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A Comprehensive Study of Orthogonal Frequency Division Multiplexing (OFDM)

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ABSTRACT

This research presents a comprehensive study of Orthogonal Frequency Division Multiplexing. Orthogonal Frequency Division Multiplexing (OFDM) is a multi-carrier transmission technique which is much popular in new wireless networks of IEEE standard, digital television, audio broadcasting and 5G mobile communications. OFDM takes the advantage of multipath-path propagation and reduces the fading effect. The idea of OFDM is to split the total transmission bandwidth into a number of orthogonal sub-carriers which reduces the Inter-Symbol Interference, Power Consumption and increases the capacity and efficiency of the system. The main drawbacks of OFDM are its high peak to average power ratio and its sensitivity to phase noise and frequency offset. This paper gives an overview of OFDM basics, development, architecture, implementations, merits and demerits.

Keywords: IEEE, ISI OFDM. Standard Technology

INTRODUCTION

With the increase in communication technology, the nature of future wireless applications demands high data rates. Naturally, dealing with unpredictable wireless channel at high data rate communications is not an easy task. The idea of multi-carrier transmission where all the subcarriers are orthogonal to each other, OFDM uses a high data rate transmission capability at a reasonable complexity and precision.

At high data rates, the channel distortion to the data is very significant, and is somehow impossible to recover the transmitted data with a simple receiver. A very complex structure is needed which makes use of computationally expensive equalization and channel estimation algorithms to correctly estimate the channel, so that the estimations can be used with receiver data to recover the originally transmitted data. OFDM can drastically simplify the equalization problem by turning the frequency-selective channel into a flat channel. A simple one-tap equalize is needed to estimate the channel and recover the data.

Further telecommunication system must be spectrally efficient to support a number of high data rate users. OFDM uses the available spectrum very efficiently which is very useful to multimedia communications. For all, OFDM has already been accepted by the future generation system.

An OFDM-based system has a long history of existence during the Second World War, which has been in use by the US military in several high-frequency military systems such as KINEPLEX, ANDEFT, and KATHRYN which uses the AN/GSC-10 variables rate data modem built for high frequency radio. A 34 parallel low-rate channels using PSK type of modulation were generated by a frequency-multiplexed set of sub-channels. Orthogonal frequency assignment was used with frequency spacing of 82Hz to provide guard time between successive signaling elements.

Robert W. Chang1 (December 1996). Outlined a theoretical way to transmit simultaneous data stream through linear band-limited channel without Inter-Symbol Interference (ISI) and Inter-Carrier Interference (ICI). Subsequently, he obtained the US permit on OFDM in 1970. Within the time frame, Saltzberg2 performed an analysis of the performance of the OFDM system. Until this time a large number of subcarrier oscillators to perform modulations and demodulations were needed.

In 1971, a major breakthrough in the history of OFDM came up when Weinstein and Ebert3 used the Discrete Fourier Transform (DFT) to perform baseband modulation and demodulation focusing on efficient processing. This

breakthrough eliminated the need of subcarrier oscillators, paving way for easier, more useful and efficient implementation of the system.
Another milestone for OFDM was when Peled and Ruiz4 introduced the cyclic prefix (CP) in 1980. This cyclic prefix solved the problem of maintaining orthogonal characteristics of the transmitted signals at severe transmission conditions. With the introduction of CP it causes loss of signal energy proportional to the length of CP compared to symbol length, but on contrary it facilitates a zero ICI advantage which pays off.

IMPLEMENTATION OF OFDM SYSTEM

The OFDM system is implemented by combining different blocks. An OFDM as a multicarrier technique uses an overlap signals to divide the frequency selective channel into a number of narrow band flat fading channels. The FFT encodes the block of symbol; instead of sending the data sequentially on a single carrier at a high symbol rate. The sub-channels are made orthogonal by spacing the subcarrier at the increase of symbol time. The multipath fading can be nullified by making the symbol period of sub-channel longer in their length as compare to multipath delay spread. The signals having high noise and interference is deactivated, thus decreasing the effect of fading and interference. OFDM modulation technique is generated through the use of complex signal processing approaches such as Fast Fourier Transform (FFTs) and Inverse Fast Fourier Transform (IFFTs) in the transmitter and receiver sections of the radio. One of the benefits of OFDM is its strength in fighting the adverse effects of multi path propagation with respect to inter-symbol interference in a channel. OFDM is also spectrally efficient because the channels are overlapped and contiguous. Block diagram of OFDM is shown in figure 2.1.
In the system the input data are FEC coded with technique such as convolution code. The diversity gain is obtained by interleaving the coded bit stream. The constellation points are mapped after a group of sub-channel bits are grouped together. Now, the data is serial which is represented by complex numbers. At this point mapping Technique such as Pilot mapped is used. A serial to parallel converter is used and IFFT is applied on the complex data.

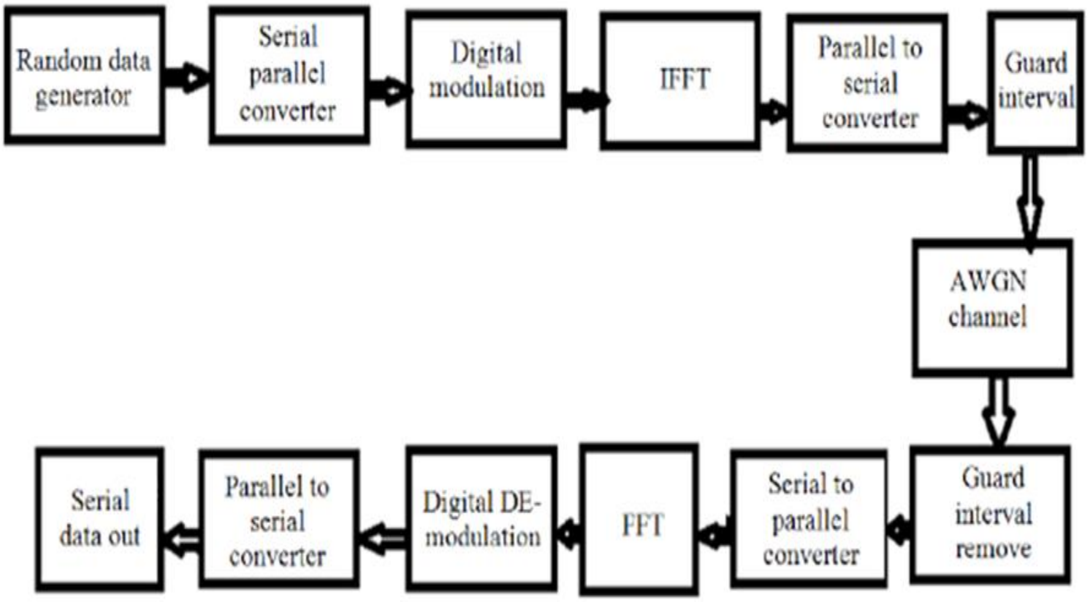

Figure 1: Block Diagram of OFDM

For the need of transmission sub-carriers, the transformed data are grouped. In every block of data Cyclic Prefix is inserted and the data is multiplexed in serial fashion. Now data are modulated and the digital data is converted into analog by using a DAC and RF modulation to perform. The transmitted OFDM signal goes through all anomalies and hostility of wireless channels. The receiver performs the down conversion of the signal and converts the signal into digital domain by using DAC. The synchronization is needed during the down conversion of the signal. The OFDM signal is demodulated by using a FFT. The channel estimation is performed and complex receiver data are de-mapped according to the constellation diagram. At last the original signal is received by using the FEC Coding and Decoding. (Syrjala5 and Valkama6, 2010). The function of random generator is to generate random uniform data in the range of (0,M -1), where M is the Mary number. The Mary can be either a scalar or a vector. If we define it as a scalar, then all output random variables are independent and identically distributed. If we consider the input signals as vector then the size of initial seed must be equal to size of vector. If the initial seed is constant then the resulting noise is repeatable. A serial to parallel conversion of data is done in accordance to the modulating technique used. The data is transmitted by assigning a unique word to each carrier. The symbols are allocated to each of the subcarriers which are phase mapped and are represented by a complex in phase or quadrature in phase (Namisha7 and mohit8, 2013). The main function of serial to parallel converter is to convert the serial data to parallel data. The parallel data is transmitted by assigning a unique word to each of the subcarriers. Once the symbol has been allocated to each of the subcarriers then they are phased mapped accordance with modulating scheme. It is one of the advantages of OFDM that different modulation scheme can be applied to each sub-channel depends on the channel condition, data rate, robustness, throughput and channel bandwidth. There could be different modulation scheme applied specified by complex number that is QPSK, 16 QAM. Modulation to OFDM sub-channel can be made adaptive after getting information and estimation of channel at transmitter. The orthogonality of sub-carrier is maintained and the frequency domain signals are converted into a time domain and the generation of real output signal is achieved by arranging the conjugate of sub-carrier. In this stage the techniques like IFFT Mapping, Zero Mapping and selector bank are included to overcome the problem of length of sub-carriers. The last part of OFDM signal is copied and inserted at the beginning of the signal. The length of the signal should be equal or greater than the time dispersion of the signals, this way increases the length of the signal from Tuto Tu + TCP. Again at the receiver the guard band is removed (Nicole et al,2014). One of the proposals suggest using quiet bursts for spectrum sensing. During the quite burst, some OFDM symbols in the sub-frames can be replaced by the sensing period. Another suggestion from the same source utilizes the proposed downlink-uplink switching time for spectrum sensing. This sensing interval is however asynchronous and the length of the sensing

ARCHITECTURE OF OFDM

For practical OFDM modulation for standard IEEE 802.20 is used by both the forward and reverse links. IEEE 802.20 also referred to as Mobile-Fi, optimized for IP and roaming in high-speed mobile environments. This standard is ready to fully mobilize IP, and major new data markets beyond the circuits-centric 2.5G and 3G cellular standards. Its main operation is to develop the specification for an efficient packet-based air interference optimized for the transport of IP-based services. For IEEE 802.20, transmission on the forward link is divided into super frames, where each super frame consists of a preamble followed by a sequence of 25 Forward Link Physical Layer (FLPHYL) frames. Transmission on the reverse link is also divided into units of super frames, with each super frame consisting of a sequence of 25reverse link PHY frames. The IEEE 802.20 support cell sizes of macro, micro and pico to operate in a traditional cellular environment to increase the availability of coverage area, increase throughput available to the users, and enable a higher spectral efficiency, advanced technology such as multi antenna at the station should be employed.
Given the mathematical description for the OFDM signal is given as follows:

For low-pass equivalent OFDM signal is expressed as

$$X(t) = X(t) = \sum_{k=0}^{N-1} X_k e^{j2\pi kt/T} \quad ,0 \le t < T \tag{1}$$

This is also Discrete Fourier Transform (DFT), where Xk are data symbols which is sequence of complex numbers representing BPSK, QPSK or QAM baseband symbol, N is the number of subcarriers and T is OFDM symbol line. The subcarrier spacing $\frac{1}{T}$makes them orthogonal over each symbol period.
Sequence of OFDM symbol is given as follows:

$$s(t) = S(t) = \sum_{k=-\infty}^{+\infty} X\ (t - kT) \tag{2}$$

In other to avoid ISI from the expression above a guard interval of length Tg is inserted before OFDM block. During this interval, a cyclic prefix is transmitted. The signal with cyclic prefix is thus given as:

$$X(t) = X(t) = \sum_{k=0}^{N-1} X_k\ e^{\frac{j2\pi kt}{T}} \quad ,-T_g \le t < T \tag{3}$$

HOW OFDM WORKS

Knowing the main wireless transmission concept (How wireless works), main channel propagation phenomena (what is Pathloss, what is Shadowing and antenna configurations (What is MIMO?) looking at the one of the most commonly used transmission scheme OFDM, but before explanations why do we use it and what are its principles, firstly take a look on another radio phenomenon namely multipath.

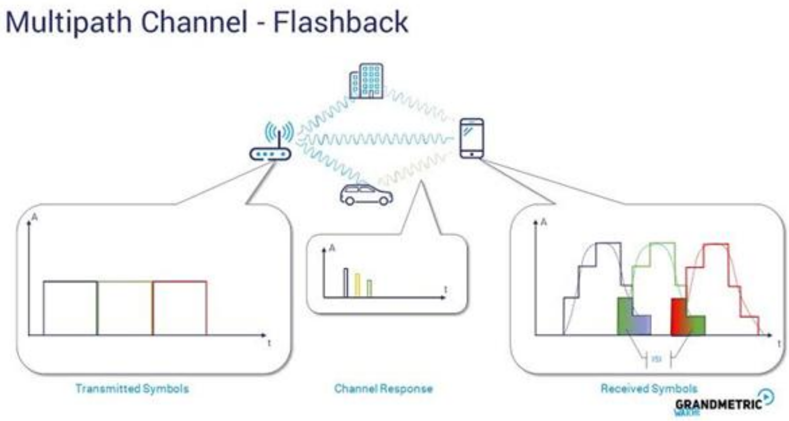

Figure 2: Multipath Channel recap

In the radio channel, the radio signal is received through multiple paths resulting from separate channel taps, when we transmit a single rectangular symbol, it shows up at the receiver as a combination that are differently delayed and attenuated. When there are multiple consecutive symbols, one right next to another results to interference from the previous symbol to the next-inter symbol interference (ISI).

INTER-SYMBOL INTERFERENCE (ISI)

Looking at the actual impairment from figure 3 below, let's assume we have 3symbols transmitted within 1 second (3sym/1sec), each carrying for simplicity, a single bit (otherwise each symbol can carry multiple bits as in the case of QPSK/QAM Mapping.

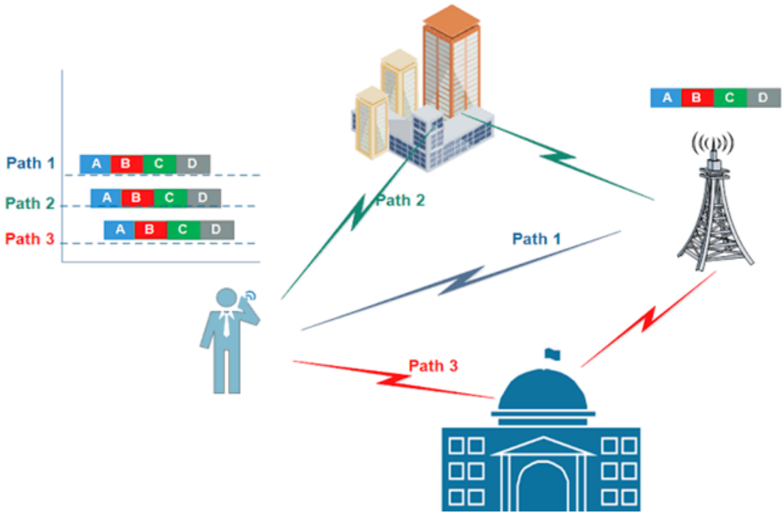

Figure 3: Inter-Symbol Interference (ISI) In LTE

They travel through a channel with 3 taps that results in the spread symbols with a duration longer than the duration of individual symbol (T) resulting in ISI. When the symbols are long (upper part of the figure) meaning low throughput – the ISI is small i.e. we are able to decode the signal as majority of the power is received without interference. However, in this case the symbols are shorter so the impairment is more severe i.e. larger part of the symbol is spreading out to the subsequent symbols. Therefore, as we see the green symbol is pretty much impaired along its whole duration (by blue and red symbols). Thus, we do have any part of the symbol being clear from interference.

SPECTRAL EFFICIENCY

Figure 2.5 illustrates the difference between conventional FDM and OFDM systems with subcarrier bandwidth (SCBD). In the case of OFDM, a spectral efficiency is achieved by maintaining orthogonality between the subcarriers. When orthogonality is maintained between different sub-channels during transmission, then it is possible to separate the signal very easily at the receiver side. FDM ensures this by inserting guard bands between sub-channels as a result in inefficient use of spectral resources.

Orthogonal makes it possible in OFDM to arrange the subcarriers in such a way that the sidebands of the individual carriers overlap and the signals are received at the receiver without being interfaced by ICI. The receiver acts as a bank of demodulators, translating each subcarrier down to DC, with the resulting signal integrated over a symbol period to recover raw data. If the other subcarriers are all down-converted to the frequencies in time domain a whole number of cycles in a symbol period T_{sym}, the integration process results in zero contribution from all other carriers. Thus, there are linearly independent (i.e. orthogonal) if the carrier spacing is a multiple of $\frac{1}{Tsym}$

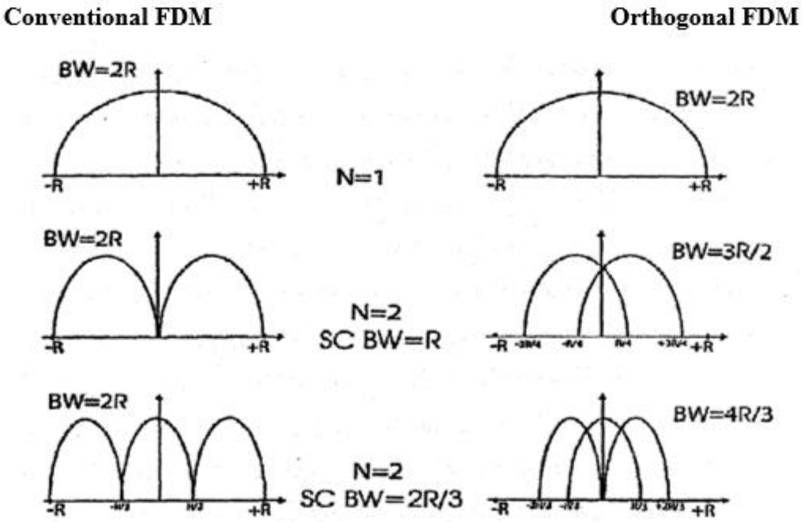

Figure 4: Spectrum efficiency of OFDM compared to conventional FDM

OFDM, are multiple carries (called subcarrier) they carry the information stream. The subcarriers are orthogonal to each other. A guard interval is added to each symbol to minimize the channel spread and inter-symbol interference. PFDM, Orthogonal Frequency Division Multiplexing is a form signal waveform or modulation that provides some significant advantages for data links.

ITS ORTHOGONALITY

The main aspect in OFDM is that it maintains its 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:

$$\int_0^T \cos\left(2\pi n \int_0^t\right)\cos\left(2\pi m \int_0^t\right)dt \; = 0 \; (n \neq m) \qquad (4)$$

Where n and m are two equal integers; f_0 is the fundamental frequency; T is the period over which the integration is taken. T is one symbol period and f_0 set to $\frac{1}{T}$ for optional effectiveness.

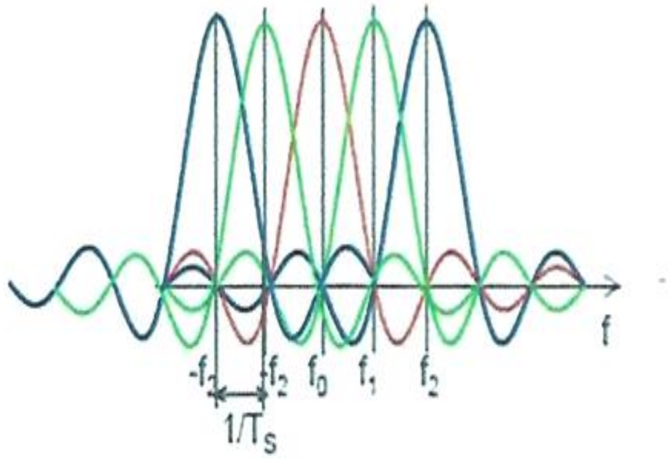

Figure 5: Diagram of OFDM (Orthogonality)

MERITS OF OFDM

- Solves the multipath propagation problem simple equalization at receiver
- Computationally efficient: for broadband systems more efficient their SC
- Supports several multiple access schemes: TDMA, FDMA, MC CDMA etc
- Supports various modulation schemes: Adaptability to SNR of sub-carriers is possible
- Elegant framework for MIMO-systems
- It has better spectral efficiency
- It can adjust modulation and coding for each subcarrier
- It is effective at combating ISI and multipath fading
- It has low-complexity modulation that can be implemented using IDFT/DFT and more efficiently using IFFT/FFT.
- It has simple equalization
- It is possible to use maximum likelihood decoding with reasonable complexity
- It is less sensitive to sample timing offsets than single carrier systems are
- Provides good protection against co-channel interference and impulsive parasitic noise.

DEMERITS OF OFDM

- Power peaks: One of the most difficult engineering concerns in the RF portion of traditional OFDM modem is handling very large Peak-to-Average Power Ratios (PAPRs)
- More PAPR Problems: In addition to creating design problems, the high peak-to- average power ratio of the OFDM modulation scheme requires high linear up-converters. This means that the up-converter must have a high-level compression point, which also results in high DC power consumption.
- Linearity concerns: OFDM modulation is also very sensitive to the inter-modulation distortion (IMD). These inter-modulation products will contribute to a noise-like cloud surrounding each constellation point.
- Image rejection: This is to reduce or eliminate the intermediate frequency (IF) state in order to eliminate costly additional filtering circuitry, it streamlines the receiver, which makes it more difficult to control image rejection because designers cannot make use of external RF and IF filtering. At best insufficient image rejection in an OFDM modem reduces the carrier-to-noise ratio available for the demodulator.

Phase distortion: this dispersion can be caused by motion of the radio units or from motion of any other object in the channel. It can also be caused by phase variation with frequency in the radio antennas, filters and other components.

Phase noise issues: This is possible due to the relatively low data rate for carrier. However, upon down-conversion in the receiver, any phase noise associated with the Local Oscillator (LO) synthesizer will be super imposed into low data rate modulation.

Addressing the RF issues: Typically linearity, image rejection phase distortion and phase noise for OFDM are addressed through the addition of costly components including surface acoustic wave (SAW) filters and crystal oscillators that contribute to a higher system bill of materials (BOM) and increases power consumption.

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 implementation technology of this era, its advantages and disadvantages, its limitations and also its applications in different fields. OFDM has played an important role in WILAN and will be part of MAN too. This paper has explored the role of OFDM in the wireless communication. There are also some limitations of this technique which can be removed with the help of suitable techniques. In years to come OFDM, will surely dominate the communication industry. Also, Wimax and 802.20 use OFDM-MIMO, which is emerging as the main technology for future cellular packet data networks, including 3GPP long-term evolution and 3GPP2 air interface evolution as well. Although OFDM has proven itself with packet-based data, it is yet clear if technology can either handle large number of voice customers or work with voice and data as well as CDMA,

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