

## A Review on Multiband OFDM Based UWB System

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### **Abstract:**

*Multiband OFDM based Ultra Wideband (UWB) system combines OFDM modulation technique with a multi banding approach, which divides the spectrum into several sub-bands, whose bandwidth is approximately 500MHz in order to meet with FCC requirements. This approach of multibanding introduces orthogonality in the frequency domain and also longer impulse radio pulses in each band are obtained. OFDM based system is very sensitive to timing and frequency offsets, the received constellation is slightly different from transmitted constellation due to processing delay and additional delay introduced from the channel. So Multiband-OFDM (MB-OFDM) is one of the promising candidates for short-range high data-rate UWB communications. It combines Orthogonal Frequency Division Multiplexing (OFDM) with the multi-band approach enabling UWB transmission to inherit all the strength of OFDM technique which has already been proven for wireless communications. In this paper overview of OFDM is discussed and UWB-OFDM system is studied and analyzed.*

**KEYWORD:** - MB-OFDM, UWB, FCC, ISI, ICI

### **INTRODUCTION**

Ultra wideband (UWB) communication systems use signals with a bandwidth that is larger than 25% of the center frequency or more than 500 MHz. It was a revolutionary change in the field of communication when the Federal Communications Commission (FCC) agreed in February 2002 to allocate 7500 MHz of spectrum for unlicensed use of ultra-wideband (UWB) devices for communication applications in the 3.1–10.6-GHz frequency band [1]. Wireless communications experts now consider UWB as available spectrum to be utilized with a variety of techniques, and not specifically related to the generation and detection of short RF pulses, as in the past. UWB communication systems offer several potential advantages, including robustness to multipath interference and inherent support for location-aware networking and multiuser access [1], [2]. UWB is the underlying technology behind

several emerging military sensor and communication networks. Systems developed to date, such as IEEE 802.11b, 11a, or 11g, do not address this market because they are designed to integrate longer-range wireless networks and are integrated on devices that can support higher power consumption and cost. The original UWB systems were based on short-duration and low-duty-cycle pulses, and time-hopping or direct-sequence (DS) spread-spectrum schemes. They usually use Simple modulation schemes such as on-off keying, pulse position modulation, and binary phase- shift keying, and provide features such as power efficiency and low complexity. Orthogonal frequency – division multiplexing technique (OFDM) is successfully used in several narrow-band systems, such as the IEEE 802.11a and g, and provides features such as frequency efficiency and robustness to multipath effects.

Multiband OFDM (MB-OFDM) is the major UWB system from the IEEE 802.15.3a activity that uses OFDM modulation in the UWB spectrum. Multiband-OFDM (MB-OFDM) [5]-[6] is one of the promising candidates for PHY layer of short-range high data-rate UWB communications. It combines Orthogonal Frequency Division Multiplexing (OFDM) with a multi-band approach enabling UWB transmission to inherit all the strength of OFDM technique which has already been proven for wireless communications (ADSL, DVB, 802.11a, 802.16.a, etc.)

### HOW UWB WORKS

A traditional UWB transmitter works by sending billions of pulses across a very wide spectrum of frequencies several GHz in bandwidth. The corresponding receiver then translates the pulses into data by listening for a familiar pulse sequence sent by the transmitter.

Modern UWB systems use other modulation techniques, such as Orthogonal Frequency Division Multiplexing (OFDM), to occupy these extremely wide bandwidths. In addition, the use of multiple bands in combination with OFDM modulation can provide significant advantages to In February 2002, FCC made the formal rules that permit Ultra Wideband to operate under certain indoor and outdoor power spectral masks [14]. FCC has authorized 3.1 - 10.6 GHz band for unlicensed use, for UWB signals and its power spectral density (PSD) should be lesser Magnitude spectrum of narrowband and UWB system than -41.3 dBm/MHz, which is less than other wireless communication system

### UWB system model

The analysis from various research papers gives a general simulation model of UWB system. It consists of three major parts: a transmitter, a channel and a receiver.

### Transmitter Model

The transmitter modulates a bit stream (or parallel bit streams) into a train of output pulses. To simulate the output of a transmitter, Gaussian monopulse with a center Frequency of 6.85 GHz and a bandwidth of 10 GHz are considered. Spectral energy outside the 3.1GHz to 10.6 GHz range is attenuated with a band pass filter and recovered with an equalizer at the receiver side.

traditional UWB systems. Fig. 1 shows the UWB spectrum division into band groups and sub-bands.

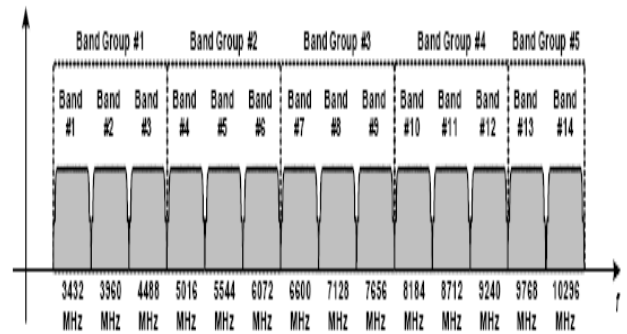


Figure 1

UWB's combination of broader spectrum and lower power improves speed and reduces interference with other wireless spectra. In the United States, the Federal Communications Commission (FCC) has mandated that UWB transmission can legally operate in the range from 3.1 GHz up to 10.6 GHz, at a limited transmit power of -41dBm/MHz. Consequently, UWB provides dramatic channel capacity at short range that limits interference.

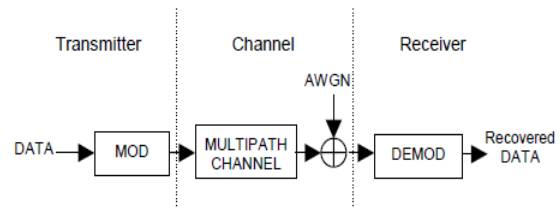


Figure 2

### Receiver Model

The performance of a basic correlator receiver under multipath fading conditions is rather poor, since the total energy is spread over the multipath. The first multipath contains relatively small energy compared with the total energy. We consider a perfect RAKE receiver (PRake) [7] to take advantage of the energy dispersed over the multipath and to provide diversity. The PRake receiver employs maximal ratio combining (MRC), which considers the energy of each multipath scaled by the gain. Note that some multipath will encounter more ISI and intra-symbol interference than others. Any narrowband

interference from the received signal is filtered out before being received by the PRake receiver.

## Digital Modulation Schemes

### Simple systems

The information can be modulated by various ways but these can be divided into three generic types, the first of the schemes is the amplitude modulation which consists of the OOK [On and Off Keying] which is the simplest form of amplitude modulation which is also known as ASK i.e. Amplitude Shift Keying, frequency shift keying and phase shift keying.

There are problems with the simple systems such as:-

- They are degraded by multipath propagation.

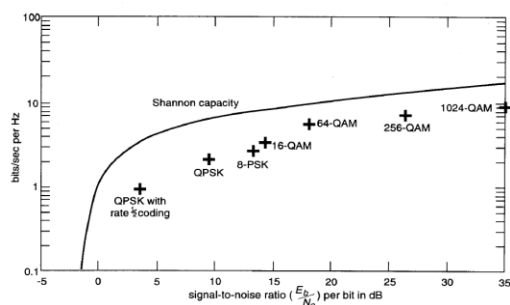


Figure 3

From fig. 3 it should be noted that  $E_b/N_0$  (Which stands for energy bit divided by noise spectral density) is often used as a measure of S/N, as it provides a common basis on which to compare the performance of different systems. The effect of common type of interferences results in the degradation in the system performance. So we look forward to some more advanced digital modulation techniques.

The advanced modulation techniques such as spread spectrum systems, orthogonal frequency division multiple (OFDM) systems and adaptive equalizers provides additional benefits to rugged performance in the presence of multipath.

This paper focuses on orthogonal frequency division multiple access and the most promising technique has been reviewed known as OFDM-UWB.

- They exhibit a relatively increase in number of errors as the signal level as the signal is reduced.
- Most PSK systems exhibit large amplitude variations in the signal envelope. As a result linear amplification is necessary to prevent regeneration of out-of-band frequency components.

To address these problems, most current system use a mixture of amplitude and phase shift keying with data being transmitted on both in-phase(I) and quadrature (Q) components of the carrier. These systems are known as Quadrature amplitude modulation systems (QAM).

### Orthogonal frequency division multiple access

The basic principle of OFDM is to split a high-rate data stream into a number of lower rate streams that are transmitted simultaneously over a number of subcarriers. An OFDM signal is a sum of subcarriers that are individually modulated by using phase shift keying (PSK) or quadrature amplitude modulation (QAM). The symbol can be written as:-

$$S(t) = \text{Re} \sum_{i=Ns/2}^{Ns-1} D_i + \frac{Ns}{2} \exp(j2\pi (F_c - \frac{i+0.5}{T})(t - ts)) ; ts \leq t \leq ts + T$$

$$S(t) = 0, t < ts \text{ and } t > ts + T$$

Where:

$N_s$  is the number of subcarriers

$T$  is the symbol duration

$F_c$  is the carrier frequency

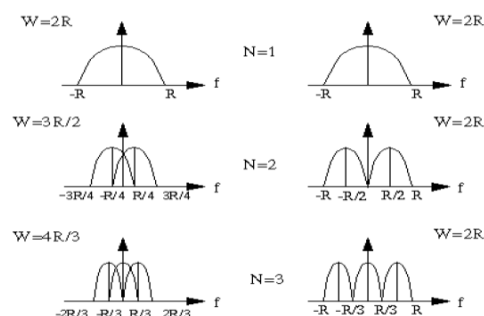


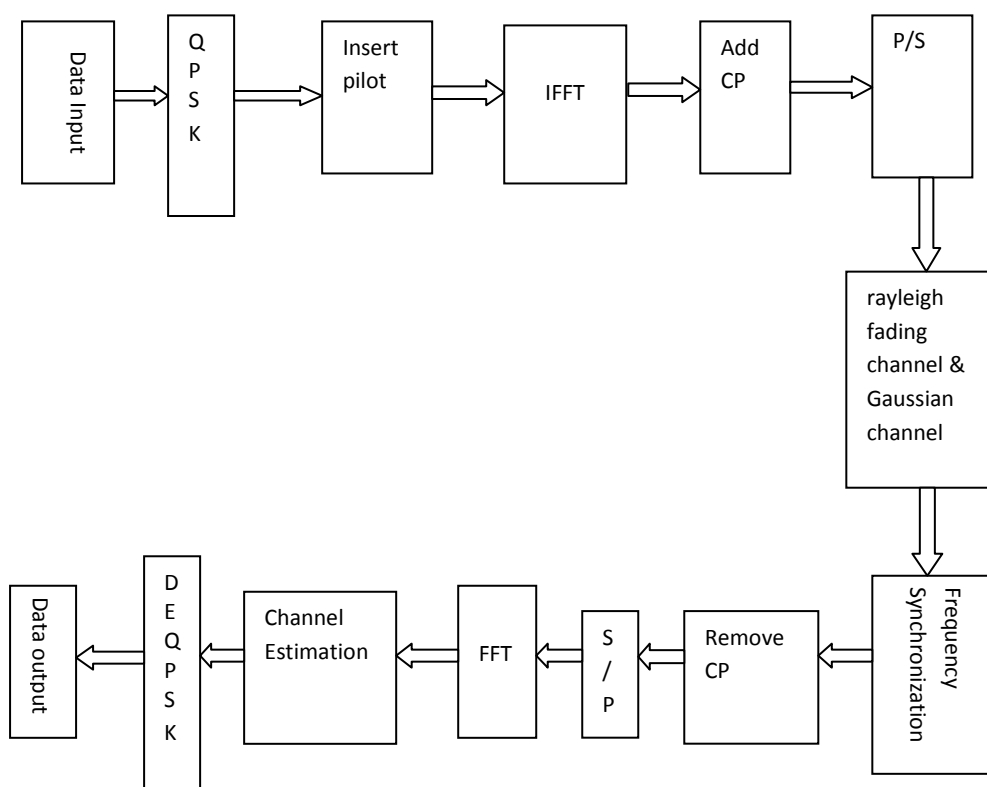
Figure 4

Fig. 4 shows that by using overlapping multicarrier modulation we save almost 50% of the bandwidth.

**OFDM Transmission:-**

Orthogonal frequency division multiplexing is a kind of multi carrier technology (MCM). With the help of OFDM, ISI is eliminated. The basic idea of OFDM is to transform the high-speed data streams into a low rate of N sub-way data flows, and then to modulate N orthogonal sub-carrier. Finally, transmit these data parallelly. In this way data flow rate is the 1 / N of the original's rate and

the symbol period expands N-fold. The guard interval is inserted in order to remove the inter symbol interference (ISI). Moreover, usually we use cyclic prefix (CP) as guard interval, and this avoids the inter-channel interference (ICI) caused by multipath. Thus the spectrum efficiency is improved. Fig.5 shows the process of generating and transmitting the OFDM data sequence.



**Figure 5**

**OFDM on UWB Techniques**

The main UWB techniques are direct sequence and MB-OFDM. These two techniques use very different methods to fill up the same allocated bandwidth and power spectral densities laid out by the FCC in 2002.

**Direct Sequence or Pulse OFDM Technique**

DS uses short impulses to send information. The shorter the pulses are in the time domain, the wider the bandwidth that these signals occupy in the frequency domain. This is due to the relationship defined by the Fourier Transform. In

general, the greatest performance is obtained when these pulses occupy the most bandwidth.

**Multiband Orthogonal Frequency Division Multiplexing (MB-OFDM)**

This technique differs from DS UWB in that instead of using short pulses to fill the bandwidth, a series of subcarriers are used to create a frame of data that is transmitted. Then taking that time domain signal and up converting it to higher frequencies for transmission. Instead, OFDM treats incoming streaming data (inherently in the time domain) as if it is already in the frequency domain by grouping the data in a parallel stream.

Then this parallel stream of data is orthogonally placed on a frequency spectrum to create an OFDM frame, hence the name orthogonal frequency division. Multiband-OFDM occurs when OFDM frames are interleaved in time to different frequencies.

### System Architecture

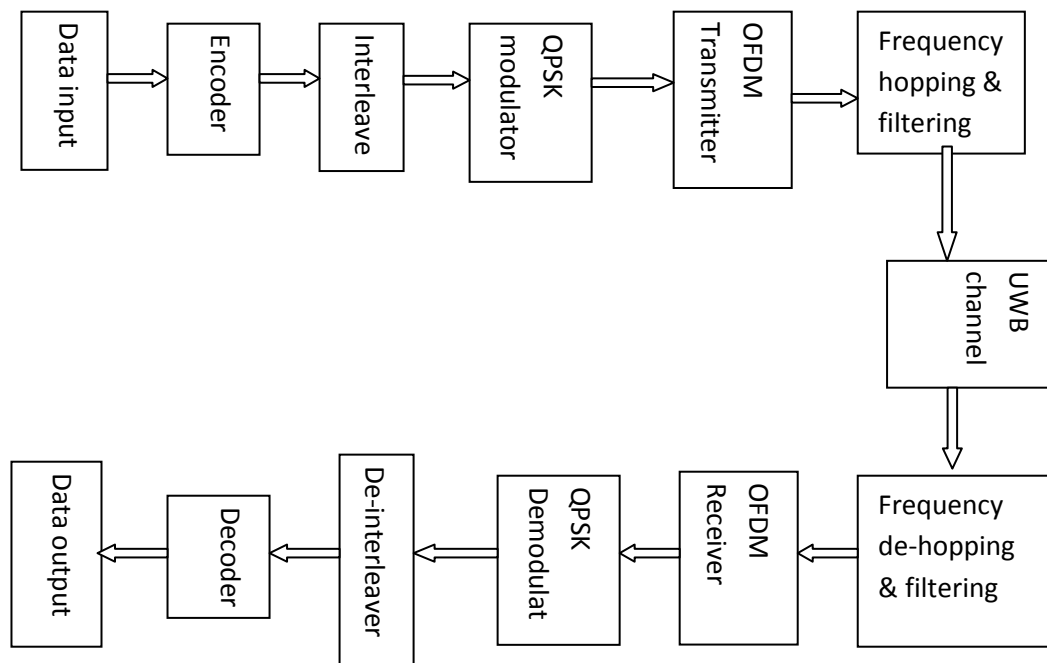


Fig. 6

The system is denoted as an ‘UWB-OFDM’ system because OFDM operates over a very wide bandwidth, much larger than the bandwidth of conventional OFDM systems. OFDM symbols are transmitted using one of the sub bands in a particular time-slot. The sub-band selection at each time-slot is determined by a Time-Frequency Code (TFC). The TFC is used not only to provide frequency diversity in the system but also to distinguish between multiple users. The proposed UWB system utilizes five sub band groups formed with three frequency bands (called a band group) and TFC to interleave and spread coded data over three frequency bands. Four such band groups with three bands each and one band group with two bands are defined within the UWB spectrum mask (Fig. 7). There are also four three-band TFCs and two two-band TFCs, which, when combined with the appropriate band groups provide the capability to define eighteen separate logical channels or independent. Devices operating in band group #1 (the three lowest frequency bands) are selected for the mandatory

Multi-carrier, multi-band systems use orthogonal frequency division multiplexing (OFDM) techniques to transmit the information on each of the sub-bands. MB-OFDM is actually done after the OFDM process above is complete. MB-OFDM is the process of time interleaving an OFDM frame across multiple frequencies. Fig. 6 shows the process of generation and transmission of UWB-OFDM signal.

mode. Figure 7 gives an example of a TFC, where the available bandwidth of 1.584GHz (3.168-4.752 GHz) is divided into three sub-bands of 528 MHz each.

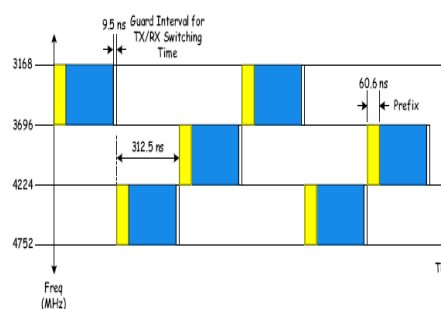


Figure 7

The advantages gained from using MB-OFDM in a UWB system are:

- Reduces the internal precision of the digital logic (IFFT & FFT).
- Reduces the precision required by the analog to digital (ADC) and digital to analog (DAC) converters.



- Relaxes the phase-noise requirements on the carrier synthesis circuitry and improves system robustness.

The only drawback of this type of system is that the transmitter is slightly more complex because it requires an IFFT and the peak-to-average ratio may be slightly higher than that of the pulse-based multi-band approaches.

### Comparison between pulsed OFDM and multiband OFDM

Multiband pulsed-OFDM uses orthogonal 'pulsed' subcarriers, instead of continuous subcarriers. Pulsed OFDM signal is generated by up-sampling the digital OFDM symbol after IFFT block. Up-sampling is done by inserting  $K-1$  zeros between samples of the signal.  $K$  can be termed as the 'redundancy factor' of the pulsed OFDM system. The up-sampled signal is fed into a D/A converter and sent over the channel. As reported in [15], up-sampling a signal in time domain by factor  $K$  results in its  $K$  time repetition in frequency-domain. Hence, pulsed-OFDM provides  $K$  diversity branches which can be combined together using any diversity combining technique (MRC, EGC, etc.), to enhance system performance in dense multipath UWB channels. Clearly, this approach has the potential of simulating large OFDM systems (i.e. with a large number of subcarriers) while actually using short FFT's, the ratio being the redundancy factor. The corresponding constraint is that the various groups of subcarriers that are commuted are now interleaved. The observations from various research papers show that using pulsed-MB-OFDM does not improve so much system performance in terms of BER compared to a robust MB-OFDM mode (almost a gain of 0.3 dB).

It was observed that for high SNR values, the latter approach gives slightly better BER results as compared to MB-OFDM system.

### Challenges of UWB system

According to Linqing Yang and Georgios Giannakis the following problems exist for UWB systems as of 2004 [9]:

- Staying within the FCC limits.
- Improved ADC speeds as well as improved high speed automatic gain control (AGC). High level of complex of complex integration required for CMOS realization.
- As UWB occupies such a wide bandwidth, there are many users whose spectrum will be affected and they need to be convinced that UWB will not cause undue interference to their existing services. The interference could be of two types, first one is that in which the narrow band signals (IEEE 802.11a) can interfere with UWB receivers, that shares 5 GHz frequency band with UWB signals; second one is that UWB signals may interfere into narrow band receivers [13], [14].
- UWB communication systems are limited by the range of power as discussed earlier. So to avoid UWB interference with other radio systems insignificant, the transmission power of UWB signals has to be bounded under the emission mask decided by the FCC [12].

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