Performance Analysis of Multiband OFDM and Pulsed OFDM
Using MATLAB Simulation

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Abstract: *In this paper, we describe a approach for reducing the power consumption and complexity of a multiband orthogonal frequency division multiplexing (MB-OFDM) for ultra wideband (UWB) system by applying ideas from pulsed UWB systems. The approach is quite general and applicable to many other systems. Unlike the MB-OFDM system, the enhancement that we propose uses pulses with duty cycles of less than 1 as the amplitude shaping pulse of orthogonal frequency-division multiplexing (OFDM) modulation. We study the spectral characteristics of pulsed OFDM and the added degrees of diversity that it provides. It is shown that, while pulsed OFDM has superior or comparable performance to MB-OFDM in multipath fading channels, it also has intrinsic low-complexity and power consumption advantages compared with MB-OFDM. To establish this fact, we describe an example design for the IEEE 802.15.3a Standard and present full simulation results for the UWB indoor propagation channels provided by the IEEE 802.15.3a Standard activity committee. In this paper design of OFDM system transmitter and receiver is introduced and simulation is done using MATLAB.*

Keywords: Multiband orthogonal frequency-division multiplexing (MB-OFDM), orthogonal frequency-division multiplexing (OFDM), pulsed OFDM, ultra wideband (UWB).

1. Introduction

Orthogonal Frequency Division Multiplexing is a special form of multicarrier modulation which is particularly suited for transmission over a dispersive channel. Here the different carriers are orthogonal to each other, that is, they are totally independent of one another. Orthogonal Frequency Division Multiplexing (OFDM) is a wideband modulation scheme that is designed to cope with the problems of the multipath reception. Essentially, the wideband frequency selective fading channel is divided into many narrow-band sub channels. If the number of sub channels is high enough, each sub channel could be considered as flat. This is because we transmit many narrowband overlapping digital signals in parallel, inside one wide band. Increasing the number of parallel transmission channels reduces the data rate that each individual carrier must convey, and that lengthens the symbol period. Therefore the delay time of reflected waves is suppressed to within 1 symbol time. Fig.1 compares the bandwidth utilization of FDM and OFDM. The development of OFDM systems can be divided into three parts. They are Frequency Division Multiplexing, Multicarrier Communication and Orthogonal Frequency Division Multiplexing [4].

Frequency Division Multiplexing is a form of signal multiplexing which involves assigning non overlapping frequency ranges or channels to different frequency ranges or channels to different signals or to each user of a medium. A gap or guard band is left between each of these channels to ensure that the signal of one channel does not overlap with the signal from an adjacent one. Multicarrier Communication involves splitting of the signal to give a number of signals over that frequency range. Each of these signals are individually modulated and transmitted over the channel. At the receiver end, these signals are fed to a demultiplexer where it is demodulated and recombined to obtain the original signal.
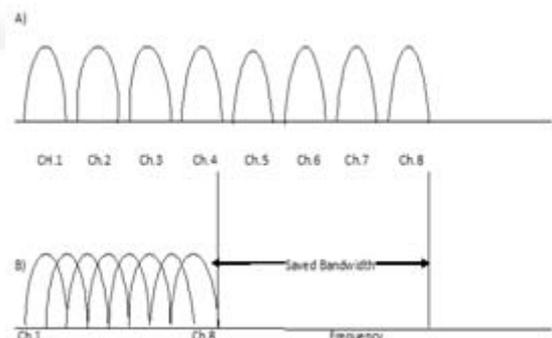

Figure 1: A) Spectrum of FDM showing guard bands, B) Spectrum of OFDM showing overlapping subcarriers

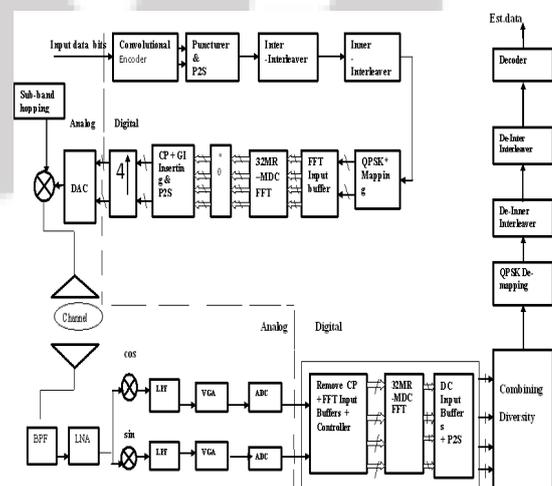## 2. Block diagram of the Pulsed-OFDM System

Figure 2: Block diagram of P-OFDM

The block diagram of P-OFDM system is shown in Figure 2. The pulsed OFDM can simply be generated by replacing the DAC in an OFDM transmitter with a pulse train generator. The generator produces amplitude-modulated pulses with duty cycles of less than 1. If the inverse of the duty cycle is integer, the same signal can also be generated by up sampling the digital baseband OFDM modulated signal before sending it to a conventional DAC. The up sampling is done by inserting K – 1 zeroes between samples of the signal. The resulting pulsed OFDM signal is then a pulse train with a duty cycle of 1/K. Since this kind of pulsed-OFDM system can easily be implemented with a simple change in normal OFDM transmitter. We also refer to parameter K as the processing gain of the pulsed-OFDM system. Both transmitter structures are shown in Figure 3 and 4.
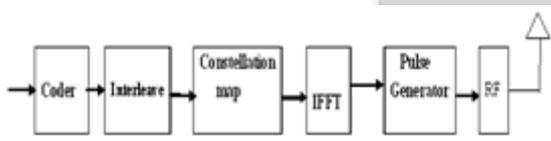

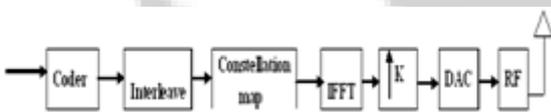**Figure 3:** Block diagram of the Pulsed-OFDM transmitter

Figure 4: Block diagram of the Pulsed-OFDM transmitter using up sampling

Since the pulsed-OFDM system is equivalent to a pulse repetition OFDM system, it can be demodulated by a normal OFDM receiver, followed by a diversity-combing scheme. However, the new implementation using up sampling gives us insights about a lower complexity receive structure. To describe the new receiver structure, we use a digital equivalent model of the system, assuming that the received signal is sampled at the same rate as that of the transmitter DAC. The entire transmission system after constellation mapping can be represented by the digital equivalent model . The main difference between pulsed OFDM and normal OFDM is the up sampling operation after the IFFT. We will show that the up sampling operation provides K branches of diversity that can be separated at the receiver.

After sampling, the signal is passed through a serial-to-parallel converter to separate the diversity branches. Each branch is separately demodulated by applying the FFT. Similar to other OFDM systems, a cyclic prefix (CP) whose length is greater than the maximum sub channel length is added after the IFFT at the transmitter and discarded from the received signals before the FFT in each branch. The CP eliminates inter symbol interference and inter channel interference in all branches. Then, we combine the diversity branches using maximal ratio combining.

Pulsed-OFDM System parameters may be adjusted to meet a wide range of power/throughput/performance requirements:

a) Up sampling factor, K .
b) Number of sub-carriers, N.

c) FFT buffering and radix/switching data paths

At the transmitter, input data bits are first encoded by a rate 1/2 convolution encoder; then a reordering back to sequential format is obtained after passing through the parallel to serial converter. The inter-inter leaver block permutes 150 bits around different sub-bands to exploit frequency diversity. An inner-inter leaver block permutes 50 bits across data tones of each OFDM symbol within each sub band to exploit frequency diversity within a sub-band. The map assigns the OPSK mapping and generates in-phase and quadrature outputs for the corresponding input sequences.

Next, several blocks apply OFDM modulation to a frame of data inputs, which are then passed onto the up sampler before digital to analog conversion. Finally, the transmitted signal is generated by an analog mixer with the assigned sub-band frequencies.

Up-sampling operation in a P-OFDM system allows diversity gains to be achieved at the receiver side. Up-sampling by a factor of K creates K diversity branches. Diversity combining at the receiver combats multipath fading.

At the receiver, as shown in figure 5 the signals from the antenna first pass through the analog front-end to obtain the in-phase and quadrature digital signals. These signals are then demodulated by the FFT module using either sequential channel processing or parallel channel processing methods. The data is then processed by the diversity combining block to enhance the performance and robustness of the system. The QPSK de-map translates the symbol back into bits before being re-permuted by the de-inter leavers. The de-inner-inter leaver and de-inter inter leaver blocks reorder the data back into the original order. Finally, the Viterbi decoder estimates the corresponding transmitted data.

Since the pulsed-OFDM system is equivalent to a pulse repetition OFDM system, it can be demodulated by a normal OFDM receiver, followed by a diversity-combing scheme. However, the new implementation using up sampling gives us insights about a lower complexity receive structure. To describe the new receiver structure, we use a digital equivalent model of the system, assuming that the received signal is sampled at the same rate as that of the transmitter DAC.

3. Simulation Design

It consists of simulation of an OFDM communication system. Figure 6 shows a simplified model of the MATLAB simulation code.
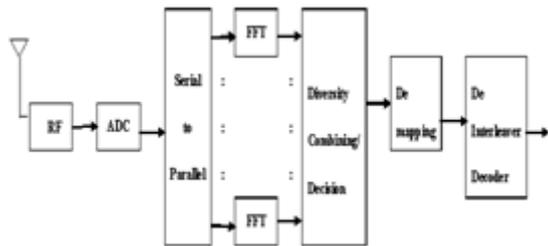
Figure 5: Block diagram of the Pulsed-OFDM Receiver

3.1 Transmitter

The transmitter first converts the input data from a serial stream to parallel sets. Each set of data contains one symbol, Si, for each subcarrier. For example, a set of four data would be [$S^0 S^1 S^2 S^3$]. Before performing the Inverse Fast Fourier Transform (IFFT), this example data set is arranged on the horizontal axis in the frequency domain as shown in Figure 7. This symmetrical arrangement about the vertical axis is necessary for using the IFFT to manipulate this data. An inverse Fourier transform converts the frequency domain data set into samples of the corresponding time domain representation of this data. Specifically, the IFFT is useful for OFDM because it generates samples of a waveform with frequency components satisfying orthogonality conditions. Then, the parallel to serial block creates the OFDM signal by sequentially outputting the time domain samples.

3.2 Channel

The channel simulation allows examination of common wireless channel characteristics such as noise, multipath, and clipping. By adding random data to the transmitted signal, simple noise is simulated. Multipath simulation involves adding attenuated and delayed copies of the transmitted signal to the original. This simulates the problem in wireless communication when the signal propagates on many paths. For example, a receiver may see a signal via a direct path as well as a path that bounces off a building. Finally, clipping simulates the problem of amplifier saturation. This addresses a practical implementation problem in OFDM where the peak to average power ratio is high.

3.3 Receiver

The receiver performs the inverse of the transmitter. First, the OFDM data are split from a serial stream into parallel sets. The Fast Fourier Transform (FFT) converts the time domain samples back into a frequency domain representation. The magnitudes of the frequency components correspond to the original data. Finally, the parallel to serial block converts this parallel data into a serial stream to recover the original input data.
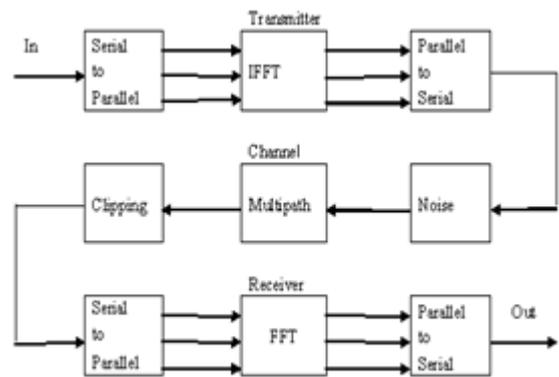

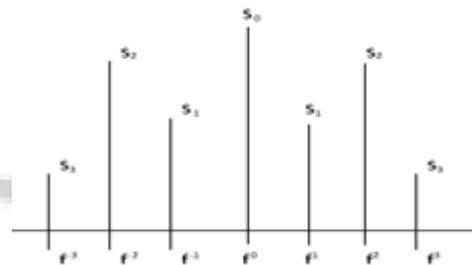
Figure 6: OFDM Simulation Model

Figure 7: Frequency Domain Distribution of Symbols

4. Pulsed-OFDM System Parameters

To transmit 110 Mb/s of information, the MB-OFDM system uses convolution coding with a rate of 1/3, followed by OFDM modulation with M = 128 subcarriers. Only 100 subcarriers are used to transmit data. A direct frequency repetition is also used by sending the same data in two subcarriers. To design a pulsed-OFDM system ,we select a processing gain of K = 4with N = 32 subcarriers. Compared with the M = 128 subcarriers used in the Non pulsed MB-OFDM system, the bandwidth of two signals are identical and equal to W = 528 MHz This condition preserves the band planning of the MB-OFDM system. To achieve the same data rate, we use a convolution error correcting code with a rate of 2/3. Twenty five subcarriers are used to send 25 QPSK symbols that are generated from 50 coded bits. The remaining subcarriers are used as pilot.

5. Performance Comparison

To compare the performance of the pulsed and non pulsed systems, we ran a complete simulation of both systems over the channel models described in the IEEE 802.15.3a UWB channel modeling report. Two channel models named CM3 and CM4 are presented to model the channels at 10 m for the 110-Mb/s mode. Here, we report the simulation results of the pulsed OFDM and MB-OFDM systems for both channels. These simulations assume complete synchronization, timing, and channel estimation for both systems.
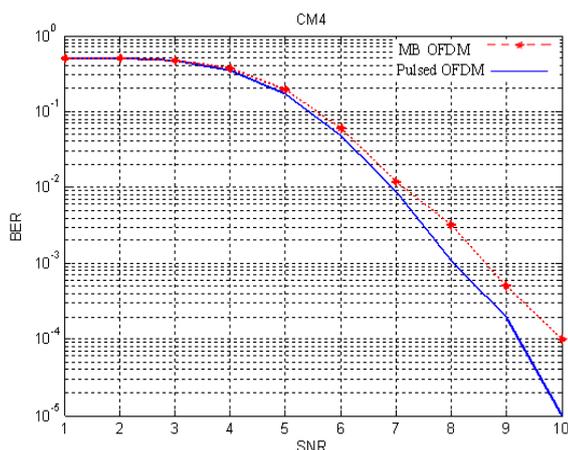
Figure 8: BER verses SNR for the pulsed and nonpulsed OFDM systems in CM4 channel

Figure 8 shows the results over the CM4 channel. This channel model has a delay spread of 250 ns. In this figure, the bit error rate (BER) is plotted versus the signal-to-noise ratio (SNR) for both systems. The simulation results show that the pulsed-OFDM system outperforms the non pulsed system in a high-SNR region. Figure.8 shows the results of the simulations of both the non pulsed and pulsed-OFDM systems when operating over the CM3 channel. This channel is a little better in terms of multipath compared to the CM4 channel and has a delay spread of 150 ns.
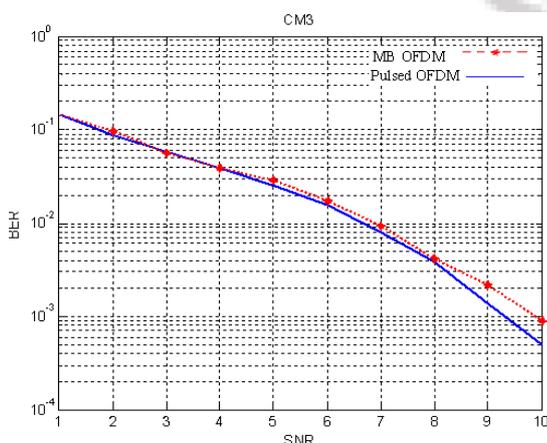

Figure 9: BER verses SNR for the pulsed and nonpulsed OFDM systems in CM3 channel

Figure 9 shows that the performance enhancement is smaller in this channel for pulsed OFDM. We expect the non pulsed system to get better as we move toward less severe multipath channels. Specifically, in the additive white Gaussian noise (AWGN) channel, the non pulsed system has better performance than the pulsed OFDM system because of better channel coding. Hence, we conclude that pulsed-OFDM systems are better in exploiting the frequency diversity of a multipath channel.

6. Performance Discussion

The simulation results in the previous section shows the slight advantage of the pulsed-OFDM system over the MBOFDM system in CM4 and CM3. However, it is important to emphasize some points. These two systems use the same bandwidth to transmit the same amount of data. Their main differences are in the coding and spreading techniques that they use.

While the MB-OFDM system uses a rate-1/3 convolution code and frequency repetition with a factor of 2, the pulsed-OFDM system uses a rate-2/3 convolution code and frequency repetition with a factor of 4. Therefore, the MB-OFDM system has a higher coding gain than the pulsed-OFDM system, whereas the pulsed-OFDM system has a higher diversity gain than the MB-OFDM system. Therefore, the performance comparison of these two systems highly depends on the channel model we use. For example, in the AWGN channel, where diversity is not important, the MB-OFDM system outperforms the pulsed OFDM system because of its higher coding gain, whereas, in a dense multipath channel such as CM4, the opposite is true.

We can say that, overall, they have similar performances. However, the main advantage of pulsed OFDM over MB-OFDM is in terms of complexity and power consumption.

7. Conclusion

MB-OFDM system has the ability to exploit frequency diversity and capture multipath energy without implementing a high-complexity rake receiver. Simple frequency and time repetition schemes along with heavy channel coding and interleaving is used to fill available UWB bandwidth and use the result processing gain to mitigate multipath and multiuser interference. Even better spreading schemes can be used to improve the performance or reduce the complexity. Pulsed-OFDM is a simple frequency spreading technique that can be used to reduce the complexity of the MB-OFDM system by lowering coding overhead and reducing the number of subcarriers while maintaining processing gain and overall performance. Even better spreading schemes can be used to improve the performance or reduce the complexity.

References

[1] H. Tewfik and E. Saberinia, "High bit rate ultra-wideband OFDM", Proc. IEEE Global Telecommunications Conference 2002 (GLOBECOME'02), Taipei, November 2002.
[2] R. Saltzberg,"Performance of an Efficient Parallel Data Transmission System", IEEE Transactions on Communications, COM-15 (6), pp. 805–811. December 1967.
[3] E. Saberinia and A. H. Tewfik, "Pulsed and non-pulsed ultra wideband wireless personal area networks", Proc. of the IEEE Conf. on Ultra Wideband Systems and Technologies (UWBST 2003), Reston, VA. November 2003.
[4] H. Taub, D. L. Schilling, G. Saha, Taub's Principles of Communication Systems,. TataMcGraw Hill,.2008.
[5] J. Balakrishnan, A. Batra and A. Dabak "A multi-band OFDM system for UWB communication", IEEE Conference on Ultra Wideband Systems and Technologies 2003, pp. 354–358, November 2003.
[6] Saberinia, J. Tang, A. H. Tewfik, and K. Parhi "Pulsed OFDM modulation for ultra wideband

communications", IEEE Int. Symp. on Circuits and Systems 2004 (ISCAS'04), Vancouver. May 2004.

[7] Nilesh Chide, Shreyas Deshmukh, Prof. P. B. Borole, "Implementation of OFDM System using IFFT and FFT" , International Journal of Engineering Research and Applications (IJERA) ISSN:2248-9622 www.ijera.com Vol.3, Issue 1, January - February 2013, pp.2009- 2014 | Page

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