Introduction to OFDM

Sheung Li and Lianne Caetano

December 2005

Introduction

SiBEAM has selected OFDM as the modulation technique of choice for their 60 GHz millimeter wave wireless communication system designs. With OFDM, SiBEAM will be able to design radios scalable to multi-gigabit data rates and longer ranges in the 60 GHz band. This will, in turn, deliver strong reliable, wireless for a range of current and future applications.

What is modulation? Modulation refers to the process of transforming data to analog signals that are sent over the air. This is the technique by which information is wirelessly transmitted by varying one or more of the signal's basic characteristics - frequency, amplitude and/or phase. Different modulation carries the information as the change from the immediately preceding state rather than the absolute state. The choice of modulation techniques affects the cost, scalability, and reliability of wireless transmissions.

OFDM, which stands for Orthogonal Frequency Division Multiplexing, is a modulation technique for transmitting large amounts of digital data over a radio wave. Other available techniques include amplitude shift keying (ASK) and direct sequence (DS), which are considered to be easier to design and less costly to design. Although the simpler modulation techniques are easier to design, they are not capable of achieving the quality multi-gigabit data rates that OFDM can facilitate.

AM/FM Radio Analogy

Traditionally, there has been a tradeoff between simple and complex radios. Simple radios are typically only capable of low data rates and are easier and less costly to design. The reason for this is that they use simpler coding or modulation for sending signals through the air. But, is easier always better?

Let's take a look at the example of AM/FM radios. AM stands for amplitude modulation, and FM refers to frequency modulation. With both AM and FM, a carrier wave must be broadcasted from the radio tower. For the radio station, they send a carrier wave for the information – a greyhound bus for the information sent to the radio station setting. The carrier wave is at a particular frequency, which is singled out as you tune in your radio station. All other frequencies are filtered out.

AM is an example of a very simple radio that sends data by changing the strength or amplitude of the signal. FM, on the other hand, is a broadcast technology that employs frequency modulation to provide hi-fidelity sound over broadcast radio. More simply stated, FM radio is able to send data by changing characteristics of the frequency.

AM radio is notably less clear because it is rather easy to change the strength of the signal, executed by the radio circuits in the radio. Amplitude modulation transmits sound waves by adjusting the amplitude of the radio wave, or carrier wave to match the changes in the sound. In AM transmissions, the frequency is kept constant and the amplitude is adjusted. If radio was broadcast using visible light, this would mean that each radio signal would have its own color, and the signal would be broadcast by brightening and dimming the light.

FM, a more complex modulation technique, delivers a more clear signal since it can send more data per signal and is less vulnerable to being distorted by natural artifacts such as mountains, humidity and other signals. Frequency modulation transmits sound by adjusting the frequency of the radio wave. The mechanics behind frequency modulation are more difficult, however, the amplitude of the radio wave stays constant, while the frequency fluctuates around a basic carrier wave. This is like keeping a light at a constant brightness, but changing the color to transmit information.

Now, Back to OFDM

The AM/FM tradeoff is analogous to the one that modern radio designers experience when designing state-of-the-art radio chips. Instead of AM or FM, the tradeoff is typically between ASK and OFDM, ASK being the most simple radio. DS complexity level sits somewhere in between ASK and OFDM.

ASK is similar to AM in that this modulation technique changes the strength of the signal as the way of communicating data. ASK is a simple and inexpensive way of building a radio and is often used for radios that have access to lots of bandwidth and therefore, do not need to be very efficient. In fact, many existing 60 GHz radios use ASK and are capable of delivering gigabit speeds in direct line of sight environments.

OFDM is more complex and expensive because it requires analysis of many frequencies and characteristics of those frequencies. It is typically used for radios that do not have access to very much bandwidth such as 802.11g or 4G cellular. Like FM, it is a technique for delivering more information in the face of more obstructions than purely amplitude-based techniques such as AM and ASK.

Orthogonal frequency-division multiplexing (OFDM) is a method of digital modulation in which a signal is split into several narrowband channels at different frequencies. The technology was first conceived in the 1960s and 1970s during research into minimizing interference among channels near each other in frequency. Priority is given to minimizing the interference, or crosstalk among the channels and symbols comprising the data stream. As in FM, this technique enables stronger, clearer and signals. Because the signal is split into many narrowband channels, wireless interference and obstructions typically disrupt only a fraction of the channels that comprise the entire signal.

Affordable OFDM for Speed and Signal Quality

Implementations of OFDM rely on very high speed digital signal processing and this has only in the last several years become available at a price that makes OFDM a competitive technology in the marketplace. OFDM is considered more difficult to design due to the intricate coding necessary to support higher order modulations.

With OFDM, Quadrature Amplitude Modulation (QAM) is employed and uses both amplitude as well as phase for encoding data for higher data rates. QAM is the encoding of information into a carrier wave by variation of both the amplitude and phase of the signal. In typical OFDM uses of QAM, the possible variations of each signal range from 2 (in BPSK or binary phase shift keying) to 256 (in 256-QAM).

The complexity associated with OFDM is largely due to the complexity of transmitting and receiving higher order modulations such as 64 QAM. However, the SiBEAM philosophy is to use OFDM but only by employing the basic modulations, such as BPSK, which is equal to 2 QAM or quadrature phase shift keying, QPSK or 4 QAM. This allows SiBEAM to achieve a relatively simple radio design but provide for scalability to future 16, 64 QAM designs which equate to the higher data rates possible in the 60 GHz frequency band. At the same time, SiBEAM takes advantage of the many benefits of OFDM, including high spectrum efficiency, resistance against multipath interference. As technology improves to enable less expensive implementations of higher modulations or more robust implementations of lower modulations, so will the speed and range of 60 GHz.

Conclusion

OFDM is the optimum modulation technique for SiBEAM's 60 GHz wireless communication systems. In the short term, SiBEAM is able to control the complexity by developing on the basic modulations. OFDM is most scalable, future-proof modulation technique that will fully take advantage of the multi-gigabit data rates capable in the 60 GHz frequency band.