Orthogonal Frequency Division Multiplexing

Intel in Communications

Orthogonal frequency division multiplexing (OFDM) is a multi-carrier transmission technique that has been recently recognized as an excellent method for high speed bi-directional wireless data communication. Its history dates back to the 1960s, but it has recently become popular because economical integrated circuits that can perform the high speed digital operations necessary have become available. OFDM effectively squeezes multiple modulated carriers tightly together, reducing the required bandwidth but keeping the modulated signals orthogonal so they do not interfere with each other. Today, the technology is used in such systems as asymmetric digital subscriber line (ADSL) as well as wireless systems such as IEEE 802.11a/g (Wi-Fi*) and IEEE 802.16 (WiMAX*). It is also used for wireless digital audio and video broadcasting.

It is based on frequency division multiplexing (FDM), which is a technology that uses multiple frequencies to simultaneously transmit multiple signals in parallel. Each signal has its own frequency range (sub-carrier) which is then modulated by data. Each sub-carrier is separated by a guard band to ensure that they do not overlap. These sub-carriers are then demodulated at the receiver by using filters to separate the bands.

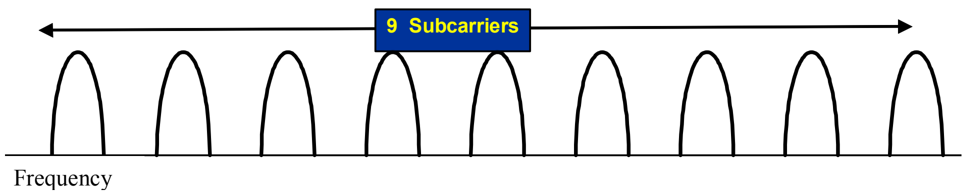

Figure 1: FDM with Nine Sub-carriers Using Filters

OFDM is similar to FDM but much more spectrally efficient by spacing the sub-channels much closer together (until they are actually overlapping). This is done by finding frequencies that are orthogonal, which means that they are perpendicular in a mathematical sense, allowing the spectrum of each sub-channel to overlap another without interfering with it. In Figure 2, the effect of this is seen as the required bandwidth is greatly reduced by removing guard bands and allowing signals to overlap. In order to demodulate the signal, a discrete Fourier transform (DFT) is needed. Fast Fourier transform (FFT) chips are commercially available, making this a relatively easy operation.

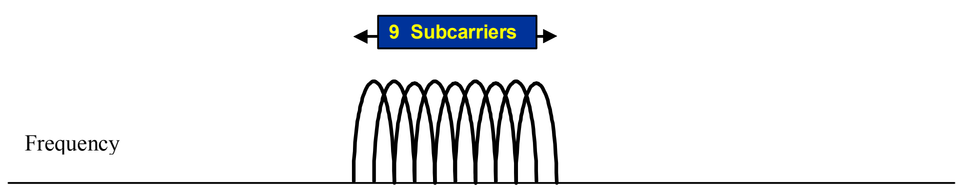

Figure 2: OFDM with Nine Sub-carriers

In the below case we have 256 OFDM with 192 data sub-carriers, eight pilot sub-carriers and 56 nulls. In its most basic form, each data sub-carrier could be on or off to indicate a one or zero bit of information. However, either phase shift keying (PSK) or quadrature amplitude modulation (QAM) is typically employed to increase the data throughput. So in this case, a data stream would be split into *n* (192) parallel data streams, each at 1/*n* (1/192) of the original rate. Each stream is then mapped to the individual data sub-carrier and modulated using either PSK or QAM. Pilot sub-carriers provide a reference to minimize frequency and phase shifts during the transmission while null carriers allow for guard bands and the DC carrier (center frequency).

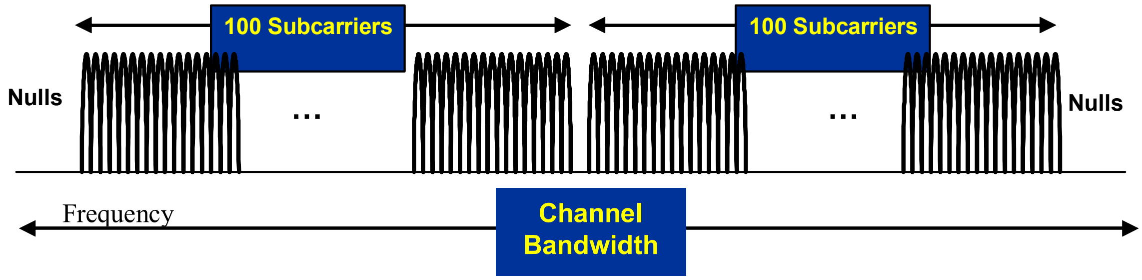

Figure 3: OFDM with 256 Sub-carriers

Orthogonal frequency division multiple access (OFDMA) allows some sub-carriers to be assigned to different users. For example, sub-carriers 1, 3 and 7 can be assigned to user 1 and sub-carriers 2, 5 and 9 to user 2. These groups of sub-carriers are known as sub-channels. Scalable OFDMA allows smaller FFT sizes to improve performance (efficiency) for lower bandwidth channels. This applies to IEEE 802.16-2004 which can now reduce the FFT size from 2048 to 128 to handle channel bandwidths ranging from 1.25–20 MHz. This allows sub-carrier spacing to remain constant independent of bandwidth which reduces complexity while also allowing larger FFT for increased performance with wide channels.

Another advantage of OFDM is its resilience to multipath, which is the effect of multiple reflected signals hitting the receiver. This results in interference and frequency-selective fading which OFDM is able to overcome by utilizing its parallel, slower bandwidth nature. This makes OFDM ideal to handle the harsh conditions of the mobile wireless environment.

OFDM's high spectral efficiency and resistance to multipath make it an extremely suitable technology to meet the demands of wireless data traffic. This has made it not only ideal for such new technologies like WiMAX* and Wi-Fi* but also currently one of the prime technologies being considered for use in future fourth generation (4G) networks.

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