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# Orthogonal Frequency Division Multiplexing–A Boon to Wireless Networks

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***Abstract:*** *The paper discusses the basic concept of Orthogonal Frequency Division Multiplexing. It is a fundamental paper and cover all the aspects related to OFDM. The coding enhances the performance of Cellular OFDM systems. The paper concludes that Digital signal Processors are the most important component of OFDM systems because even the concept of OFDM was not new it was developed in 1960 but as soon as Digital signal processors developed they give revolution to the OFDM concept.*

***Keywords****: OFDM, Coding, Digital Signal Processor, Inter Symbol Interference.*

## 1. INTRODUCTION

Orthogonal Frequency Division Multiplexing (OFDM) is a Multicarrier transmission technique, which divides the available spectrum into many carriers, each one being modulated by a low rate data stream. OFDM is similar to FDMA in that the multiple user access is achieved by subdividing the available bandwidth into multiple channels, which are then allocated to users. However, OFDM uses the spectrum much more efficiently by spacing the channels much closer together. This is achieved by making all the carriers orthogonal to one another, preventing interference between the closely spaced carriers. It is identical to Coded OFDM (COFDM) and Discrete multi-tone modulation (DMT). [1]

In this scheme a large number of closely-spaced orthogonal *sub-carriers* are used to carry data. The data are divided into several parallel data streams or channels, one for each sub-carrier. Each sub-carrier is modulated with a conventional modulation scheme (such as quadrature amplitude modulation or phase shift keying) at a low symbol rate, maintaining total data rates similar to conventional *single-carrier* modulation schemes in the same bandwidth.

OFDM has developed into a popular scheme for Wideband Digital Communication, whether wireless or over copper wires, used in applications such as digital television and audio broadcasting, wireless networking and broadband internet access.

## 2. ADVANTAGES OF OFDM

- The primary advantage of OFDM over single-carrier schemes is its ability to cope with severe channel conditions—for example, attenuation of high frequencies in a long copper wire, narrowband interference and frequency-selective fading due to multipath—without complex equalization filters.
- Channel equalization is simplified because OFDM may be viewed as using many slowly-modulated narrowband signals rather than one rapidly-modulated wideband signal.
- The low symbol rate makes the use of a guard interval between symbols affordable, making it possible to handle time-spreading and eliminate Inter symbol interference (ISI).
- This mechanism also facilitates the design of single-frequency networks, where several adjacent transmitters send the same signal simultaneously at the same frequency, as the signals from multiple distant transmitters may be combined constructively, rather than interfering as would typically occur in a traditional single-carrier system.
- It Provides High spectral efficiency and can be efficiently implemented using FFT.

OFDM splits the available bandwidth into many narrow band channels (typically 100-8000). The carriers for each channel are made orthogonal to one another, allowing them to be spaced very close together, with no overhead as in the FDMA Because of this there is no great need for users to be time multiplex as in TDMA, thus there is no overhead associated with switching between users. The orthogonality of the carriers means that each carrier has an integer number of cycles over a symbol period. Due to this, the spectrum of each carrier has a null at the centre frequency of each of the other carriers in the system. This results in no interference between the carriers, allowing then to be spaced as close as theoretically possible. This overcomes the problem of

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overhead carrier spacing required in FDMA. Each carrier in an OFDM signal has a very narrow bandwidth (i.e. 1 kHz), thus the resulting symbol rate is low. This results in the signal having a high tolerance to multipath delay spread, as the delay spread must be very long to cause significant inter-symbol interference (e.g. > 100 msec).

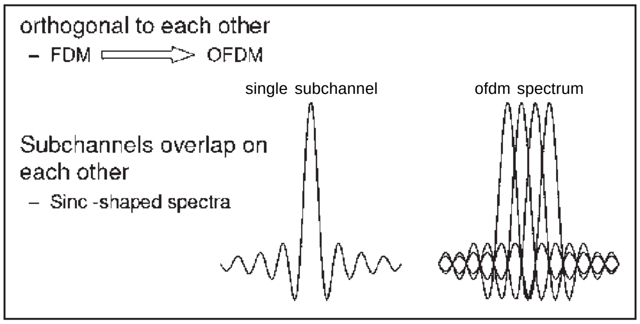



**Figure 1:** Basics of OFDM

### 3. OFDM GENERATION

To generate OFDM successfully the relationship between all the carriers must be carefully controlled to maintain the orthogonality of the carriers. For this reason, OFDM is generated by firstly choosing the spectrum required, based on the input data, and modulation scheme used. Each carrier to be produced is assigned some data to transmit. The required amplitude and phase of the carrier is then calculated based on the modulation scheme (typically differential BPSK, QPSK, or QAM). The required spectrum is then converted back to its time domain signal using an Inverse Fourier Transform. In most applications, an Inverse Fast Fourier Transform (IFFT) is used. The IFFT performs the transformation very efficiently, and provides a simple way of ensuring the carrier signals produced are orthogonal.

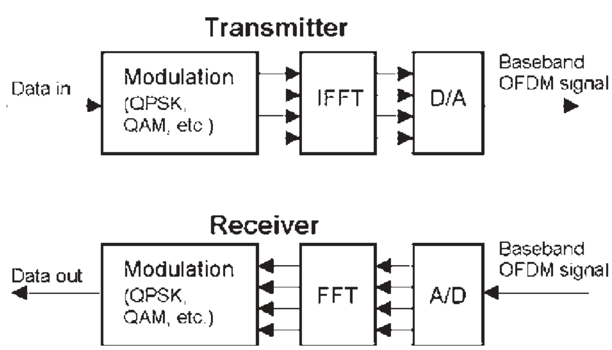



**Figure 2:** OFDM Transmitter/Receiver

The Fast Fourier Transform (FFT) [2] transforms a cyclic time domain signal into its equivalent frequency spectrum. This is done by finding the equivalent waveform, generated by a sum of orthogonal sinusoidal components. The amplitude and phase of the sinusoidal components represent the frequency spectrum of the time domain signal. The IFFT performs the reverse process, transforming a spectrum (amplitude and phase of each component) into a time domain signal. An IFFT converts a number of complex data points, of length that is a power of 2, into the time domain signal of the same number of points. Each data point in frequency spectrum used for an FFT or IFFT is called a bin.

The orthogonal carriers required for the OFDM signal can be easily generated by setting the amplitude and phase of each frequency bin, then performing the IFFT. Since each bin of an IFFT corresponds to the amplitude and phase of a set of orthogonal sinusoids, the reverse process guarantees that the carriers generated are orthogonal.

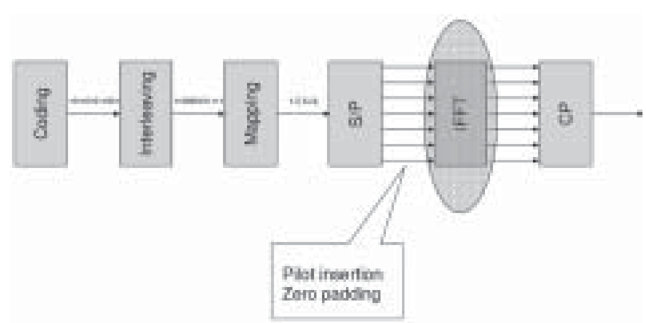
The orthogonality requires that the sub-carrier spacing is $\Delta f = k/(T_U)$ Hertz, where $T_U$ seconds is the useful symbol duration (the receiver side window size), and $k$ is a positive integer, typically equal to 1. Therefore, with $N$ sub-carriers, the total passband bandwidth will be $B \approx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

The orthogonality also allows high spectral efficiency, with a total symbol rate near the Nyquist rate. Almost the whole available frequency band can be utilized. OFDM generally has a nearly 'white' spectrum, giving it benign electromagnetic interference properties with respect to other.

OFDM requires very accurate frequency synchronization between the receiver and the transmitter; with frequency deviation the sub-carriers will no longer be orthogonal, causing *inter-carrier interference* (ICI), *i.e.* cross-talk between the sub-carriers. Frequency offsets are typically caused by mismatched transmitter and receiver oscillators, or by Doppler shift due to movement. While Doppler shift alone may be compensated for by the receiver, the situation is worsened when combined with multipath, as reflections will appear at various frequency offsets, which is much harder to correct. This effect typically worsens as speed increases, and is an important factor limiting the use of OFDM in high-speed vehicles. Several techniques for ICI [3] suppression are suggested, but they may increase the receiver complexity.

### 4. IMPLEMENTATION USING THE FFT ALGORITHM

The orthogonality allows for efficient modulator and demodulator implementation using the FFT algorithm on the receiver side, and inverse FFT on the sender side. Although the principles and some of the benefits have been known since the 1960s, OFDM is popular for wideband



communications today by way of low-cost digital signal processing components that can efficiently calculate the FFT.

### Guard Interval for Elimination of Inter-symbol Interference

One key principle of OFDM is that since low symbol rate modulation schemes (*i.e.* where the symbols are relatively long compared to the channel time characteristics) suffer less from intersymbol interference caused by multipath, it is advantageous to transmit a number of low-rate streams in parallel instead of a single high-rate stream. Since the duration of each symbol is long, it is feasible to insert a guard interval between the OFDM symbols, thus eliminating the intersymbol interference.

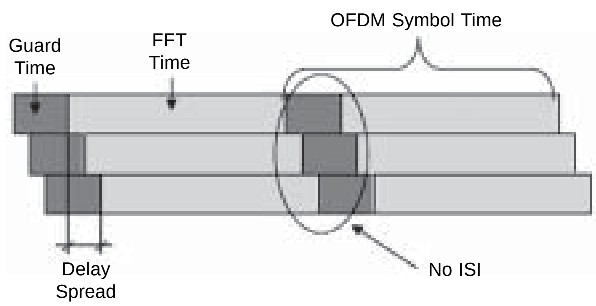



**Figure 3:** Concept of Elimination of ISI

The guard interval also eliminates the need for a pulse-shaping filter, and it reduces the sensitivity to time synchronization problems.

### Channel Coding and Interleaving

OFDM is invariably used in conjunction with channel coding (forward error correction), and almost always uses frequency and/or time interleaving. Frequency (subcarrier) interleaving increases resistance to frequency-selective channel conditions such as fading. For example, when a part of the channel bandwidth is faded, frequency interleaving ensures that the bit errors that would result from those subcarriers in the faded part of the bandwidth are spread out in the bit-stream rather than being concentrated. Similarly, time interleaving ensures that bits that are originally close together in the bit-stream are transmitted far apart in time, thus mitigating against severe fading as would happen when travelling at high speed.

However, time interleaving is of little benefit in slowly fading channels, such as for stationary reception, and frequency interleaving offers little to no benefit for narrowband channels that suffer from flat-fading (where the whole channel bandwidth is faded at the same time).

The reason why interleaving is used on OFDM is to attempt to spread the errors out in the bit-stream that is presented to the error correction decoder, because when such decoders are presented with a high concentration of errors the decoder is unable to correct all the bit errors, and a burst of uncorrected errors occurs.

A common type of error correction coding used with OFDM-based systems is Convolutional coding, which is often concatenated with Reed-Solomon coding. [4] Convolutional coding is used as the inner code and Reed-Solomon coding is used for the outer code—usually with additional interleaving (on top of the time and frequency interleaving mentioned above) in between the two layers of coding. The reason why this combination of error correction coding is used is that the Viterbi decoder used for convolutional decoding produces short errors bursts when there is a high concentration of errors, and Reed-Solomon codes are inherently well-suited to correcting bursts of errors.

Newer systems, however, usually now adopt the near-optimal types of error correction coding that use the turbo decoding principle, where the decoder iterates towards the desired solution. Examples of such error correction coding types include turbo codes and LDPC codes. These codes only perform close to the Shannon limit for the Additive White Gaussian Noise (AWGN) channel, however, and some systems that have adopted these codes have concatenated them with either Reed-Solomon (for example on the MediaFLO system) or BCH codes (on the DVB-S2 system) to improve performance further over the wireless channel.

### Adaptive Transmission

The resilience to severe channel conditions can be further enhanced if information about the channel is sent over a return-channel. Based on this feedback information, adaptive modulation, channel coding and power allocation may be applied across all sub-carriers, or individually to each sub-carrier. In the latter case, if a particular range of frequencies suffers from interference or attenuation, the carriers within that range can be disabled or made to run slower by applying more robust modulation or error coding to those sub-carriers.

## 5. OFDM EXTENDED WITH MULTIPLE ACCESS

OFDM in its primary form is considered as a digital modulation technique, and not a multi-user channel access technique, since it is utilized for transferring one bit stream over one communication channel using one sequence of OFDM symbols. However, OFDM can be combined with multiple access using time, frequency or coding separation of the users.

In Orthogonal Frequency Division Multiple Access (OFDMA), frequency-division multiple access is achieved by assigning different OFDM sub-channels to different users. OFDMA supports differentiated quality-of-service by assigning different number of sub-carriers to different users in a similar fashion as in CDMA, and thus complex packet scheduling or media access control schemes can be avoided. OFDMA is used in the IEEE 802.16 Wireless MAN standard, commonly referred to as WiMAX.

In Multi-carrier code division multiple access (MC-CDMA), also known as OFDM-CDMA, OFDM is combined with CDMA spread spectrum communication for coding separation of the users. Co-channel interference can be mitigated against, meaning that manual fixed channel allocation (FCA) frequency planning is simplified, or complex dynamic channel allocation (DCA) schemes are avoided.

## 6. APPLICATIONS

The following list is a summary of existing OFDM based standards and products.

### Cable

- ADSL and VDSL broadband access via POTS copper wiring.
- Power line communication (PLC).
- Multimedia over Coax Alliance (MoCA) home networking.

### Wireless

- The wireless LAN radio interfaces IEEE 802.11a, g, n and HIPERLAN/2.
- The digital radio systems DAB/EUREKA 147, DAB+, Digital Radio Mondiale, HD Radio, T-DMB and ISDB-TSB.
- The terrestrial digital TV system DVB-T.
- The terrestrial mobile TV systems DVB-H, T-DMB, ISDB-T and MediaFLO forward link.
- The cellular communication systems Flash-OFDM.
- The mobile broadband 3GPP Long Term Evolution air interface named High Speed OFDM Packet Access (HSOPA).
- The Wireless MAN / Fixed broadband wireless access (BWA) standard IEEE 802.16 (or WiMAX).
- The Mobile Broadband Wireless Access (MBWA) standards IEEE 802.20, IEEE 802.16e (Mobile WiMAX) and WiBro.
- The wireless Personal Area Network (PAN) Ultra wideband (UWB) IEEE 802.15.3a implementation suggested by WiMedia Alliance.

## 7. CONCLUSION

The paper concludes that the day to day development of OFDM will ease the problems associated with wireless communication because the concept of orthogonality improves the problem of Security which is very important parameter of wireless networks design. New coding schemes are coming up to improve the drawbacks of present OFDM system.

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