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Analaysis and Implementation of UWB Receiver in Multi-Band OFDM Systems

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Abstract: *Orthogonal Frequency Division Multiplexing (OFDM) is a digital multi carrier modulation scheme, which uses a large number of closely spaced orthogonal sub-carriers. In frequency and time must be extremely good. An OFDM system offers inherent robustness to multi-path dispersion with a low-complexity receiver. In OFDM systems Cyclic Prefix uses to maintain orthogonality of transmission. Now days For transmission purpose Ultra-Wideband (UWB) systems use Multi-Band OFDM Techniques. In these the application like Wireless Personal Area Network (WPAN). It is Power limited by the regulation of FCC. CP forces the linear convolution with the channel impulse response to resemble a circular convolution in transmitted data sequence and introduces the ripples in Power spectral Density , So due to this Transmission reduces. The zero-pad suffix (ZPS) will have a flat PSD and hence does not suffer from the range degradation problem. In the UWB receiver, ZP removal requires use of a technique called as overlap and add (OLA) in order to capture the multipath energy of the channel and maintain the orthogonality in the received data. In this paper, we propose a method which adapts the length of Overlap-and-Add depending on the reception of current band. The Existing method shows high delay Spread channel like CM4.For this technique achieves the gain at 10-2 of BER.*

Keywords: *UWB Receiver, Multi Band OFDM System, Adaptive Over lap technique.*

I. INTRODUCTION

Over the last year and half, ultra-wideband (UWB) communication systems have received significant attention from industry, media and academia. The reason for all this excitement is that this technology promises to deliver data rates that can scale from 110 Mbit/s at a distance of 10 meters up to 480 Mbit/s at a distance of two meters in realistic multi-path environments all while consuming very little power and silicon area. It is expected that UWB devices will provide low cost solutions that can satisfy the consumer's insatiable appetite for data rates as well as enable new consumer market segments. But for UWB systems to move from the lab environment to real-life system designs, engineers must battle traditional design issues such as complexity, power consumption, cost, and flexibility. Fortunately, an answer to these problems has arrived. By turning to a multiband OFDM approach, designers can overcome many of these barriers. Even though the FCC has allocated the entire spectrum from 3.1 GHz and 10.6 GHz for UWB, it has been shown that using an upper frequency beyond 4.8 GHz leads to an improvement in the overall link margin of only 1 dB with current RF CMOS technology. This comes at the expense of higher complexity, and higher power consumption.

The minimal gains in the link budget and the increase in complexity and power consumption lead one to conclude that the bandwidth between 3.1 and 4.8 GHz will provide the most effective bandwidth for initial deployments of UWB devices. Indeed, limiting the upper frequency to 4.8 GHz also has several decided advantages, including shortening time to market, simplifying the design of the RF and analog front-end circuits (low noise amplifiers and mixers), making it more amenable to CMOS technology, and avoiding interference from the U-NII band, where IEEE 802.11a signals reside. Of course, limiting the bandwidth of UWB, at least initially, still leaves the possibility that the entire bandwidth will eventually be utilized. As RF technology improves, it will become more efficient to use the upper frequencies in the UWB range. If defined with forethought and proper planning, the UWB systems can accommodate an effective migration path to the upper end of the spectrum when market conditions dictate such a move.

The main advantage of building UWB communication systems based on spread-spectrum techniques are that these techniques are well understood and have been proven in other commercial technologies (ex. wideband CDMA). However, building RF and analog circuits as well as high speed analog-to-digital converters (ADCs) to process this extremely wideband signal is a challenging problem. In addition, the digital complexity needs to be quite large (at least 16 RAKE fingers) in order to capture sufficient multi-path energy to meet the range requirements of 10 meters for a 110 Mb/s system.

In addition to allocating spectrum, the FCC also specified that a UWB signal must occupy a minimum 10-dB bandwidth of 500 MHz. In many ways, this portion of the ruling has revolutionized the design of UWB communication systems. Instead of having to use the entire band to transmit information, the spectrum can now be divided into several sub-bands, whose bandwidth is approximately 500 MHz. By interleaving the symbols across sub-bands, UWB systems can still maintain the same transmit power as if they were using the entire bandwidth.

The advantage is that the information can now be processed over a much smaller bandwidth, thereby reducing the complexity of the design, reducing the power consumption, lowering the cost, and improving spectral flexibility and worldwide compliance. Other advantages of this approach include using lower-rate ADCs and simplifying the digital complexity. Systems built using this type of approach are often referred to as multiband systems. Now that we've taken a brief look at the different multi-band approaches available to designers, let's examine the OFDM-based multiband approach further.

Given the frequency band from 3.1 GHz to 4.8 GHz and the FCC requirement that UWB signals have to be at least 500 MHz, only three sub-bands can be used in the initial deployment of multi-band OFDM systems. Figure 1 illustrates one way to allocate the three sub-bands with the given frequency allocation.

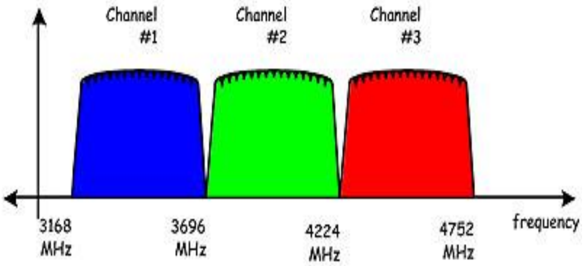

Figure 1: Frequency allocation of sub-bands for a multi-band OFDM system.

The frequency planning shown in Figure 1 was chosen for two reasons. First it allows sufficient guard band on the lower side of channel number 1 and the upper side of channel number 3 to simplify the pre-select filter's design. Second it ensures that both the transmitter and receive can switch to the next center frequency within a few nanoseconds. Figure 2 provides an example of how the OFDM symbols are transmitted in a multi-band OFDM system. This figure shows that the first OFDM symbol is transmitted on channel number 1, the second OFDM symbol is transmitted on channel number 3, the third OFDM symbol is transmitted on channel number 2, the fourth OFDM symbol is transmitted on channel number 1, and so on.

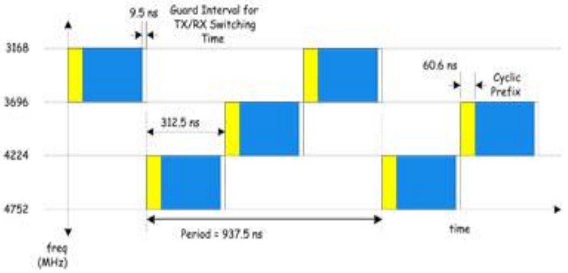

Figure 2: An example of time-frequency interleaving for the multi-band OFDM system

In Figure 2, it is assumed that time-frequency interleaving (TFI) is performed across just three OFDM symbols. In practice, the TFI period can be much longer. The exact length and pattern of the TFI may differ from super frame to super frame and piconet to piconet.

From Figure 2, it is also apparent that a cyclic prefix (CP) is inserted at the beginning of each OFDM symbol and a guard interval (9.5 ns) is appended to each OFDM symbol. The guard interval has been inserted to ensure that only a single RF transmit and RF receiver chain are needed for all channel environments and all data rates and that there is sufficient time for the transmitter and receiver to switch to the next channel. A circular convolution in the time domain is equivalent to a multiplication operation in the discrete Fourier transform (DFT) domain. Hence, a one-tap frequency domain equalizer is sufficient to undo the effect of the multi-path channel.

The length of the CP determines the amount of captured multi-path energy. Any multi-path energy outside the CP window would result in inter-carrier-interference (ICI). The CP length should be chosen to minimize the performance degradation due to the loss in collected multi-path energy and the resulting ICI, while still keeping the CP overhead small. This paper proposes an adaptive reception technique for ZP based systems in an attempt to minimize ISI incursions from subsequent OFDM symbols. In section II, we review the impact of CP and ZP in OFDM systems in general, and outline one of the key motivation factors for this paper. In section III, we relook the ZP removal process in view of multi-band UWB system. In section IV, we discuss our proposed adaptive overlap-add technique. Section V discusses our simulation results and finally we conclude our paper in section VI

II. CP VS ZP IN OFDM BASED SYSTEM

In traditional OFDM systems, a cyclic prefix is used before the OFDM symbol in order to maintain the orthogonality in the received signal after passing through the multipath channel. However as CP introduces a structure in the symbols transmitted, the system suffers from the ripple in the power spectral density (PSD) necessitating power back-off in the transmitter which can be as large as 1.5 dB for MB-OFDM based system [9]. In an alternative, it was pointed out in [7], that we can use zero-padding instead of cyclic-prefix in the transmitted OFDM symbols. The transmission using ZP does not suffer from the ripple in PSD and hence can transmit at maximum power and hence to a longer distance. However to retain the circular convolution property, which essentially provides robustness against multipath channel for OFDM system and facilitates the use of a single-tap frequency domain equalizer in receiver, we require to do a slight modification in signal processing in OFDM receiver. CP based system, can simply discard the CP portion of the received symbol, however for ZP based system we need to do overlap-add (OLA) operation in the receiver shown in Figure 3.

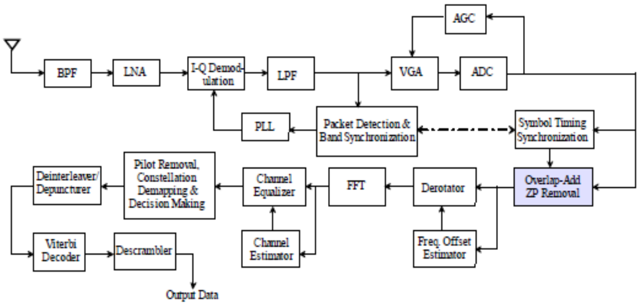

Figure 3: A typical MB-OFDM based receiver architecture

In general, the ZP length should be greater than the delay spread of the channel. As per ECMA-368, this length is 32 samples. Due to multipath propagation, the received OFDM symbol gets smeared at the most by 32 samples, as per assumption that channel length is not greater than 32 samples duration. To mimic what would have happened if there were CP in the transmitted symbol, we need to do overlap-add operation in the receiver. This is illustrated in Figure 4. First we should estimate the start point of true FFT window. As the FFT length in ECMA-368 is 128 samples, from that we should count and pick up 32 consecutive received samples starting from 129th sample onwards. Then we should do a sample-by-sample addition as following. If $r(n)$ is the received samples and n □□0 corresponds to the true FFT window start point, then overlap-add process modifies $r(n)$ as per eqn. (2).

$$\begin{aligned} r'(n) &= r(n) + r(n+128)\ for\ n = 0\ to\ 31, \\ &= r(n), otherwise. \end{aligned} \tag{2}$$

Note that, CP based system is not very sensitive to symbol timing synchronization error. As long as we estimate the start of the FFT window in the portion of CP, the equalizer can correct the phase offset incurred due to the estimation error. However a ZP based system requires more accurate estimation of the start of FFT window. This is because in CP based system the circular convolution is an effect of natural phenomenon. The physical propagation of the OFDM signal through multipath channel causes linear convolution, which appears to be a circular convolution due to the cyclic property artificially maintained due to CP addition. However linear convolution does not appear naturally as circular convolution for ZP based system. Overlap-add operation makes sure this artificial circular convolution appearance, which depends on the true start point of the FFT window. Hence ZP based system is quite sensitive to the timing synchronization estimation error compared to CP based system. This is one of the key motivation factors of this paper.

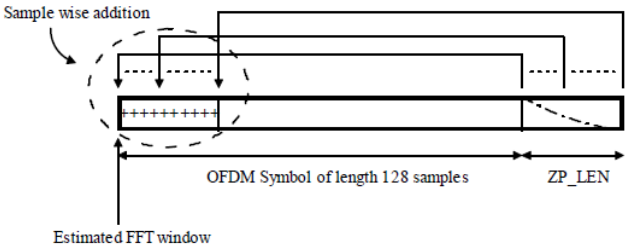

Figure 4: ZP removal by overlap-add operation using ZP length equal to 'ZP_LEN'. Note that, 'ZP_LEN' can be fixed (32 samples), as in traditional system, or could be variable depending on some parameter, as proposed in this paper

III. AN FOR ZP REMOVAL IN VIEW OF MULTI BAND TIMING SYNCHRONIZATION (MBTS)

In UWB, we see four type of channel models proposed for research and developmental work, they are CM1, CM2, CM3 and CM4. Without going into details of them, it should be highlighted that CM1 corresponds to small delay spread channel, whereas delay spread increases as we go towards CM4 [11 and references therein]. In [9] and [10], it is pointed out that there exists an overlap-add length ('ZP_LEN' in Fig. 4) for which the receiver performs optimally. This is because for small delay spread channel (say CM1 with a delay spread of 4 samples as one realization), if we use ZP_LEN = 32 samples, then we are essentially picking up some (28 in this example) pure noise samples during overlap-add process, which affects BER adversely. This essentially means we should estimate the channel delay spread and use a variable 'ZP_LEN' during overlap-add procedure, as outlined in [9-10]. The estimation of channel delay spread can be done in a few ways mainly from the cross-correlation characteristics in time domain in timing synchronizer block and one of the methods has been proposed in [9].

This type of adaptive overlap-add method based on estimation of channel delay spread is more beneficiary for small delay spread channel and hardly benefits anything for large enough delay spread channel. It also should be pointed out that the above method demands a very small estimation error in locating the FFT window, which is quite difficult to achieve in UWB system. On the other hand, in [11], it was pointed out that the mean delay of the UWB channel differs significantly depending on the band of transmission. Accordingly they have proposed a timing synchronization algorithm, which they called as multi band timing synchronization (MBTS) algorithm, which essentially proposes to estimate the true start point of FFT window depending on the band of transmission. Note that, this variance of mean delay is due to the manifestation of the multipath channel in multi-band scenario while the channel length remains same.

Hence it may happen for a band, the FFT start point might get estimated say at the sample number 16, rather than 0 or closed to 0. In that case if we use a fixed 'ZP_LEN' of 32 samples for overlap-add operation, then we are essentially picking up samples from the next OFDM symbol which leads to ISI. Figure 5 shows the offset sensitivity of BER performance of MB-OFDM system. Here offset = 0 implies the true start point of FFT window if there is no noise and there exists a non-zero multipath component at the first sample location. Note that, even if there is no non-zero multipath component at 0th location, still a start point of FFT window at that location will always perform optimally in no noise condition, because equalizer can take care as no multipath component to equalizer will appear as non-causal component. Note that, the curves show that MB-OFDM system is quite sensitive to the ISI incursions from the next OFDM symbol.

IV. A PROPOSED ADAPTIVE OVERLAP-ADD TECHNIQUE

In this section we propose a technique to reduce the ISI incursions from the subsequent OFDM symbol due to the use of fixed 'ZP_LEN' during overlap-add process. At the same time we try to make the method robust with respect to the estimation error of the true start point of the FFT window in the smeared received signal. In general the timing synchronizer block provides the estimated offsets over different bands as signed numbers because the estimation point can shift in left as well as right depending on the situation. If any of the estimated offsets becomes negative, we first make all of them positive using the following algorithm (Alg#1) and provide necessary delay in data path in order to make the receiver a causal system.

Alg#1:

Say, OB_i denotes the signed offset of band i, where $i \in 1, 2, or\ 3$. Let UOB_i denotes the unsigned offset of band i after making the system causal.

```
If $(OB_1 < 0\ or\ OB_2 < 0\ or\ OB_3 < 0)$ Then
{
    For $i = 1\ to\ 3$, %''i' is the band number
    $UOB_i = OB_i + \max(abs(all\ negative\ OB_j));$
    Where $j \in 1, 2, 3$.
}
Else,
    $UOB_i = OB_i$;
```

We notice that it is expected that $(OB_i \sim OB_j) \leq 32$, i, j belonging to band number, as the channel length is 32 samples. This also guarantees that the range of UOB_i is 0 to 32.

The variation in i UOB is solely due to channel manifestation and the channel length remains same as 32 samples. So to avoid ISI incursion from the next OFDM symbol we use band-dependent variable ZP length ('ZP_LEN_Bi') during overlap-add operation over multiple bands as per the following algorithm (Alg#2).

Alg#2:

```
For $i = 1\ to\ 3$, % band number
    $ZP\_LEN\_B_i = 32 - \{UOB_i - Min(UOB_1, UOB_2, UOB_3)\};$
End for loop;
```

Note that in Alg#2, apart from making the scheme robust to the estimation error of the true start point of the FFT window, we have also made sure that the chances of the equalizer of seeing non-causal multipath components minimal.

The above algorithm (Alg#2) is valid for single band or dual band transmission as well. For single band transmission, the process ceased to be band dependent adaptive and becomes fixed 'ZP_LEN' as 32 samples. So, as per Alg#2, a band-dependent 'ZP_LEN' number of samples after the FFT window is picket up and added to the front portion as shown in Figure 4

V. SIMULATION RESULTS

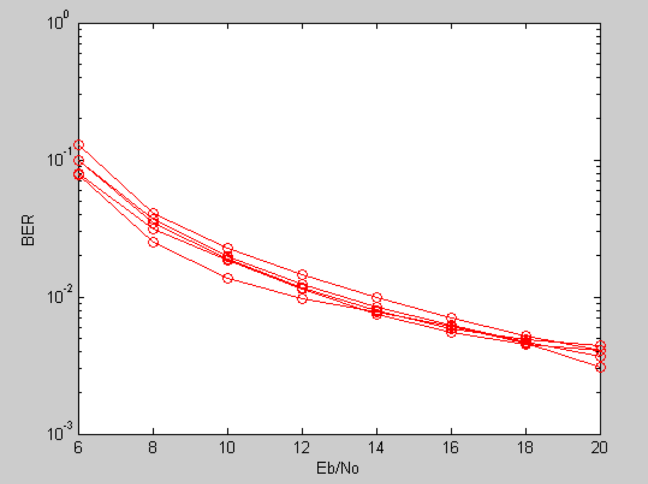

Figure. 5. Offset sensitivity of BER for all channel models at 10 dB Eb/N0 with fixed (32 samples) 'ZP_LEN'

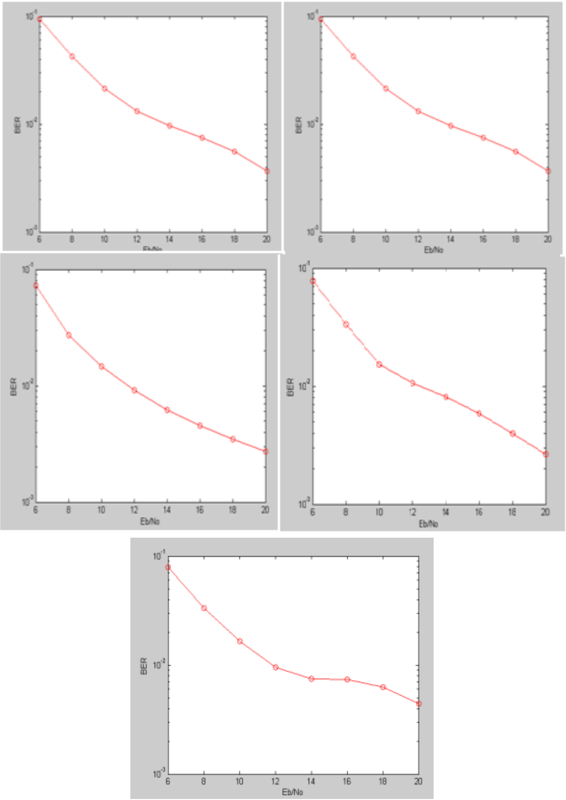

Fig. 6. BER vs Eb/No (in dB) simulation for all channel models in uncoded MB-OFDM system. Data1: using variable ZP length. Data2: Using fixed ZP length of 32.

Figure 6 shows the BER curves for un coded MB-OFDM based UWB system with and without band wise variable ZP length for overlap and add operation. For large delay-spread channels in UWB systems the mean excess delay is more compared to small delay-spread channels. This implies for large delay spread channel, the estimation of FFT window will be more away from the true FFT window resulting in more ISI incursions from next OFDM symbol. Hence the proposed technique is more promising for large delay-spread channels. The curves show a significant amount of performance improvement (for CM4 around 1 dB of Eb/N0 savings at 10-2 BER for un coded system) is achieved for large delay-spread channels.

VI. CONCLUSION

In this paper as well as in some prior arts that adaptive overlap-add technique is beneficiary for OFDM based receivers in terms of BER performance. In some related literature [9], it had been proposed to adapt 'ZP_LEN' for overlap-add operation depending on the true channel length in order to avoid picking up pure noise samples during the OLA process. This method is more fruitful to channels having small delay-spread (e.g. CM1) and hence a small estimation error in FFT window will eventually reduce the benefit significantly. Moreover in [9], two independent process runs. One is estimation of the channel delay spread and the other is estimation of FFT window. Both of them are used in adaptive OLA process and hence may make things worse instead of improving if they are not aligned properly.

In an alternative, in this paper, we have proposed a band dependent adaptive OLA technique which tries to minimize ISI incursion from subsequent OFDM symbols. This method is not so sensitive on the estimation of true start point of FFT window, in a sense that a small estimation error will not be able to take away the benefits of the technique. Moreover in this method all the signal processing is dependent on one independent process i.e. estimation of the FFT window and hence the question of dependency of two independent process does not arise at all. The method is more promising for large delay spread channels and provides a significant Eb/N0 improvement in the detection process. A natural choice of future work would be to mix the above two independent ideas (i.e. one in [9], and the one proposed in this paper) and study its impact on overall system performance.

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