OFDM: MODULATION TECHNIQUE FOR WIRELESS COMMUNICATION.

D. Surya
Peri Institute of Technology ECE 3rd yr

ABSTRACT
Orthogonal Frequency Division Multiplexing (OFDM) has become the modulation technique for many wireless communication standards. In a wireless system, a signal transmitted into channel bounces off from various surfaces resulting in multiple delayed versions of the transmitted signal arriving at the receiver. The multiple signals are received due to the reflections from large objects, diffraction of electromagnetic waves around objects. This causes the received signal to be distorted. OFDM provides tolerance to such frequency selective channels and provides high data rates. In this paper we propose to analyze the theory of OFDM, simulate the OFDM transceiver using MATLAB and perform BER analysis.

Keywords— OFDM, FFT, IFFT, ISI, BPSK, QPSK, AWGN, RAYLEIGH CHANNEL

INTRODUCTION
The progress in the semiconductor technology has made radio transmission without any physical connection possible throughout the world. The goal of future wireless communication is to provide communication with high data rates. The most popular technique in wireless communication is Orthogonal Frequency Division Multiplexing (OFDM). When the data is transmitted at high data rates over wireless radio channels, the symbols may overlap over each other which can lead to inter symbol interference (ISI). OFDM can combat the effect of ISI. OFDM is increasingly used in high mobility wireless communication systems, e.g. mobile WiMAX (IEEE 802.16e) and 3GPP’s UMTS Long-Term Evolution (LTE). The developments of OFDM systems can be divided into three parts. They are Frequency Division Multiple Access (FDMA), Multicarrier Communication and Orthogonal Frequency Division Multiplexing.

In FDMA, the available bandwidth is divided into multiple channels and then allocated to the users. In Multicarrier Communication the signal is divided into a number of signals over a frequency range, whereas OFDM spaces the channels much closer by placing the carriers orthogonal to each other, thus using the spectrum efficiently.

In 1960’s, the concept of using parallel data transmission by multicarrier modulation was published. However it was not practical to implement until the discovery of using the Discrete Fourier Transform (DFT). DFT is implemented using the computationally efficient Fast Fourier Transform (FFT).

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OFDM, Orthogonal Frequency Division Multiplexing is a form of signal waveform or modulation that provides some significant advantages for data links. Accordingly, OFDM, Orthogonal Frequency Division Multiplexing is used for many of the latest wide bandwidth and high data rate wireless systems including Wi-Fi, cellular telecommunications and many more.

The fact that OFDM uses a large number of carriers, each carrying low bit rate data, means that it is very resilient to selective fading, interference, and multipath effects, as well providing a high degree of spectral efficiency.

What is OFDM?

OFDM is a form of multicarrier modulation. An OFDM signal consists of a number of closely spaced modulated carriers. When modulation of any form - voice, data, etc. is applied to a carrier, then sidebands spread out either side. It is necessary for a receiver to be able to receive the whole signal to be able to successfully demodulate the data. As a result when signals are transmitted close to one another they must be spaced so that the receiver can separate them using a filter and there must be a guard band between them. This is not the case with OFDM. Although the sidebands from each carrier overlap, they can still be received without the interference that might be expected because they are orthogonal to each other.

This is achieved by having the carrier spacing equal to the reciprocal of the symbol period.

Traditional selection if signals on different channels

To see how OFDM works, it is necessary to look at the receiver. This acts as a bank of demodulators, translating each carrier down to DC. The resulting signal is integrated over the symbol period to regenerate the data from that carrier. The same demodulator also demodulates the other carriers. As the carrier spacing equal to the reciprocal of the symbol period means that they will have a whole number of cycles in the symbol period and their contribution will sum to zero - in other words there is no interference contribution.

Basic concept of OFDM, Orthogonal Frequency Division Multiplexing

One requirement of the OFDM transmitting and receiving systems is that they must be linear. Any non-linearity will cause interference between the carriers as a result of inter-modulation distortion. This will introduce unwanted signals that would cause interference and impair the orthogonality of the transmission.

In terms of the equipment to be used the high peak to average ratio of multicarrier systems such as OFDM requires the RF final amplifier on the output of the transmitter to be able to handle the peaks whilst the average power is much lower and this leads to inefficiency. In some systems the peaks are limited. Although this introduces distortion that results in a higher level of data errors, the system can rely on the error correction to remove them.
In a single carrier system, a single fade or interference can cause the entire link to fail, but in a multicarrier system, only a small percentage of the subcarriers will be affected. The term orthogonal in OFDM refers to the fact that the center frequencies of the sub channel are separated by the reciprocal of the OFDM block time $T$. Suppose the symbol length is $T$, sinusoidal signals differing in frequency by $1/T$, will be orthogonal over the period $T$. The bandwidth upon which the channel response can be assumed to be flat is known as coherence bandwidth of the channel. If the data is transmitted at high rate, the bandwidth of the channel becomes wide and may exceed the coherence bandwidth of the channel. This distorts the signal and causes Inter Symbol Interference (ISI). A guard interval is introduced in every OFDM symbol to eliminate ISI. Two approaches are followed in OFDM to insert guard interval. The first one is known as zero padding, where zeros are inserted between OFDM symbols. The second one is known as cyclic prefix, where a part of the end of the OFDM symbol is copied and inserted in the beginning of the next OFDM symbol in time domain.

The length of the guard interval must be at least equal to the length of the channel response to avoid the ISI. Usage of cyclic prefix is preferred than zero padding when FFT is used. Because FFT algorithms require the signal to be periodic to produce accurate results and cyclic prefix makes the signal periodic.

**System description**

OFDM symbols are generated as follows. The transmitter section converts the digital data to be transmitted into a mapping of the sub carrier’s amplitude and phase using modulation techniques. The modulation technique such as the BPSK, QPSK or QAM can be used. The modulated data is converted into parallel stream for faster and optimum utilization of the bandwidth. Time domain representation of the data is created by using an Inverse Fast Fourier Transform (IFFT) which is an efficient method to implement DFT. OFDM symbol time domain representation is extended by addition of cyclic prefix to each symbol that solves both ISI and inter carrier interference (ICI).
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The time domain signal is passed through the channel. At the receiver side, the cyclic prefix is removed and converted to frequency domain by using FFT. Finally the parallel data is converted back to serial data. Mathematically, each subcarrier can be formulated as follows:

\[
S_c(t) = A_c(t) e^{j(\omega_c t + \phi_c(t))}
\]

(1)

where \(A_c(t)\) is amplitude and \(\phi_c(t)\) is phase. An OFDM symbol consists of many subcarriers. It is represented by:

\[
S_s(t) = \frac{1}{N} \sum_{n=0}^{N-1} A_n(t) e^{j(\omega_n t + \phi_n(t))}
\]

(2)

where \(\omega_n = \omega_0 + n \Delta \omega\)

\(A_n(t)\) and \(\phi_n(t)\) get different values in different symbols, but they are constant in every symbol and only depend on frequency of carriers.

In every symbol, we have,

\[
\phi_n(t) \Rightarrow \phi_n\quad A_n(t) \Rightarrow A_n
\]

(3)

If the signal is sampled with \(1/T\) where \(T\) is the duration of a symbol and substituting (3) in (2) we get,

\[
S_s(kT) = \frac{1}{N} \sum_{n=0}^{N-1} A_n e^{j((\omega_0 + n \Delta \omega) kT + \phi_n)}
\]

(4)

When \(\omega_0 = 0\), (3) is converted to an IDFT transform.

By adding cyclic prefix in time domain, ISI can be prevented.

\[
S_T(n) = \begin{cases} 
0 & n < N_p \\
A(n - N_p) & n = N_p + 1, \ldots, N-1 
\end{cases}
\]

(5)

where \(N_p\) is the length of the cyclic prefix.

SIMULATION

In this paper, we have simulated the OFDM transceiver using model shown in Fig.4. We have used two modulation schemes, namely BPSK (Binary Phase Shift Keying), QPSK (Quadrature Phase Shift Keying). The OFDM symbols created after taking ifft is passed through the Gaussian channel which adds additive white Gaussian noise (AWGN). Cyclic prefix does not hold any significance in AWGN channel. The demodulation is performed at the receiver. Multipath Rayleigh fading channel is also considered for simulation. It is generated by considering sum of two random variables. Each path in the multipath scenario can be modelled as circularly symmetric Gaussian random variables with respect to time when central limit theorem is applied, the envelope of the random variables will follow Rayleigh distribution. Hence it is known as Rayleigh fading channel. We have plotted the Bit error rate (BER) by considering the signal-to-noise ratio for the modulation techniques specified.
An OFDM symbol is created after taking the 64 point ifft of the modulated data. An OFDM containing 64 subcarriers generated using BPSK modulation is as shown. Simulated BER curves for BPSK, and QPSK in Rayleigh channel is as shown. A 10 tap Rayleigh channel has been considered with a cyclic prefix of length 16. Cyclic prefix is used to minimize the effect of ISI. AWGN will also have an influence in the BER value in the Rayleigh fading channel. It is observed that for a particular value of SNR, the BER for BPSK and QPSK is almost equal in AWGN channel and in Rayleigh channel. The advantage of using QPSK modulated data is that it can be transmitted as twice the data rate when

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Specification</th>
</tr>
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<tbody>
<tr>
<td>FFT size</td>
<td>64</td>
</tr>
<tr>
<td>No of subcarriers</td>
<td>64</td>
</tr>
<tr>
<td>Channel Model</td>
<td>AWGN &amp; Rayleigh</td>
</tr>
<tr>
<td>Signal constellation</td>
<td>BPSK &amp; QPSK</td>
</tr>
<tr>
<td>No of symbols</td>
<td>10000</td>
</tr>
<tr>
<td>Cyclic Prefix length</td>
<td>16</td>
</tr>
</tbody>
</table>

BER vs. SNR plot for OFDM using BPSK, QPSK modulation techniques in Rayleigh channel.
compared to BPSK modulated data. However, QPSK transmitters and receivers are complicated and expensive when compared to BPSK.

**Key features of OFDM**
The OFDM scheme differs from traditional FDM in the following interrelated ways:
- Multiple carriers (called subcarriers) carry the information stream
- The subcarriers are orthogonal to each other.
- A guard interval is added to each symbol to minimize the channel delay spread and intersymbol interference.

**Usage:**
**ADSL**
OFDM is used in *ADSL* connections that follow the ANSI T1.413 and G.dmt (ITU G.992.1) standards, where it is called *discrete multitone modulation* (DMT).[34] DSL achieves high-speed data connections on existing copper wires. OFDM is also used in the successor standards ADSL2, ADSL2+, VDSL, VDSL2, and G.fast. ADSL2 uses variable subcarrier modulation, ranging from BPSK to 32768QAM (in ADSL terminology this is referred to as bit-loading, or bit per tone, 1 to 15 bits per subcarrier).

Long copper wires suffer from attenuation at high frequencies. The fact that OFDM can cope with this frequency selective attenuation and with narrow-band interference are the main reasons it is frequently used in applications such as ADSL modems.

**Powerline technology**
OFDM is used by many *powerline* devices to extend digital connections through power wiring. Adaptive modulation is particularly important with such a noisy channel as electrical wiring. Some medium speed smart metering modems, "Prime" and "G3" use OFDM at modest frequencies (30–100 kHz) with modest numbers of channels (several hundred) in order to overcome the intersymbol interference in the power line environment.[35] The **IEEE 1901** standards include two incompatible physical layers that both use OFDM.[36] The ITU-T G.hn standard, which provides highspeed local area networking over existing home wiring (power lines, phone lines and coaxial cables) is based on a PHY layer that specifies OFDM with adaptive modulation and a Low-Density Parity-Check (LDPC) FEC code.

**WAN and MAN**
OFDM is extensively used in wireless LAN and MAN applications, including IEEE 802.11a/g/n and WiMAX.

IEEE 802.11a/g/n, operating in the 2.4 and 5 GHz bands, specifies per-stream airside data rates ranging from 6 to 54 Mbit/s. If both devices can use "HT mode" (added with 802.11n), the top 20 MHz per-stream rate is increased to 72.2 Mbit/s, with the option of data rates between 13.5 and 150 Mbit/s using a 40 MHz channel. Four different modulation schemes are used: BPSK, QPSK, 16-QAM, and 64-QAM, along with a set of error correcting rates (1/2–5/6). The multitude of choices allows the system to adapt the optimum data rate for the current signal conditions.

**Digital radio**
COFDM is also used for other radio standards, for Digital Audio Broadcasting (DAB), the standard for digital audio broadcasting at VHF frequencies, for Digital Radio Mondiale (DRM), the standard for digital broadcasting at shortwave and medium wave frequencies (below 30 MHz) and for DRM+ a more recently introduced standard for digital audio broadcasting at VHF frequencies. (30 to 174 MHz) The USA again uses an alternate standard, a proprietary system developed by iBiquity dubbed *HD Radio*. However, it uses COFDM as the underlying broadcast technology to add digital audio to AM (medium wave) and FM broadcasts.

Both Digital Radio Mondiale and HD Radio are classified as in-band on-channel systems, unlike Eureka 147 (DAB: Digital Audio Broadcasting) which uses separate VHF or UHF frequency bands instead.
OFDM advantages

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 it 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.

OFDM disadvantages

Whilst OFDM has been widely used, there are still a few disadvantages to its use which need to be addressed when considering 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.

CONCLUSION

OFDM provides high data rates and is robust in frequency selective channels. It minimizes the effect of ISI. Hence it is suitable for wireless communication. Simulation was performed for OFDM using BPSK and QPSK modulation in AWGN and in Rayleigh channels. The BER performance is similar for both, but QPSK is expensive in terms of bandwidth when compared to BPSK

REFERENCES

