplitude variations and these factors mean the amplifier cannot operate with a high efficiency level.
- **Sensitive to carrier offset and drift:** Another disadvantage of OFDM is that is sensitive to carrier frequency offset and drift. Single carrier systems are less sensitive.
- Sensitive to Doppler shift.
- Sensitive to frequency synchronization problems.
- High peak-to-average-power ratio (PAPR), requiring linear transmitter circuitry, which suffers from poor power efficiency.
- Loss of efficiency caused by cyclic prefix/guard interval

IV. LIMITATIONS OF OFDM:

There are some obstacles in using OFDM in transmission system in contrast to its advantages.

- A major obstacle is that the OFDM signal exhibits a very high Peak to Average Power Ratio (PAPR).
- RF power amplifiers should be operated in a very large linear region. Otherwise, the signal peaks get into non-linear region of the power amplifier causing signal distortion. This signal distortion introduces intermodulation among the subcarriers and out of band radiation. Thus, the power amplifiers should be operated with large power back-offs. On the other hand, this leads to very inefficient amplification and expensive transmitters. Thus, it is highly desirable to reduce the PAPR.
- The other limitation of OFDM in many applications is that it is very sensitive to frequency errors caused by frequency differences between the local oscillators in the transmitter and the receiver.
- Carrier frequency offset causes a number of impairments including attenuation and rotation of each of the subcarriers and intercarrier interference (ICI) between subcarriers. In the mobile radio environment, the 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 subcarriers and thus intercarrier interference (ICI) occurs. A Number of methods have been developed to reduce this sensitivity to frequency offset.

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V. OFDM APPLICATIONS:

OFDM is dominantly used in this digital time technologies .Various applications of the technology are ass following:

- Digital Audio Broadcasting (DAB);
- Digital television DVB-T/T2 (terrestrial), DVB-H (handheld), DMB-T/H, DVB-C2 (cable);
- Wireless LAN IEEE 802.11a, IEEE 802.11g, IEEE 802.11n, IEEE 802.11ac, and IEEE 802.11ad;
- WiMAX;
- ADSL (G.dmt/ITU G.992.1);

- The LTE and LTE Advanced 4G mobile phone standards.
- Modern narrow and broadband power line communications

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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