Enhancement Orthogonal Frequency Division Multiplexing (OFDM) in Wireless Communication Network by Using PTS(Partial Transmit Sequences) Technique

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Abstract

Wireless telecommunications has been significantly growing due to the need of high data rate during the last decade. In this paper, OFDM with different scenarios are experimentally tested and the results demonstrate the strengths of OFDM technique as a key technology that fulfils the need of high data rate and high performance in wireless communication. Furthermore, we demonstrate that the complexity of OFDM technology can be reduced and the capacity is increased by using Partial Transmit Sequences (PTS) method. This method shows the best performance of OFDM where increased capacity, coverage, and reliability are clearly evident from the test results presented in this paper.

Keywords: Orthogonal Frequency Division Multiplexing (OFDM), FFT (Fast Fourier Transform), BPSK (Binary Phase Shift keying) and QAM (Quadrature Amplitude Modulation), PAPR (Peak to Average Power Ratio), Partial Transmit Sequences (PTS).

1. Introduction

Orthogonal Frequency Division Multiplexing (OFDM) is also known as a multicarrier modulation technique, which has been the key behind the most advances and achievements associated with high data rate communications. OFDM nowadays has become so popular due to its flexible and efficient management of inter-symbol interference (ISI). Moreover, OFDM grants high spectral efficiency and mitigates the multipath environment effects. OFDM divides the data stream into multiple sub-streams and sends them through multiple orthogonal sub-channels. Generally, the overall system performance and communication link quality is improved by OFDM technology [1-4].

There is a lot work introduced in literature that focusses on Orthogonal-Frequency-Division-Multiplexing (OFDM) technology. In 1960, the parallel data transmission was proposed to increase data processing and transmission traffic due to the desired demand of high data rate in communication networks. Furthermore, Frequency Division Multiplexing (FDM) was introduced as a technique in parallel data transmission [3].

FDM divides the frequency spectrum into slots that are called transmission channels. Furthermore, each slot should be assigned to one transmission channel. These frequency sub-bands cannot be overlapped neither can be placed adjacently, which means that multicarrier FDM communication link designers should not only assign non-overlapped frequency bands for transmission channels but also leave frequency guard bands in between those assigned frequency bands [5]. Consequently, multicarrier modulation technique has two disadvantages. The first one is the implementation complexity and the second one is the spectral inefficiency.

Weinstein and Ebert proposed a multicarrier system which works with discrete Fourier Transform (DFT) [14, 15]. DFT was implemented as a part of the modulation and demodulation process in the multicarrier communication systems to reduce complexity. Inverse Discrete Fourier Transform (IDFT) and Discrete Fourier Transform (DFT), according to Weinstein and Ebert proposed approach, are used to perform the modulation and demodulation processes, respectively. Then, many research efforts have been made to improve multicarrier communication system complexity even more. The most successful improvement is the use of Fast Fourier Transform (FFT) and Inverse Fast Fourier Transform (IFFT) instead of DFT and IDFT respectively. By that time, both system complexity and bandwidth inefficiency problems were handled through modifications being added one after another and the last one was introduced by Weinstein and Ebert as mentioned before. Furthermore, OFDM divides the high rate input data stream into lower rate multiple sub-streams. Then, those sub-streams are modulated on orthogonal subcarriers offering high spectral efficiency, frequency flat fading sub-channels, free ISI communication link, and robust modulation and multiple access schemes [17] and [18].

2. OFDM Concepts

The straightest forward idea of OFDM is to divide the high rate data stream into lower rate sub-streams and send them over through multiple parallel sub-channels [13]. Many advantages, therefore, have been accomplished after applying the idea of OFDM multi carrier communication system.

3.1 OFDM Orthogonality

One of the aspects that have made OFDM so popular multicarrier communication technique is that OFDM system occupies the frequency spectrum efficiently and wisely. OFDM satisfies orthogonality of communication system subcarriers which means that a mathematical relationship between these subcarriers is developed to allow these subcarriers to overlap without having any adjacent sub-channels interference [6]. In any OFDM system, if we have N equally spaced subcarriers, for instance, we would satisfy the orthogonality property when we place them within the specified frequency spectrum with frequency spacing equals to:

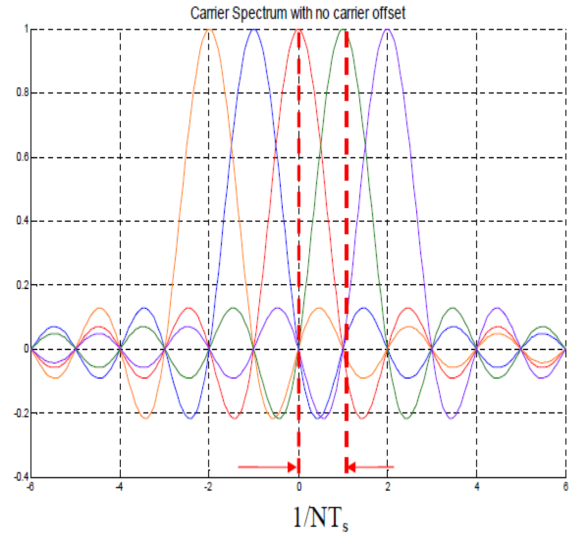

Figure 1: Orthogonality property for five sub carriers [5].

$$\Delta f = 1/(N.Ts) \qquad (1)$$

Where N. Ts = Symbol duration [6].

This mathematical relationship creates a sine frequency response for all these N subcarriers where each one of them has maximum amplitude at a point, whereas others have nulls [6]. Figure1 shows how OFDM works.

The mathematical proof, which shows there is no interference between signals if spaced as in equation (1), is provided in [9] as the following:

$$\int_0^{N.Ts} X_k\,(t) X_1 * (t) = \begin{cases} 0\,, k \neq 1 \\ C\,, k = 1 \end{cases} \qquad (2)$$

Where, C is constant.

Equation (2) shows that out of 5 OFDM subcarriers, shown in Figure 1, the amplitude of only one subcarrier can be non-zero value at a frequency of multiples of 1/(N.Ts) while the remaining ones should have zero amplitudes.

As a result of this orthogonality aspect, the spectral inefficiency problem has been taken care of as it has been shown in Figure 2. Considering that the system frequency bandwidth is the most valuable component in any communication system, OFDM system has met the aim of occupying the communication system spectrum efficiently. According to [8, 11, 12], OFDM multi carrier system occupies 50% of the bandwidth that regular FDM multicarrier system does.

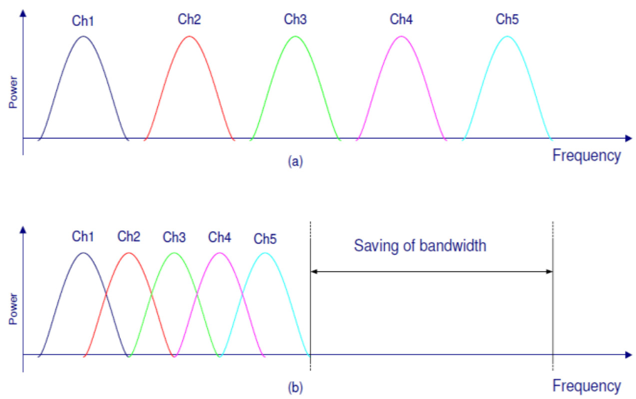

Figure 2: Shows what the differences between the. FDM and OFDM spectral efficiencies are [16].

3.2 ISI, ICI, guard time, CP in OFDM system

Another reason why OFDM is preferred over regular single carrier modulation is the fact that OFDM mitigates the effects of multipath delay spread significantly. By dividing the data stream into N sub-streams, the symbol duration time of each sub-stream is smaller than the original one by a factor of (1/Ns) [8]. This shorter symbol duration helps reducing the effects of multipath delay spread by a factor of (1/Ns) as well.

ISI is unwanted phenomenon which happens during the communication process when one symbol interferes with the adjacent symbols, or i.e. when the energy of one symbol spills over the adjacent symbols [1]. When the channel delay spread time (τ) is larger than the symbol spread time (T), ISI becomes severe. In addition, ISI becomes ever more serious issue with high data rate communication systems so this phenomenon needs to be overcome to maintain communication quality. Therefore, one of the goals that communication link designers were trying to achieve is handling ISI and supporting high data rates at the same time. The idea of OFDM that has handled ISI problem is dividing high data rate stream wanted to be transmitted into (L) lower rate sub-streams such that each one has (Ts/L) >> (τ). This property gives almost free ISI communication, as a result of ISI criterion mentioned above [1]. Moreover, OFDM handles ISI problem from another angle to improve the results and eliminate effects even more. That angle is to insert a guard time slots in between OFDM symbols as it is shown in Figure 3. These guard slots should be chosen to be larger than the expected symbol delay spread time. Doing so, OFDM ensures that multiple components received of one symbol due to multipath environment do not interfere with the adjacent symbols components [8].

That inserted guard time can be zero content signals. However, introducing such guard slots raises the effects of Inter Carrier Modulation (ICI). ICI is the consequences of losing subcarriers orthogonality in OFDM system and that happens when the receiver tries to retrieve one of the subcarriers while a portion from the adjacent symbol is being added causing ICI [7]. Simply means when OFDM subcarriers are not properly synchronized, the problem of ICI would arise, or i.e. when having frequency offset between OFDM subcarriers as it is illustrated in Figure 4. That frequency offset causes ICI between adjacent subcarriers when trying to demodulate one subcarrier which is not synchronized properly with the adjacent one.

The proposed solution for this problem is adding cyclic prefix (CP). CP was proposed first in 1980 by Peled and Ruiz as in [9]. Their idea was to occupy those time guard slot of any OFDM symbol with the last portion of that symbol as it is shown in Figure 5, a & b. That portion duration chosen to have *Ng* samples. This time duration should be longer than the longest expected symbol delay spread. Therefore, the transmitted signal will have (Ng + N) samples. The advantage of CP is to create an integer number of cycles of each subcarrier when being passed through FFT process or simply to maintain subcarriers orthogonality [8].

As a result of adding CP, energy from one subcarrier will not interfere with others within FFT process. At the receiver side, in order to retrieve the original N samples, the added *Ng* samples should be excluded out. Doing so means that the signal to noise ratio (SNR) gets decreased due to the fact that these samples are being transmitted and received and they have no useful information. In addition to the drop in SNR, power consumption is a drawback of adding CP. That high power consumption takes place because the transmitter consumes power to transmit CP samples which contain no useful data.

taken care of than the selective frequency fading consequences are. One of the most valued benefits of not having frequency selective fading is that the receiver no longer needs complex equalizers and RAKE receivers [10].

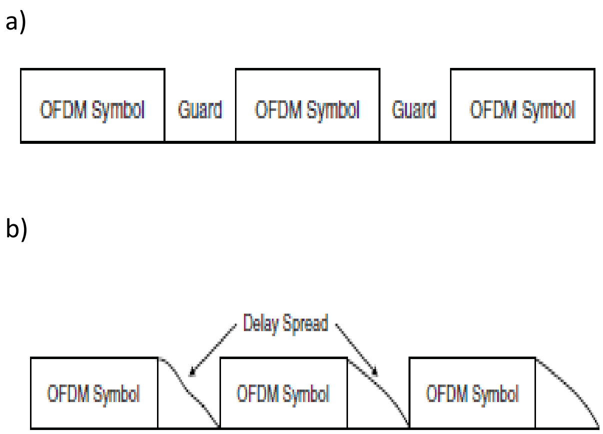

Figure 3: (a) & (b) show how the guard band is left In between OFDM symbols [8].

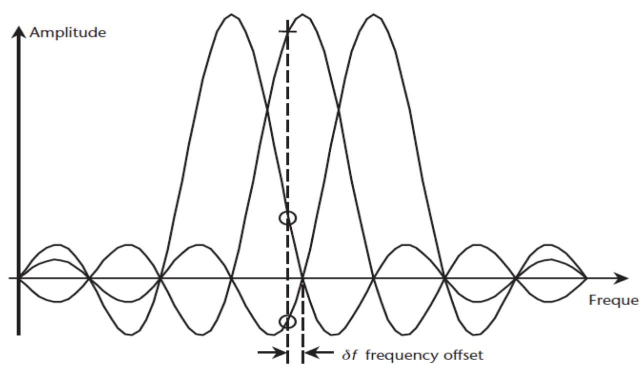

Figure 4: Shows frequency offset problem which yields to ICI.

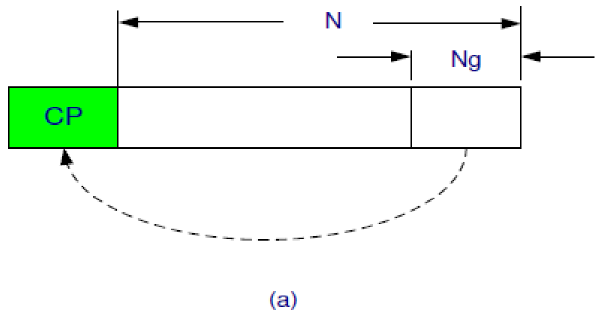

Figure 5: a) Shows CP procedure [16].

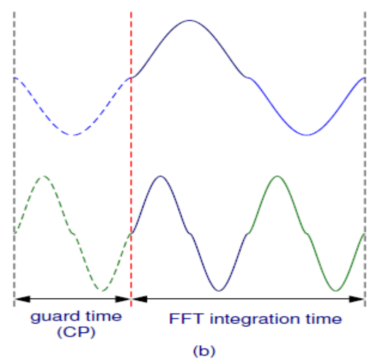

Figure 5: b) Shows how CP is being added [16]

3.1 OFDM frequency flat fading

OFDM has been the most known modulation scheme candidate for high data rate wireless communications. OFDM does group high data rate input stream into smaller lower rate multiple sub-streams to ensure that each sub-stream would have a flat fading not a frequency selective one [10].

Selective frequency fading takes place when having a wide range of frequencies and some of these frequencies are more vulnerable to be faded than other frequencies are. Therefore, when OFDM divides the wideband frequencies into narrower frequency sub-bands, those narrow bands experience the same fading effects along that sub-band which is called flat frequency fading. It is known that flat frequency fading consequences are lighter and easier to be

To be more specific, a communication system with flat frequency fading needs only simple equalizer at the receiver side, while the same communication system would need more than one complex tap equalizers if having frequency selective fading.

4. PAPR in OFDM

One of the OFDM implementation challenges is peak to average power ration (PAPR).The major challenge of implementing OFDM system is the high PAPR. IFFT procedure in OFDM system involves adding up N subcarriers which are all sinusoids. This summation of N subcarriers, at some points gives high peaks values compared to the average ones and that is well known as high PAPR. This high PAPR is simply described as an envelope fluctuation which causes many issues that degrade the system performance as in [1], [4], and [13]. The most commonly used technique to evaluate the system PAPR is the cumulative distribution function (CDF). In the most recent publications, the complementary cumulative distribution function (CCDF), which can be derived from the CDF, is also used to evaluate the system PAPR.

5. PTS in OFDM

Partial Transmit Sequences (PTS) is one of the best techniques that reduce the effect of the peak to average power ration (PAPR) in OFDM scheme. For this technique, the input data block is divided into N sub-blocks and each one of these sub-blocks has multiple subcarriers. For each sub-block, the subcarriers are weighted by a phase factor. These phase factors are developed in a way to get the PAPR of the combined OFDM signal reduced. The block diagram of PTS is shown in Figure 6.

6. Results

Simulation results are shown in Figure 7 for OFDM signals by calculating its PAPR (Peak to Average Power Ratio) based on different sample points Ns, 64, 128,256,512 and 1024. The x-axis represents the diverse OFDM values, while y-axis represents the CCDF values. The simulation in Figure 8 shows that OFDM performs better when the some partial transmit sequences (PTS) are chosen for different sub blocks points. The x-axis represents the PAPR (dB) values, while y-axis represents the probability of (PAPR > PAPR0) values.

The result of OFDM when PAPR is considered shows that CCDF (Complementary Cumulative Distribution Function) increases when the number of chosen points of OFDM increase which make the system fast and more applicable. The results illustrated the performance of OFDM signal in response to using FFT, BPSK and QAM. Moreover, the CCDF of OFDM signal is more accurate when the number of OFDM points is increased. Using PTS of PAPR the OFDM performance has clear improvement and strong ability. The results show that probability of (PAPR > PAPR0) increased from 10^{-4} to 10^{-1}.

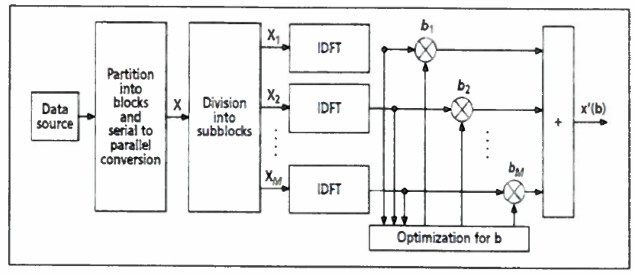

Figure 6: PTS system block diagram [4]

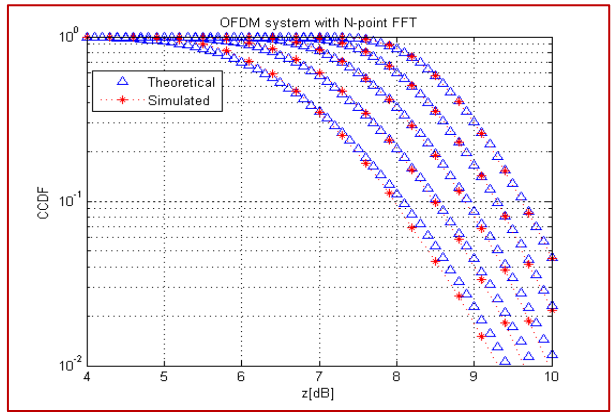

Figure 7: the relation between OFDM and CCDF for different points with N= 64, 128, 256, 512, and 1024

7. Conclusion

Orthogonal Frequency Division Multiplexing (OFDM) is an efficient technique that increases speed, range, reliability and spectral efficiency for wireless systems. In this paper we present OFDM using Partial Transmit Sequences (PTS). The simulation results demonstrate the improvement in capacity and reliability of OFDM using PTS. Furthermore, we demonstrate that OFDM signal becomes more accurate when the number of OFDM points is increased. Also, using FFT, BPSK and QAM techniques improve OFDM performance and throughput. Moreover, OFDM is more efficient and flexible when the PTS PAPR reduction technique is used.

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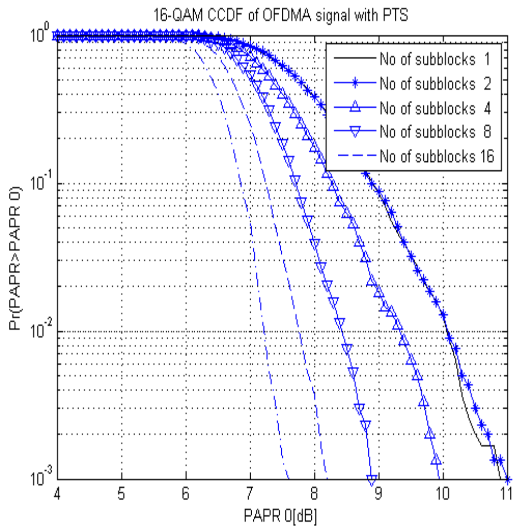

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Figure 8: the relation of 16 QAM CCDF signal with PTS for different sub blocks points with N= 1, 2, 4, 8, and 16.

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