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BASICS OF OFDM AND CHARACTERISTICS OF MOBILE RADIO CHANNEL

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ABSTRACT

The propagation characteristics of mobile radio channels and basics of OFDM are presented in this paper. The link between the transmitter and the receiver that carries information bearing signals in the form of electromagnetic waves is the radio channel. The radio channel is commonly characterized by scatterers (local to the receiver) and reflectors (local to the transmitter). Small scale fading, or simply fading, is used to describe the rapid fluctuations of the amplitude of a radio signal over a short period of time or travel distance, so that the large scale path loss effect may be ignored. Characteristics of radio channel and a basic of OFDM such Orthogonality principle, history of OFDM etc is discussed below.

Keywords: OFDM, Multiplexing, Radio channel, Transmitter, Receiver

1.0 INTRODUCTION

In modulations, information is mapped on to changes in frequency, phase or amplitude (or a combination of them) of a carrier signal. Multiplexing deals with allocation/accommodation of users in a given bandwidth.

OFDM is a combination of modulation and multiplexing. In this technique, the given resource (bandwidth) is shared among individual modulated data sources. Normal modulation techniques (like AM, PM, FM, BPSK, QPSK, etc.) are single carrier modulation techniques, in which the incoming information is modulated over a single carrier. OFDM is a multicarrier modulation technique, which employs several carriers, within the allocated bandwidth, to convey the information from source to destination. Each carrier may employ one of the several available digital modulation techniques (BPSK, QPSK, QAM etc.).

Chang [1] proposed the first OFDM scheme in 1996. Now, OFDM acts as a high performance local area network transmission technique orthogonal frequency division multiplexing (OFDM) is based on multicarrier communication techniques. The idea of multicarrier communications is to divide the total signal bandwidth into number of subcarriers and information is transmitted on each of the subcarriers. Unlike the conventional multicarrier communication scheme in which spectrum of each subcarrier is non-overlapping and band-pass filtering is used to extract the frequency of interest, in OFDM the frequency spacing between subcarriers is selected such that the subcarriers are mathematically orthogonal to each others.

The spectra of subcarriers overlap each other but individual subcarrier can be extracted by baseband processing. This overlapping property makes OFDM more spectral efficient than the conventional multicarrier communication scheme.

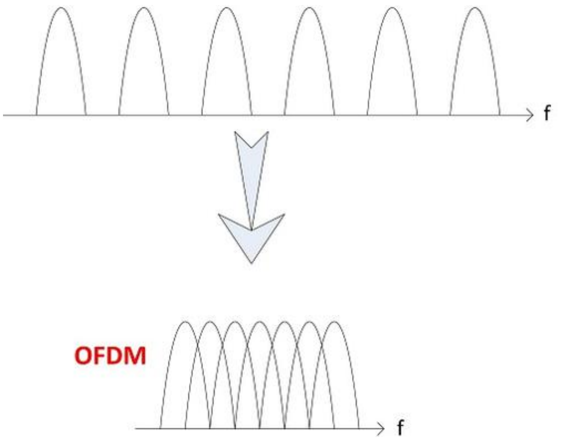

Fig.1orthogonal frequency division multiplexing.

OFDM is very effective for communication over channels with frequency selective fading (different frequency components of the signal experience different fading). It is very difficult to handle frequency selective fading in the receiver, in which case, the design of the receiver is hugely complex. Instead of trying to mitigate frequency selective fading as a whole (which occurs when a huge bandwidth is allocated for the data transmission over a frequency selective fading channel), OFDM mitigates the problem by converting the entire frequency selective fading channel into small flat fading channels (as seen by the individual subcarriers). Flat fading is easier to combat (compared to frequency selective fading) by employing simple error correction and equalization schemes.

Thus, Orthogonal Frequency Division Multiplexing (OFDM) is a digital multi-carrier modulation scheme that extends the concept of single subcarrier modulation by using multiple subcarriers within the same single channel. Rather than transmit a high-rate stream of data with a single subcarrier, OFDM makes use of a large number of closely spaced orthogonal subcarriers that are transmitted in parallel. Each subcarrier is modulated with a conventional digital modulation scheme (such as QPSK, 16QAM, etc.) at low symbol rate. However, the combination of many subcarriers enables data rates similar to conventional single-carrier modulation schemes within equivalent bandwidths. OFDM is based on the well-known technique of Frequency Division Multiplexing (FDM). In FDM different streams of information are mapped onto separate parallel frequency channels. Each FDM channel is separated from the others by a frequency guard band to reduce interference between adjacent channels.

The OFDM scheme differs from traditional FDM in the following ways:

- Multiple carriers (called subcarriers) carry the information stream,
- The subcarriers are orthogonal to each other, and
- A guard interval is added to each symbol to minimize the channel delay spread and inter symbol interference.

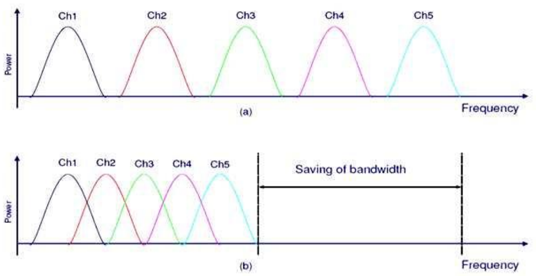

Fig.2 difference between FDM and OFDM

As shown in fig.2, in FDM, the transmission signals need to have a large frequency guard band between channels to prevent interference. The overall spectral efficiency becomes low. In the OFDM, the orthogonal packing of the subcarriers greatly reduces this guard- band, improving spectral efficiency. Orthogonal frequency division multiplexing (OFDM) is a parallel transmission scheme, where a high-rate serial data stream is split up into a set of low-rate sub streams, each of which is modulated on a separate sub-carrier (SC) (frequency division multiplexing). Thereby, bandwidth of the sub-carriers becomes small compared with the coherence bandwidth of the channel, i.e., individual sub-carrier experience flat fading, which allow for simple equalization. This implies that the symbol period of the sub-streams is made long compared to the delay spread of time-dispersive radio channel.

In OFDM system, the frequencies used are orthogonal. Thus neighboring frequencies with overlapping spectrum can be used. This leads to efficient usage of bandwidth. Therefore the OFDM provides higher data rate for the same BW introduced between the different carriers and in the frequency domain, which result in a lowering of spectrum efficiency.

Completely digital implementations could be built around special-purpose hardware performing the fast Fourier transform (FFT), which is an efficient implementation of the DFT is used to eliminate the banks of subcarrier oscillators and coherent demodulators required by the frequency-division multiplex.

Another advantage of OFDM is that, because the symbol period has been increased, channel delay spread is significantly a shorter fraction of a symbol period than in the serial system, potentially rendering the systems less sensitive to ISI than the conventional serial system.

1.1 Basic Principle of OFDM

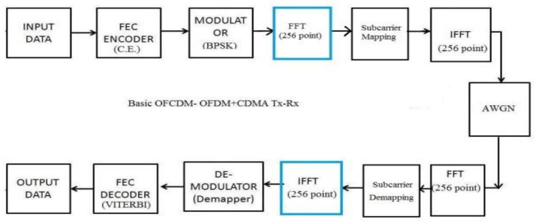

Fig.3 Block diagram of OFDM system

As shown in fig.3, at the transmitter side, the binary information is first grouped and mapped into complex-valued symbols according to the modulation by different mapping scheme, such as BPSK, QPSK, 16QAM, and 64QAM. Then there is a serial to parallel conversion to prepare different data groups for different OFDM subcarrier. The mapped signals are modulated into N orthogonal subcarrier by the IFT. A cyclic prefix (CP) is then added to the multiplexed IFFT output. Finally, the obtained signal is converted to a time continuous analog signal before it is transmitted through the channel. At the receiver side, an inverse operation is carried out and the information data is detected. OFDM is a modulation technique where multiple low data rate carriers are combined by a transmitter to form a composite high data rate transmission. Digital signal processing makes OFDM possible. To implement the multiple carrier schemes using a bank of parallel modulators would not be very efficient in analog hardware. However, in the digital domain, multi-carrier modulation can be done efficiently with currently available DSP hardware and software. Not only can it be done, but it can also be made very flexible and programmable. This allows OFDM to make maximum use of available bandwidth and to be able to adapt to changing system requirements.

Each carrier in an OFDM system is a sinusoid with a frequency that is an integer multiple of a base or fundamental sinusoid frequency. Therefore, each carrier is like a Fourier series component of the composite signal. In fact, it will be shown later that an OFDM signal is created in the frequency domain, and then transformed into the time domain via the Discrete Fourier Transform (DFT).Two periodic signals are orthogonal when the integral of their product, over one period, is equal to zero. OFDM is a modulation technique where multiple low data rate carriers are combined by a transmitter to form a composite high data rate transmission. Digital signal processing makes OFDM possible. To implement the multiple carrier scheme using a bank of parallel modulators would not be very efficient in analog hardware.

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1.3 Brief History of OFDM

The concept of using parallel data transmission by means of frequency division multiplexing (FDM) was published in mid 60s by Fazel & Fettwis [2]. Some early development can be traced back in the 50s. A U.S. patent was filled and issued in January, 1970. The idea was to use parallel data streams and FDM with overlapping sub channels to avoid the use of high speed equalization and to combat impulsive noise, and multipath distortion as well as to fully use the available bandwidth. The initial applications were in the military communications. In the telecommunications field, the terms of discrete multi-tone (DMT), multichannel modulation and multicarrier modulation (MCM) are widely used and sometimes they are interchangeable with OFDM. In OFDM, each carrier is orthogonal to all other carriers. However, this condition is not always maintained in MCM. OFDM is an optimal version of multicarrier transmission schemes.

For a large number of sub channels, the arrays of sinusoidal generators and coherent demodulators required in a parallel system become unreasonably expensive and complex. The receiver needs precise phasing of the demodulating carriers and sampling times in order to keep crosstalk between sub channels acceptable. Weinstein and Ebert [3] applied the discrete Fourier transform (DFT) to parallel data transmission system as part of the modulation and demodulation process. In addition to eliminating the banks of subcarrier oscillators and coherent demodulators required by FDM, a completely digital implementation could be built around special-purpose hardware performing the fast Fourier transform (FFT). Recent advances in VLSI technology enable making of high-speed chips that can perform large size FFT at affordable price. In the 1980s, OFDM has been studied for high-speed modems, digital mobile communications [4] and high-density recording. One of the systems used a pilot tone [5] for stabilizing carrier and clock frequency control and trellis coding was implemented.

1.4 Orthogonality in OFDM

Signals are orthogonal if they are mutually independent of each other. Orthogonality is a property that allows multiple information signals to be transmitted perfectly over a common channel and detected, without interference.

Loss of Orthogonality results in blurring between these information signals and degradation in communications. Many common multiplexing schemes are inherently orthogonal. Time division multiplexing (TDM) allows transmission of multiple information signals over a signal channel by assigning unique time slots to each spate information signal.

During each time slot only the signal from a single source is transmitted preventing any interference between multiple information sources. Because of this TDM is orthogonal in nature. In the frequency domain most FDM systems are orthogonal as each of the separate transmission signals are well spaced out in frequency preventing interference. Although these methods are orthogonal the term OFDM has been reserved for a special form of FDM. The subcarriers in an OFDM signal are spaced as close as is theoretically possible without maintaining Orthogonality between them.

OFDM achieves Orthogonality in the frequency domain by allocating each of the separate information signals onto different sub carriers. OFDM signals are made up of sum of sinusoids, with each corresponding to a subcarrier. The baseband frequency of each subcarrier is chosen to be an integer multiple of the inverse of the symbol time, resulting in all subcarriers having an integer number of cycles per symbol.

2.0 Propagation Characteristics of Mobile Radio Channels

Large-scale variations can be observed in a signal over large distances. Received power or its reciprocal, path loss, is generally the most important parameter predicted by large scale propagation models. Large-scale variations in a signal are mainly due to Path loss and shadowing. Path loss is caused by dissipation of the power radiated by the transmitter as well as by effects of the propagation channel. Path-loss models generally assume that path loss is the same at a given transmit–receive distance (assuming that the path-loss model does not include shadowing effects). Shadowing is caused by obstacles between the transmitter and receiver that attenuate signal power through absorption, reflection, scattering, and diffraction.

When the attenuation is strong, the signal is blocked. Received power variation due to path loss occurs over long distances, whereas variation due to shadowing occurs over distances that are proportional to the length of the obstructing object. In urban or dense urban areas, there may not be any direct line-of-sight path between a mobile and a base station antenna. Instead, the signal may arrive at a mobile station over a number of different paths after being reflected from tall buildings, towers, and so on. Because the signal received over each path has a random amplitude and phase, the instantaneous value of the composite signal is found to vary randomly about a local mean. Since these variations are rapid and occur over short distances these variations are termed as short term variations. Understanding these effects on signal is important because the performance of a radio system is dependent on the radio channel characteristics.

2.1 Attenuation

Attenuation is a telecommunication term that refers to a reduction in signal strength occurring while transmitting analog or digital signal over long distances. While transmission from one point to another, there is a drop of signal which is termed as attenuation. Attenuation can be caused by any object that obstructs the line of sight of the signal from transmitter to receiver. Reasons for attenuation are transmission path length, obstructions in the signal path and multipath effects.

Whenever there is an obstruction between the transmitter and receiver, shadowing of signal may occur. The most important environmental attenuation factors are buildings and hills. In heavily built up areas, the shadowing is most severe, due to shadowing from the buildings. However, hills can cause a large problem due to the large shadow they produce. Radio signal diffract off the boundaries of obstruction, thus preventing total shadowing of the signals behind hills and building. However, the amount of diffraction depends on the radio frequency used, with high frequencies scatter more than low frequency signals. Thus high frequency signals, especially, Ultra High Frequencies (UHF) and microwave signals require line of sight for adequate signal strength, because these scatter too much. To overcome the problem of shadowing, the transmitters are usually elevated as high as possible to minimize the number of obstructions.

Attenuation may relate to both the hard wired connections and the wireless transmissions. There are many instances of attenuation in telecommunications and digital network circuitry. Inherent attenuation can be caused by a number of signaling issues including the following which are given below:

- Transmission medium - All electrical signals transmitted down electrical conductors cause an electromagnetic field around the transmission. This field causes energy loss down the cable and gets worse depending upon the frequency and length of the cable run. Losses due to
- Crosstalk from adjacent cabling causes attenuation in copper or other conductive metal cabling.
- Conductors and connectors - Attenuation can occur as a signal passes across different conductive mediums and mated connector surfaces.

Different types of attenuation include:

- Deliberate attenuation can occur for example where a volume control is used to lower the sound level on consumer electronics.
- Automatic attenuation is a common feature of televisions and other audio equipment to prevent sound distortion by automatic level sensing that triggers attenuation circuits.
- Environmental attenuation relates to signal power loss due to the transmission medium, whether that be wireless, copper wired or fiber optic connected.

2.2 Multipath effect Rayleigh Fading

The RF signal from the transmitter may be reflected from objects such as hills, buildings, or vehicles, in a radio link. It results in multiple transmission paths at the receiver. The constructive or destructive interference at the receiver can be caused by the relative phase of multiple reflected signals. This is known as fast fading and experienced over very short distances (typically at a half wavelength distances). These variations can vary from 10-30dB over a very short distance. The statistical time varying nature of the received signal power is described by Rayleigh distribution. It describes the probability of the signal level being received due to fading.

2.3 Frequency Selective Fading

The channel spectral response is not flat in any radio transmission. Due to reflections causing cancellation of certain frequencies at the receiver it has dips or fades in the response. Reflections off near-by objects (e.g. ground, buildings, trees, etc) may cause the multipath signals of similar signal power as the direct signal. This leads in deep nulls in the received signal power due to destructive interference. For the narrow bandwidth transmissions if the null in the frequency response occurs at the transmission frequency then entire signal can be lost. This can be partly overcome in two ways. By transmitting a wide bandwidth signal or spread spectrum as in the case of the CDMA, any dips in the spectrum only result in a small loss of signal power, rather than a complete loss. Another method is to split the transmission up into many carriers carrying low rate data, as done in OFDM.

2.4 Delay Spread

In telecommunications, the delay spread is a measure of the multipath richness of a communications channel. In general, it can be interpreted as the difference between the time of arrival of the earliest significant multipath component (typically the line-of-sight component) and the time of arrival of the latest multipath components. The delay spread is mostly used in the characterization of wireless channels, but it also applies to any other multipath channel (e.g. multipath in optical fibers.

Thus the delay spread is the measure of how the signal power is spread over the time between the arrivals of the first and last multipath signal seen by the receiver. The delay spread can lead to inter-symbol interference in the digital system. It happens because of the delayed multipath signal overlapping symbols that follows. This results in significant errors in high bit rate systems, especially when using time division multiplexing (TDMA). As the transmitted bit rate increases, the amount inter- symbol interference also increases. The effect starts to become very significant when the delay spread is greater than 50% of the bit time.

The importance of delay spread is how it affects the Inter Symbol Interference (ISI). If the symbol duration is big enough compared to the delay spread (typically 10 times as big would be good enough), one can expect an equivalent ISI-free channel. The correspondence with the frequency domain is the notion of coherence bandwidth (CB), which is the bandwidth over which the channel can be assumed flat. Coherence bandwidth is related to the inverse of the delay spread. The shorter the delay spread, the larger is the coherence bandwidth.

3.0 Conclusion

OFDM is a multicarrier modulation technique with densely spaced sub carriers which has achieved popularity among the wireless communication in last few years. It has found large number of applications in the wireless communication system. OFDM is an effective technique for mitigating intersymbol interference. Also the propagation characteristics of mobile radio channels are discussed.

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