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PEAK-TO-AVERAGE-POWER-RATIO (PAPR) REDUCTION TECHNIQUES FOR ORTHOGONAL-FREQUENCY-DIVISION-MULTIPLEXING (OFDM) TRANSMISSION

A Dissertation

Presented to

the Faculty of Engineering and Computer Science

University of Denver

In Partial Fulfillment

of the Requirements for the Degree

Doctor of Philosophy

by

Bader Hamad Alhasson

June 2012

Advisor: Dr. Mohammad A. Matin

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Author: Bader Hamad Alhassoun Title: PEAK-TO-AVERAGE-POWER-RATIO (PAPR) REDUCTION TECHNIQUES FOR ORTHOGONAL-FREQUENCY-DIVISION-MULTIPLEXING (OFDM) TRANSMISSION Advisor: Mohammad A. Matin Degree Date: June 2012

ABSTRACT

Wireless communication has experienced an incredible growth in the last decade. Two decades ago, the number of mobile subscribers was less than 1% of the world's population. As of 2011, the number of mobile subscribers has increased tremendously to 79.86% of the world's population.

Robust and high-rate data transmission in mobile environments faces severe problems due to the time-variant channel conditions, multipath fading and shadow fading. Fading is the main limitation on wireless communication channels. Frequency selective interference and fading, such as multipath fading, is a bandwidth bottleneck in the "last mile" which runs from the access point to the user. The "last mile" problem in wireless communication networks is caused by the environment of free space channels through which the signal propagates. Orthogonal Frequency Division Multiplexing (OFDM) is a promising modulation and multiplexing technique due to its robustness against multipath fading. Nevertheless, OFDM suffers from high Peak-to-Average-Power-Ratio (PAPR), which results in a complex OFDM signal.

In this research, reduction of PAPR considering the out-of-band radiation and the regeneration of the time-domain signal peaks caused by filtering has been studied and is

presented. Our PAPR reduction was 30% of the Discrete Fourier Transform (DFT) with Interleaved Frequency Division Multiple Access (IFDMA) utilizing Quadrature Phase Shift Keying (QPSK) and varying the roll-off factor. We show that pulse shaping does not affect the PAPR of Localized Frequency Division Multiple Access (LFDMA) as much as it affects the PAPR of IFDMA. Therefore, IFDMA has an important trade-off relationship between excess bandwidth and PAPR performance, since excess bandwidth increases as the roll-off factor increases. In addition, we studied a low complexity clipping scheme, applicable to IFDMA uplink and OFDM downlink systems for PAPR reduction. We show that the performance of the PAPR of the Interleaved-FDMA scheme is better than traditional OFDMA for the uplink transmission system. Our reduction of PAPR is 53% when IFDMA is used instead of OFDMA in the uplink direction. Furthermore, we also examined an important trade-off relationship between clipping distortion and quantization noise when the clipping scheme is used for OFDM downlink systems. Our results show a significant reduction in the PAPR and the out-of-band radiation caused by clipping for OFDM downlink transmission system.

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List of Abbreviations

ADC	Analog to Digital Converter
DAC	Digital to Analog Converter
BPSK	Binary Phase Shift Keying
BER	Bit Error Rate
CR	Cognitive Radio
CDMA	Code Division Multiple Access
СР	Cyclic Prefix
CDF	Cumulative Distribution Function
DVB	Digital Video Broadcasting
DFT	Discrete Fourier Transform
DTV	Digital Television
FFT	Fast Fourier Transform
FDM	Frequency Division Multiplexing
FDMA	Frequency division Multiple Access
GSM	Global System for Mobile Communication
ISI	Inter Symbol Interference
ICI	Inter Carrier Interference
IFDMA	Interleaved Frequency Division Multiplexing Access
IFFT	Inverse Fast Fourier Transform
LTE	Long Term Evolution
LAN	Local Area Network

- LFDMA Localized Frequency Division Multiplexing Access
- MIMO Multiple Input Multiple Output
- MISO Multiple Input Single Output
- **OFDM** Orthogonal Frequency Division Multiplexing
- PSD Power Spectral Density
- PTS Partial Transmit Sequences
- PSK Phase Shift Keying
- PAPR Peak to Average Power Ratio
- **QPSK** Quadrature Phase Shift Keying
- **QAM** Quadrature Amplitude Modulation
- **SNR** Signal to Noise Ratio
- SC-FDMA Single Carrier Frequency Division Multiple Access
- SISO Single Input Single Output SIMO Single Input Multiple Output
- SQNR Signal to Quantization Noise Ratio
- **TR** Tone Reservation
- TI Tone Injection
- **WiMAX** Worldwide Interoperability for Microwave Access
- Wi-Fi Wireless Fidelity
- WLAN Wireless Local Area Network
- WCDMA Wide Code Division Multiple Access
- WLAN Wireless Local Area Network

Chapter 1

INTRODUCTION

1.1 Background

Wireless communication has experienced an incredible growth in the last decade [1]. Two decades ago, the number of mobile subscribers was less than 1% of the world's population. In 2001, the number of mobile subscribers was 16% of the world's population according to the International Telecommunication Union (ITU) [2]. By the end of 2001, the number of countries worldwide having a mobile network has tremendously increased from just 3% to over 90% [2]. In reality, the number of mobile subscribers worldwide exceeded the number of fixed-line subscribers in 2002. As of 2010 the number of mobile subscribers was around 73% of the world's population, which is equivalent to 5 billion mobile subscribers. "Five billion phones means there are more than three times as many phones as personal computers Ben Wood Analyst, CCS Insight". As of 2011 the number of mobile subscribers was around 79.86% of the world's population, which is equivalent to 5.6 billion mobile subscribers. An analyst at Wireless Intelligence predicts six billion connections worldwide by the middle of 2012. Table 1.1 lists some countries by the number of mobile subscribers.

Country	Population	Mobile	% of population	
		Subscribers		
World	6,852,472,823	5,000,000,000	73%	
Argentina	40,134,425	50,409,800	125.6%	
China	1,340,980,000	841,900,000	63.4%	
France	65,073,842	58,730,000	90.2%	
Germany	81,882,342	107,000,000	130.1%	
Japan	127,530,000	107,490,000	84.1%	
Nepal	28,500,000	10,001,670	35.09%	
Russia	141,940,000	213,900,000	147.3%	
Saudi Arabia	27,137,000	46,000,000	169.5%	
United States	308,505,000	285,610,580	91%	

Table 1.1 List of countries by number of mobile subscribers [3-8]

In addition to mobile phones, Wireless Local Area Network (WLAN) has experienced a rapid growth during the last decade. WLAN is popular due to its convenience, cost efficiency, and flexibility to share data exchange with other networks in one building. IEEE 802.11 a/b/g/n is a set of standards that specify the physical and data link layers in ad-hoc mode or access point for current wide use. In 1997 WLAN standard – IEEE 802.11, also known as Wi-Fi, was first developed with speeds of up to 2 Mbps. The rapid growth of WLAN hotspots in public places, such as hotels, hospitals, restaurants, train stations, airports, military bases, libraries, and coffee shops has been astonishing. The IEEE 802.11 standard evolution is shown in Table 1.2. The evolution of IEEE 802.11 technology is due to the sustained user demand for higher bit-rates. At present, WLANs are capable of offering up-to 600 Mbps for the IEEE 802.11n in the 2.4 GHz and 5 GHz license-free industrial, scientific and medical (ISM) bands. It is important to note that WLANs do not offer the type of mobility, which mobile systems offer.

Protocol	Release	Bandwidth (MHz)	Frequency (GHz)	Data rate Mbps	MIMO Streams	Modulation	Indoor range (m)	Outdoor range (m)
802.11	Jun 1997	20	2.4	Up to 2	1	DSSS, FHSS	20	100
802.11a	Sep 1999	20	5	up to 54	1	OFDM	35	120
802.11b	Sep 1999	20	2.4	up to 11	1	DSSS	38	140
802.11g	Jun 2003	20	2.4	up to 54	1	OFDM, DSSS	38	140
802.11n	Oct 2009	40	2.4/5	up to 600	4	OFDM	70	250

Table 1.2 Evolution of 802.11 network standards [9-10]

Wireless communication systems refer to various types of wireless area networks. Depending on the type of application, capacity and coverage, different types of wireless area networks are utilized. In general there is a tradeoff between capacity and coverage (mobility). For instance, Wireless Personal Area Network (WPAN) is regarded as a short distance of a few meters (Pico-cell) network providing several tens of Mbps. On the other hand cellular wireless standards 2G, 3G and 4G provide services to longer distances of about several kilometres, but have data rates limited to less than 6 Mbps. As a result, mobile communication systems search for enhancing capacity whereas wireless data search for enhancing coverage, they will both move in the direction of convergence. Next generation mobile communication systems will develop enhanced services with high data rates, integrated and converged services with IP-based seamless networks. Among the key technologies to facilitate the objective of enhanced services are modulation and multiple access schemes such as Orthogonal-Frequency-Division-Multiplexing (OFDM), multiple antenna techniques such as Multiple-Input-Multiple-Output (MIMO), and scalable network architecture based on Internet Protocol (IP).

1.2 Statement of the Problem and Purpose of the Study

Robust and high-rate data transmission in mobile environments faces severe problems due to the time-variant channel conditions, multipath fading and shadow fading. The continuing growth of the use of digital networks requires new higher capacity communications networks. Fiber optics can handle terahertz of bandwidth; however; the limitation comes from the wireless part known as the "last mile" of the network. The last mile is the bottleneck of the network, this runs from the access point to the user.

Fading is the main limitation on wireless communication channels. Frequency selective interference and fading, such as multipath fading is a bandwidth bottleneck in the last mile. The "last mile" problem in wireless communication networks is caused by the environment of free space channels which the signal propagates. The environment of free space channel can significantly degrade the quality of the traveling signal by reflecting, refracting or scattering the signal.

Multipath fading distorts the signal propagating through free space by destructive or constructive interference. The distorted signal can be enhanced by the use of OFDM modulation and demodulation technique. OFDM is a promising technique due to its robustness against multipath fading. The utilization of OFDM as a modulation and multiplexing technique means a large number of orthogonal, narrowband sub-carriers are being transmitted simultaneously in parallel. In that fashion if one of the subcarriers suffers from severe channel conditions then the rest of the subcarriers do not necessarily get degraded. Nevertheless, OFDM suffers from high Peak-to-Average-Power-Ratio (PAPR) which results in making the OFDM signal a complex signal. This would imply the need for linear amplification. The consequence of linear amplification is more power consumption. This has been an obstacle that limits the optimal use of OFDM as a modulation and demodulation technique especially in the uplink direction. The outcome of high PAPR on the transmitted OFDM symbols results in two disadvantages, high bit error rate and inference between adjacent channels. The drawback of PAPR affects the uplink and downlink channels differently. On the downlink, it is simple to overcome this drawback by the use of power amplifiers and distinguished PAPR reduction methods. These reduction methods can't be applied to the uplink due to their difficulty in low processing power devices. On the uplink, it is important to reduce the cost of power amplifiers.

The purpose of this study is to find a suitable optimal model to test and optimize the high peak to average power ratio problem both on the uplink and downlink. The model will use Inverse Fast Fourier Transform (IFFT) and Fast Fourier Transform (FFT) on the transmitter and receiver side of the OFDM respectively to process the signal. The study will focus on the reduction of PAPR considering the out of band radiation and the regeneration of the time-domain signal peaks caused by filtering.

1.3 Literature Review

The birth of OFDM was more than four decades ago. The first OFDM scheme was born in 1966 when Robert W. Chang published his revolutionary work on the synthesis of band-limited orthogonal signals for multi-channel data transmission. The

idea was to utilize the spectrum efficiently. Inter-carrier interference (ICI) becomes an issue when transmitting data in a parallel form. Therefore, the classical way of transmitting data in parallel was to use non-overlapping subchannels with spaces between subchannels to prevent ICI; however; this wastes the spectrum. In the mid-1960s the idea of Frequency-Division-Multiplexing (FDM) with overlapping subchannels was proposed to eliminate the unused spaces or band guards between the subchannels and to ultimately use the spectrum efficiently. When subchannels are overlapped, ICI becomes an issue.

Doppler frequency shifts takes place when a mobile user moves in a radio environment between a transmitter and a receiver or when there is a mismatch between the carrier frequencies at both transmitter and receiver. The consequences of frequency errors in OFDM systems result in distorting the orthogonality between subcarriers leading to ICI. The evolution of FDM to OFDM was to overcome the ICI issue where carriers must be mathematically orthogonal to the adjacent channel, hence the name Orthogonal-Frequency-Division- Multiplexing. As mentioned the concept of OFDM has been known for more than four decades now. During that time OFDM was very complicated to implement with electronic hardware due to its computational complexity. It continued to be an area of research until semiconductor came into the picture and made it possible.

OFDM is a broadband multicarrier modulation scheme that leads to a better performance than a single carrier scheme over wireless channels since OFDM uses a large number of orthogonal, narrowband sub-carriers that are transmitted simultaneously in parallel. The use of OFDM scheme can boost data rate and solve the increase demand problem for future bandwidth-hungry wireless applications.

The most important gain of OFDM over single carrier schemes is the capabilities to handle sever channel impairments without complex equalization filters. OFDM is most likely to be the selected modulation scheme for future wireless communication applications because of the capability that OFDM provides such as the robustness against multipath fading in transmitting high data rate. Various research has be been done on studying different methods to optimize OFDM. Most of the research focuses on two main drawbacks with OFDM, the large peak-to-average power ratio and the sensitivity to frequency errors.

The transmitter can recode the binary data, add power to free carriers or distort the data carrier constellation points. These techniques can be combined, and each has its own tradeoffs, hence several PAPR reduction schemes have been proposed in the literature.

According to a study done by L. J. Cimini, Jr. on peak-to-average-power-ratio reduction of an OFDM signal using partial transmit sequences (PTS) which was published in IEEE Communication Letter states that coding schemes like PTS are quite flexible because they modify the data set. However, the PTS transmitter must send side information to the receiver for correct decoding [11].

According to another study done by Chih-Chun Feng on embedding and detection of side information for peak-to-average-power-ratio reduction of an OFDM signal using partial transmit sequences, which was published in IEEE Vehicular Technology Conference. The study concludes that even if the side information is embedded in the signal to maintain spectral efficiency, the receiver structure must be changed, making PTS incompatible with existing OFDM standards [12].

J. Armstrong study on peak-to-average-power reduction for OFDM by repeated clipping and frequency domain filtering published in Electronics Letter concludes that clipping techniques are easy to understand and implement. Unfortunately, clipping causes data carrier distortion and out-of-band noise [13].

A study done by A. Gatherer on Controlling clipping probability in DMT transmission concludes that tone reservation algorithms reduce PAPR by adding power to unused carriers. These methods do not distort the constellation but the free carriers waste power and lower the data rate [14].

Research on minimizing the peak-to-average-power-ratio of OFDM signals Using Convex Optimization was done by Alok Aggarwal from Stanford University, Electrical Engineering department published in IEEE. The study proposed an optimization algorithm in an OFDM transmitter to reduce the PAPR. However, applying the proposed optimization algorithm in an OFDM transmitter would require dedicated digital signalprocessing hardware [15].

(FDD) frequency-division-demultiplexing facilitates the use of OFDM for various data streams that are sent simultaneously over a shared broadband medium such as fiber-optic cable. Nevertheless, FDD has a drawback limiting the bandwidth since carriers are

transmitted simultaneously in parallel, therefore a space between carriers (guard band) is vital. This space or guard band is not used to transmit data and is a waste of bandwidth. Therefore, researchers have found that with digital transmissions the carriers can be separated very closely resulting in an efficient use of the spectrum.

Spectral efficiency is what makes OFDM a unique technique. Spectral efficiency means sending data at a higher data rate within the same bandwidth and environment. Spectral efficiency is expressed in bits per second per Hertz. The number of bits per time per frequency is what determines the bandwidth efficiency. Data rate is the multiplication of bandwidth and spectral efficiency. Bandwidth is determined by the regulators and the spectral efficiency is determined by technology or standard utilized. When utilizing OFDM as a technology or standard, different modulation schemes can be used. Each results in a different value for the maximum data rate for a specified noise level and Bit Error Rate (BER). Besides, some modulation schemes are subject to noise and low signal levels more than others. Some of the simple modulation schemes are Frequency Shift Keying (FSK) and Amplitude Shift Keying (ASK). Both FSK and ASK don't perform as well as Binary Phase Shift Keying (BPSK) which is popular and Quadrature Phase Shift Keying (QPSK) yet they are simple. On the other hand, Quadrature Amplitude Modulation (QAM) performs better but can suffer from weak signal levels and noise. Code-Division-Multiple-Access (CDMA) performs even better than all but nothing so far can exceed the performance of OFDM as far as the maximum data rate. OFDM is in close proximity to the Shannon limit theorem which is the best achievable signal-to-noise

ratio (SNR) utilizing the finest modulation method as explained by Shannon's theorem discussing channel capacity to SNR.

1.4 OFDM Disadvantages

1.4.1 OFDM Peak-to-Average-Power-Ratio (PAPR)

PAPR results in making the OFDM signal a complex signal, which distorts the signal if the transmitter contains nonlinear power amplifiers. The nonlinearity effects on the transmitted OFDM symbols are spectral spreading and intermodulation. Both the inband and out-of-band interference to signals is caused by the nonlinear distortion. The out-of-band interference causes adjacent channel interference through spectral spreading while the in-band interference increases the BER of the received signal through warping of the signal constellation and intermodulation. This would imply the need for linear amplification or a backoff equal to the PAPR for distortionless transmission. The consequence of linear amplification is more power consumption which decreases the efficiency of power amplifiers.



Figure.1.1 Fresnel diagram illustrating the PAPR issue.

Figure 1.1 shows a constructive addition of subcarriers on a random basis, which causes the PAPR problem. The outcome of high PAPR on the transmitted OFDM symbols results in high bit error rate and the inference between adjacent channels (spectral spreading).

The drawback of PAPR affects the uplink and downlink channels differently. On the downlink, it's simple to overcome this problem by the use of power amplifiers and complex PAPR reduction methods. These reduction methods can't be applied to the uplink due to their difficulty in low processing power devices. On the uplink, it is important to reduce the cost of power amplifiers. Therefore, 3rd Generation Partnership Project (3GPP) Long Term Evolution (LTE) has adopted Single-Carrier-Frequency-Division-Multiple-Access (SC-FDMA) as the uplink multiple access scheme, which uses single carrier modulation and frequency domain equalization.

1.4.2 OFDM sensitivity to frequency errors

OFDM tends to be sensitive to the change in carrier frequency. A pilot carrier is sent with each subcarrier or subchannel. When the signal is received, the pilot carriers help with the synchronization and the sensitivity problem is solved.

1.5 Wireless technologies using OFDM

- Long-Term Evolution (LTE). LTE is the standard for 4G cellular technology.
- Wireless local-area networks (LANs) such as Wi-Fi.
- Ultra-Wideband (UWB) uses an OFDM standard set by the WiMedia Alliance.
- IEEE 802.11a/g/n

- ADSL (Asymmetric Digital Subscriber Line) and VDSL (Very high bit-rate Digital Line Subscriber) used for Internet access use a form of OFDM known as discrete multi-tone (DMT).
- Digital radio broadcasting and TV broadcasting such as Europe's Digital Video Broadcasting-Terrestrial (DVB-T) and (Digital Video Broadcasting - Handheld (DVB-H).
- ETSI BRAN in Europe
- ARIB MMAC in Japan has adopted the OFDM transmission technology as a physical layer for future broadband WLAN systems.

Chapter 2

OFDM MODELING

OFDM is a promising technique due to its robustness against multipath fading [16]. The utilization of OFDM as a modulation and multiplexing technique, means a large number of orthogonal, narrowband sub-carriers are being transmitted simultaneously in parallel. In this fashion if one of the subcarriers suffers from severe channel conditions then the rest of the subcarriers do not necessarily get degraded. Figure 2.1 shows how the narrowband sub-carriers are transmitted simultaneously in parallel based on the OFDM modulation.



Figure 2.1 OFDM modulations. [17]

2.1 Orthogonality

The main benefit of the orthogonality functions is the efficiency of the modulator and demodulator implementation using Inverse Fast Fourier Transform (IFFT) on the transmitter side, and the Fast Fourier Transform (FFT) algorithm on the receiver side [18]. One of the reasons OFDM became popular today is because of the low-cost in digital signal processing to calculate the FFT efficiently.

The conventional FDM divides the total signal into a nonoverlapping subchannels. This makes sense if we are trying to prevent channels from overlapping and ultimately to avoid interchannel interference; however; the conventional FDM wastes the spectrum by not utilizing the spectrum efficiently. Therefore, various networks adopted orthogonal FDM to better utilize the bandwidth by overlapping subchannels where the center of each subchannel is where the adjacent channels end and start. The spacing between the subcarriers is minimized by the use of the orthogonality functions to better utilize the spectrum. Figure 2.2 shows how the FDM wastes the spectrum where OFDM utilizes the spectrum more efficiently.



Figure 2.2. FDM VS. OFDM 14

The word orthogonal indicates that there is a mathematically relationship, two vectors are orthogonal if they form a right angle, i.e., they are perpendicular to each other. Two signals are said to be orthogonal if their dot product is equal to zero. If we multiply the two signals together and integrate the result then we should get zero. An OFDM carrier signal is the sum of a number of orthogonal sub-carriers. One of the great advantages of OFDM is the fact that FFT modulates the orthogonality functions, which results in, reducing the computational complexity. Figure 2.3 shows how FFT can act as a bank of modulator to reduce the processing time and complexity.



Figure 2.3. Modulation of the Orthogonality functions within FFT for OFDM baseband signal

OFDM splits a high-rate data carrier into a number of lower rate subcarriers that are transmitted simultaneously over a number of subcarriers. The main components of an OFDM system are the Inverse FFT in the transmitter and the FFT in the receiver and they must implement respectively. The following operations perform reversible linear mapping between N complex data symbols $\{X\}$ and N complex line symbols $\{x\}$. The two operations are identical.

$$X[n] = \frac{1}{\sqrt{N}} \sum_{k=0}^{N-1} x[k] e^{-j\frac{2\pi}{N}kn} n = 0, \dots, N-1$$
(2.1)

The term $\frac{1}{\sqrt{N}}$ preserves power and provides symmetry between the operations. Usually

 $\frac{1}{N}$ is used in one direction and unity in the other instead.

Let $(e^{j2\pi f_k t})_{K=0}^{N=1}$ be the exponential signals representing different subcarriers at $f_k = \frac{k}{T}$ in the OFDM signal, where $0 \le t \le T$. The signals are orthogonal if their dot

product is equal to zero.

$$\frac{1}{T}\int_{0}^{T}e^{j2\pi f_{k}t}e^{-j2\pi f_{i}t}dt = \frac{1}{T}\int_{0}^{T}e^{j2\pi \frac{k}{T}t}e^{-j2\pi \frac{i}{T}t}dt$$
(2.2)

$$=\frac{1}{T}\int_{0}^{T}e^{j2\pi\frac{(k-i)}{T}t}dt$$
(2.3)

$$= \begin{cases} 1, \forall \text{integer} k = i \\ 0, otherwise \end{cases}$$
(2.4)

Equation (2.4) describes the orthogonality condition.

$$\frac{1}{N}\sum_{n=0}^{N-1} e^{j2\pi\frac{k}{T}\cdot nTs} e^{-j2\pi\frac{i}{T}\cdot nTs} = \frac{1}{N}\sum_{n=0}^{N-1} e^{j2\pi\frac{k}{T}\cdot\frac{nT}{N}} e^{-j2\pi\frac{i}{T}\cdot\frac{nT}{N}}$$
(2.5)

$$=\frac{1}{N}\sum_{n=0}^{N-1}e^{j2\pi\frac{(k-i)}{N}.n}$$
(2.6)

$$= \begin{cases} 1, \forall integerk = i \\ 0, otherwise \end{cases}$$
(2.7)

The above orthogonality condition has to be met to avoid ICI for OFDM signals. OFDM is a broadband multicarrier modulation scheme. Research on multi-carrier transmission is an interesting research area [19-21]. OFDM modulation scheme leads to better performance than a single carrier scheme over wireless channels since OFDM uses a large number of orthogonal, narrowband sub-carriers that are transmitted simultaneously in parallel, however, high PAPR becomes an issue that limits the uplink performance more than the downlink due to the low power processing terminals. SC-FDMA adds the additional advantage of low PAPR compared to OFDM making it appropriate for uplink transmission at the cost of performance.

The use of OFDM scheme is the solution to the increase demand for future bandwidth-hungry wireless applications [22]. One of the wireless technologies using OFDM is Long-Term Evolution (LTE). LTE is the standard for fourth generation (4G) cellular technology, Association of Radio Industries Business (ARIB) Multimedia Mobile Access Communications System (MMAC) in Japan, the European Telecommunications Standards Institute (ETSI) Broadband Radio Access Networks (BRAN) and IEEE 802.11 in the United States; all have adopted the OFDM transmission technology as a physical layer for future broadband WLAN systems.

Due to the robustness of OFDM systems against multipath fading, the integration of OFDM technology and Radio-Over-Fiber (RoF) technology made it possible to transform the high speed RF signal to the optical signal utilizing the optical fibers with broad bandwidth [23]. Nevertheless, OFDM suffers from high PAPR both in the uplink and downlink direction which results in making the OFDM signal a complex signal [24].

2.2 Cyclic Prefix and Guard Intervals

The Cyclic Prefix (CP) is the insertion of guard spaces between OFDM symbols and as a result Inter-symbol Interference (ISI) can be prevented provided the length of the CP exceeds the delay spread of the impulse response of the channel without channel equalization [25].

Cyclic prefixing also maintains the orthogonality between subcarriers by maintaining the OFDM symbol periodic over the extended symbol duration, which results in reducing Inter-carrier Interference [26]. Cyclic prefixing prefixes a symbol with a repetition of the end as shown in Figure 2.4. Even though at the receiver the CP samples are removed, the CP eliminates intersymbol interference from the previous symbol and as a repetition of the end of the symbol, it allows the linear convolution of a frequency-selective multipath channel to be modeled as circular convolution. In order to avoid ISI and ICI, the length of the CP should be made longer than the experienced impulse response, i.e., at least equal to the length of the multipath channel. Mathematically, a cyclic convolution is the conversion of the CP or guard interval from the linear convolution with the channel impulse response, which results in the prevention of both ISI and ICI.

Figure 2.4. Cyclic Prefix insertion

The Guard Interval T_G represent the CP in terms of samples. The duration of the

extended OFDM symbol becomes $T = T_{SUB} + T_G$.

$$\frac{1}{Tsub} \int_{0}^{T_{sub}} e^{j2\pi f_k.(t-t_0)} e^{-j2\pi f_i(t-t_0)} dt = 0, k \neq i$$
(2.8)

The above signal arrives with a delay t_0 , and

$$\frac{1}{Tsub} \int_{0}^{T_{sub}} e^{j2\pi f_{k} \cdot (t-t_{0})} e^{-j2\pi f_{i} \cdot (t-t_{0}-T_{s})} dt = 0, k \neq i$$
(2.9)

the above signal arrives with a delay spread $t_0 + T_s$ because of multipath fading.

2.3 OFDM modulation and demodulation

OFDM is a broadband multicarrier modulation and multiplexing method which transmits a large number of orthogonal, narrowband sub-carriers simultaneously in parallel. The data stream to be transmitted is divided into many slower data streams, and every data stream is modulated onto a distinct carrier in the selected spectrum. These carriers are named tones or subcarriers. The most common modulation forms are QAM, BPSK, and QPSK [27]. This method of transmission ensures that if one of the subcarriers suffers from severe channel conditions then the rest of the subcarriers do not necessarily get degraded. OFDM modulation and demodulation use Inverse Fast Fourier transform (IFFT) and Fast Fourier transform (FFT) on the transmitter and receiver side of the OFDM respectively to process the signal. IFFT and FFT can be thought of as banks of modulators and demodulators. When transmitting thousands of parallel subcarriers, hardware becomes an issue even with the semiconductor technology. Another way of accomplishing this process is by the use of computer hardware that utilizes IFFT and FFT to process the signal.

The main advantages of OFDM are the utilization of spectral efficiency, capability to handle sever channel impairments due to its robustness against multipath fading in transmitting high data rate, and it's tolerance to delay spread.

2.4 Distribution of OFDM signal

For a sequence of modulated data symbols, X[k]. The discrete time domain signal x[n] is the addition of N different time domain signals $e^{j\frac{2\pi}{N}kn}$ where each signal corresponds to different orthogonal subcarriers as shown in Figure 2.5.

Figure 2.5. Illustrates the block diagram of OFDM system [28]

The discrete time signal after IFFT can be expressed as:

$$x[n] = \frac{1}{N} \sum_{k=0}^{N-1} X[k] e^{j\frac{2\pi}{N}kn}$$
(2.10)

The distributions of x[n] as well as the imaginary and real parts for N=16 are shown in Figure 2.6 where the real and imaginary parts of x[n] follow a Gaussian distribution while x[t] follow a Rayleigh distribution.

Figure 2.6—Magnitude distribution of OFDM signal for N=16 [28]

Chapter 3

METHODOLOGY

MATLAB version 7.7.0.471 (R2008b) software was used to design and simulate the wireless links to study the performance analysis of OFDM peak-to-average-powerratio (PAPR) problem and its sensitivity to frequency errors in OFDM communication systems. Transmission utilizing OFDM is similar to multi-carrier- transmission. The feature that differentiates OFDM from all other multi-carrier-transmission schemes is the closely spaced narrow-band transmission resulting in the utilization of the bandwidth. OFDM utilizes hundreds to several thousands of narrowband subcarriers, where Wideband-Code-Division-Multiple-Access (WCDMA) uses a fewer number of subcarriers with a very wide bandwidth for each channel. Each channel in WCDMA occupies 5 MHz of bandwidth where LTE subcarrier spacing is 15 kHz. The symbol length of WCDMA is 256 shorter than LTE. Each 15 kHz subcarrier in LTE has the capability of transmitting 15 kbps.

Radio over fiber (RoF) integrates the wireless and fiber optic networks. Besides, RoF facilitates the extension of existing radio coverage and capacity by means of centralizing the RF (Radio Frequency) signal processing function and using fiber optic
links that can handle Terahertz to feed RF signals to the distributed simplified radio access units (RAUs) by the use of single mode fibers (SMF) for outdoor wireless communications.

The idea of OFDM and FDM transmission can be thought of as comparing running water out of a faucet as one big stream and out of a head shower as many small streams. This analogy can help us visualize the difference between FDM and OFDM. One can think of the frequency-division-multiplexing as water running in one big stream out of a faucet where the orthogonal-frequency-division-multiplexing can be thought of as the head shower where many streams of water are coming out simultaneously. It is important to note that in both cases the amount of water is the same. The water streams are the sub-carriers.

The response to interference is what distinguishes OFDM. When dealing with interferences, OFDM acts better than FDM since only part of the data (water streams) will experience interference unlike FDM where only one big stream is being transmitted. In complex baseband, an OFDM signal x(t) during time interval $mT_u \le t \prec (m+1)T_U$ can be expressed as

$$x(t) = \sum_{k=0}^{N_c - 1} x_k(t) = \sum_{k=0}^{N_c - 1} a_k^{(m)} e^{j2\pi k\Delta f t}$$
(3.1)

Where $x_k(t)$ is the *kth* modulated subcarrier at a frequency $f_k = k \Delta f$. The modulation symbol $a_k^{(m)}$ is applied to the *kth* subcarrier during the *mth* OFDM interval

which is $mT_u \le t < (m+1)T_U$. Therefore, during each OFDM symbol interval transmission, N_C modulation symbols are transmitted in parallel. The modulation symbols are dependent on the use of this technology and can be any form of modulation such as 16QAM, 64QAM or QPSK. The choice of modulation scheme varies is dependent on the environment and the application.



Figure 3.1 OFDM time-frequency grids [23]

Figure 3.1 shows the OFDM time-frequency grid where each column represents one OFDM symbol and each row represents one OFDM subcarrier. Subcarriers spacing range hundreds of kHz to a small number of kHz depending on the environment of operation. Once the spacing between subcarriers has been specified, then the choice of how many subcarriers to be transmitted in parallel has to be made. It is important to note that allocating the number of subcarriers is dependent on the transmission bandwidth. For instance, LTE uses 15 kHz as the basic spacing with 600 subcarriers assuming the operation is in the 10 MHZ spectrum.

3.1 Computer Modeling

3.1.1 Peak-to-average-power-ratio (PAPR)

One of the major difficulties of OFDM is the high PAPR. The PAPR ratio affects the uplink and downlink differently. For instance, LTE uses OFDM as the modulation technology on the downlink where high power signal processing is possible. The use of such modulation technology is impossible in the uplink direction due to low power signal processing such as mobile devices. Therefore, the 3GPP (3rd Generation Partnership Project) standardization group has decided to select SC-FDMA as the uplink modulation technology for LTE while Worldwide Interoperability for Microwave Access (WiMAX) uses Orthogonal Frequency Division Multiple Access (OFDMA) as the core modulation technology for uplink transmission. OFDMA is as fast as the SC-FDMA but has a high PAPR. They are very similar where both use subcarriers in the air interface; however; SC-FDMA adds an additional block to OFDMA in order to spread the information and ultimately use less power. The difference between the two different modulation technologies in the uplink direction is SC-FDMA spreads the information of *each bit* over the entire sub-carriers where OFDMA puts more bits together in one subcarrier.

The most significant advantage of OFDM over single carrier schemes is the capability to handle sever channel impairments without complex equalization filters,

which reduces complexity. OFDM is a scheme for wideband digital communication, whether wireless or over copper wires.

When transmitting data from the mobile terminal to the network, a power amplifier is mandatory to increase the power of the signal to a certain level that is high enough to be picked up by the network [29]. The power amplifier is one of the major consumers of energy in a device and must be as power efficient as possible to prolong the battery life of the device. The efficiency of a power amplifier is determined by the ability to amplify the highest peak value of the wave. Due to silicon constraints, the peak value decides the power consumption of the amplifier. An additional factor is the peaks of the wave, which do not carry additional information than the average power of the signal over time. Therefore, transmission speed doesn't depend on the peak power output required for the peak values of the wave but rather on the average power level [29]. The lower the difference between the peak powers to the average power the longer is the operating time of a mobile device at a certain transmission speed compared to devices that use modulation schemes with a higher PAPR. The literature papers suggest that LTE has a better PAPR than WiMAX due to different modulation schemes used in the uplink direction. Although WiMAX uses OFDMA, which is fast but has a high PAPR, LTE designers choose to use SC-FDMA which is as fast but is said to have a better PAPR.

The schematics in Figure 3.2 illustrate a graphical view of an OFDMA that transmits 4 QPSK data symbols in parallel, each data symbol occupies a subcarrier, and a

SC-FDMA that transmits the 4 data symbols in series rather then in parallel at four times the rate, with each data symbol utilizing N x 15 kHz bandwidth.



Figure 3.2 System configuration of SC-FDMA and OFDMA [30]

The following simulation helps understand the effects of the channel noise and high power amplifier on downlink OFDM signals. Results show the reductions are significant.



Figure 3.3 OFDM block diagram

The OFDM block diagram shown in Figure 3.3 consists of the transmitter, channel and receiver. In the transmitter, data is first converted from serial into parallel. Each set of data contains one symbol for each subcarrier, and then data passes through an inverse Fourier transform where each data set is converted into the time domain representation of each data set. Finally, each data set is converted from parallel to serial to generate the OFDM signal.

The signal then propagates through free space. This simulation investigates common wireless channel characteristics such as multipath, noise, and clipping. Channel multipath refers to when the signal is reflected, refracted or scattered which causes a delay. Noise comes from the environment of the channel the signal is propagating through. Finally, the reduction method reduces the peak to average power ratio.

On the receiver side data is converted from serial into parallel sets, and then the FFT transforms data from the time domain into the frequency domain. Finally, data is converted from parallel sets to a serial stream to recover the original signal.

3.2 Down-Link (DL) Peak-to-average-power-ratio (PAPR) reduction methods 3.2.1 Clipping method

One of the major drawbacks of OFDM is the high peak-to-average power ratio (PAPR) of the transmitted signals. We propose a low complexity clipping scheme applicable to Interleaved-FDMA (IFDMA) uplink and OFDM downlink systems for PAPR reduction. We show the performance of PAPR of the proposed Interleaved-FDMA scheme is better than traditional OFDMA for uplink transmission system. Our reduction of PAPR is 53% when IFDMA is used instead of OFDMA in the uplink transmission. We also examine an important trade-off relationship between clipping distortion and quantization noise when the clipping scheme is used for OFDM downlink systems. Our results show that we were able to reduce the PAPR by 50% and reduce the out-of-band radiation caused by clipping for OFDM downlink transmission system. The output of

IFFT is clipped to reduce the PAPR and then filtered to reduce the out-of-band radiation as shown in Figure 3.4.



Figure 3.4 Clipping and Filtering at the Transmitter of OFDM system [31] In complex baseband, an OFDM signal x(t) during time interval $mT_u \le t < (m+1)T_U$ can be expressed as

$$x(t) = \sum_{k=0}^{N_c - 1} x_k(t) = \sum_{k=0}^{N_c - 1} a^m e^{j2\pi k \Delta f t}$$
(3.2)

Where $x_k(t)$ is the *kth* modulated subcarrier at a frequency $f_k = k \Delta f$. The modulation symbol $a_k^{(m)}$ is applied to the *kth* subcarrier during the *mth* OFDM interval, which is $mT_u \le t < (m+1)T_U$ as shown in Figure 3.5. Therefore, during each OFDM symbol interval transmission, N_C modulation symbols are transmitted in parallel. The modulation symbols are dependent on the use of this technology and can be any form of modulation such as 16QAM, 64QAM or QPSK. The choice of which modulation scheme to implement varies depending on the environment and application.



Figure 3.5 OFDM modulation valid for time interval $mT_u \le t \prec (m+1)T_U$ [31]

3.2.2 Clipping and signal to quantification noise ratio

An OFDM signal has the tendency to have a large peak to average power ratio when each subcarrier by chance has the highest amplitude and identical phases at the same time. The likelihood of such an event is rare yet it does occur. As the number of subcarriers increase, the maximum power increases. The probability of that maximum power signal actually decreases as N increases. This is due to the statistical magnitude distribution of the time-domain OFDM signal.

The simplest approach to reduce the PAPR is to clip the amplitude of the signal to a desired maximum level. Although clipping is the simplest method, in our method it enhances the signal to quantization noise ratio (SQNR) in the conversion from analog to digital.

As the clipping threshold increases, clipping distortion decreases at the expense of PAPR and quantization noise. On the other hand as the clipping threshold decreases, PAPR and quantization noise decrease at the expense of clipping distortion. Therefore, it is important to take into consideration this trade-off relationship between clipping distortion and quantization noise when picking the number of bits for quantization and the clipping threshold.

3.2.3 Partial Transmit Sequence (PTS) method

The Partial Transmit Sequence (PTS) technique suffers from search complexity of finding the optimum set of phase vectors. We propose a suboptimal combination algorithm that reduces the search complexity. The number of commutations in the suboptimal combination algorithm is much lower than that required by the original PTS technique.

The PTS technique partitions the data block of N symbols into Z disjoint sublocks as follows:

$$X = [X^{0}, X^{1}, X^{2}, ..., X^{z-1}]^{T}$$
(3.3)

Where X^i are the subcarriers, which are of equal size and consecutively located. In the PTS technique scrambling is applied to each subblock where in the selective mapping technique scrambling is applied to all subcarriers. As shown in Figure 3.6 each subblock is multiplied by a phase factor $b^z = e^{j\phi z}$, z = 1, 2, 3, ..., Z, the IFFT becomes

$$x = IFFT\{\sum_{z=1}^{Z} b^{z} X^{z}\} = \sum_{z=1}^{Z} b^{z} IFFT\{X^{z}\} = \sum_{z=1}^{Z} b^{z} x^{z}$$
(3.4)



Figure 3.6 Block diagram of partial transmit sequence (PTS) technique for PAPR

Where x^{z} is referred to as a partial transmit sequence. As shown in Figure 3.6 the phase vector is selected so that PAPR can be minimized as follow:

$$[\tilde{b}^{1}, ... \tilde{b}^{Z}] = \underset{[\tilde{b}^{1}, ... \tilde{b}^{Z}]}{\arg\min} \{ \max_{n=0, 1, ..., N-1} \left| \sum_{z=1}^{Z} b^{z} . x^{z}[n] \right|$$
(3.5)

The time domain signal with the lowest PAPR vector can be expressed as follow:

$$\widetilde{x} = \sum_{z=1}^{Z} \widetilde{b}^{z} x^{z}$$
(3.6)

The PAPR improves as the number of subblocks increases.

3.3 Up-Link (UL) PAPR reduction methods

Orthogonal-Frequency-Division-Multiple-Access (OFDMA) is a multi user version of OFDM used for uplink transmission. OFDMA suffers from high PAPR in the uplink, which results in making the signal a complex signal [33].

The problem of PAPR affects the uplink and downlink channels differently. On the downlink, it is simple to overcome this difficulty by the use of power amplifiers and distinguished PAPR reduction methods. These reduction methods can't be applied to the uplink due to their difficulty in low processing power devices such as mobile devices. On the uplink, it is important to reduce the cost of power amplifiers therefore assigning subsets of subcarriers to individual users allow simultaneous low data rate transmission from several users.

Unlike OFDM used for downlink transmission, OFDMA is utilized in the uplink direction where subcarriers are separated and designated for several mobile units. Each unit utilizes a number of subcarriers; let *N* denote the number of subcarriers assigned to each unit for uplink transmission. The effectiveness of reduction in PAPR is greatly influenced by the technique in the method utilized to assign *N* to each unit [34]. Discrete Fourier Transform (DFT) spreading technique is a promising solution to reduce PAPR in the uplink direction because of it's superiority in PAPR reduction performance compared to block coding, Selective Mapping (SLM), Partial Transmit Sequence (PTS), and Tone Reservation (TR) [35, 36]. SC-FDMA and OFDMA are both multiple-access versions of OFDM. There are two subcarrier-mapping schemes in single carrier frequency division multiple accesses to allocate subcarriers between units: Distributed FDMA and Localized FDMA.

Chapter 4

RESULTS AND DISCUSSION

Distribution of the PAPR

The complex baseband signal for one OFDM symbol can be written as:

$$x(t) = \frac{1}{\sqrt{N}} \sum_{n=1}^{N} a_n \exp(j\omega_n t)$$
(4.1)

where N is the number of subcarriers and a_n is the modulating symbol. From the central limit theorem, we can assume that the real and imaginary parts of the time domain complex OFDM signal x(t) have a Gaussian distribution for a large number of subcarriers. Therefore, the amplitude of the OFDM signal x(t) follows a Rayleigh distribution, whereas power follows a central chi-square distribution with the cumulative distribution expressed as:

$$F(z) = 1 - e^z \tag{4.2}$$

An OFDM system with a certain number of subcarriers suffers from maximum power which arises when all of the subcarriers add up coherently with identical phases. The largest PAPR happens randomly with a very low probability. The main interest is actually in the probability of the occurrence of high signal power. This high signal power is out of the linear range of high power amplifiers. The probability of PAPR below a certain threshold can be expressed as:

$$P(PAPR \le z) = F(z)^N = (1 - \exp(-z))^N$$
 (4.3)

Equation (4.3) holds for samples that are mutually uncorrelated; however; when over sampling is applied then it does not hold. This is because a sampled signal does not certainly include the maximum point of the original continuous time signal. Nevertheless, it is important to note that it is difficult to derive the exact cumulative distribution function for the peak power distribution. The following simplified proposed PAP distribution will be used:

$$F(z)^{N} \approx (1 - \exp(-z^{2}))^{\alpha N}$$
(4.4)

where α has been found by fitting the theoretical Cumulative Distribution Function (CDF) into the actual one. From our simulation, it was shown that α =2.8 is suitable for adequately large number of subcarriers. The theoretical and simulated curves are plotted in Figure 4.1 for different number of subcarriers. As N decreases, the deviation between the obtained simulation and theoretical results increases, which indicates that equation (4.4) is quite accurate for N>256. It is worth noting that equation (4.3) is more accurate for large CDF values as shown in Figure 4.1.



Figure 4.1 OFDM system with N-point FFT. CCDFs of signal PAP ratio with N=16, 32, 64, 128 and 1024. Solid lines are calculated; dotted lines are simulated. [37]

4.1 Clipping and signal to quantization noise ratio

An OFDM signal has the tendency to have a large peak to average power ratio when each subcarrier by chance has the highest amplitude and identical phases at the same time. The likelihood of such an event is rare yet it does occur. As the number of subcarriers increase, the maximum power increases as shown in Figure 4.1. The probability of that maximum power signal actually decreases as N increases and that is due to the statistical magnitude distribution of the time-domain OFDM signal.

The simplest approach to reduce the PAPR is to clip the amplitude of the signal to a desired maximum level. Although clipping is the simplest method, in our method it enhances the signal to quantization noise ratio (SQNR) in the conversion from analog to digital. SQNR is a measurement of the difference between the analog value and the quantized digital. As the clipping threshold increases, clipping distortion decreases at the expense of PAPR and quantization noise. On the other hand as the clipping threshold decreases, PAPR and quantization noise decrease at the expense of clipping distortion. Therefore, it is important to take into consideration this trade-off relationship between clipping distortion and quantization noise when picking the number of bits for quantization and the clipping threshold.

Figure 4.2 shows the SQNR values of an OFDM signal quantized with 5, 6, 7, 8 bits against the clipping threshold and N=128. The optimal clipping threshold to maximize the signal to quantization noise ratio fluctuates with the quantization level; however; we can see that the maximum points are approximately around 3.5 of the clipping level. Clipping distortion is more significant to the left of the maximum points due to the low threshold of clipping whereas the clipping distortion is not as significant to the right of the maximum points where the clipping threshold is higher. Clipping distortion degrades the system performance.



Figure 4.2 Clipping threshold against SQNR of quantized OFDM signal. N=128 [37]

The performance of any PAPR reduction scheme is evaluated based on out-of-band radiation, in-band ripple, distribution of PAPR and the BER performance.

4.2 Downlink Clipping and filtering method

To evaluate the performance of the clipping and filtering method used in our simulation, the following parameters were used to in the simulation.

N	256
Clipping Ratio	1.4
Carrier frequency	5 MHz
Modulation	QPSK
Sampling frequency	10 MHz
Bandwidth	1MHz
Guard interval samples	32

Table 4.1 Simulation parameters



Figure 4.3 Baseband signals [37]

The Power Spectral Density (PSD) of the oversampled baseband signal is shown in Figure 4.3. The PSD is the output of IFFT. Let x(s) be the output of IFFT. Then the output of IFFT can be expressed mathematically as:

$$x(s) = \frac{1}{\sqrt{L.N}} \sum_{k=0}^{L.N-1} X(k) e^{2\pi i s \Delta f k / L.N}, s = 0,1,...NL - 1$$

$$x(k) = x(k), \text{ for } 0 \le k < \frac{N}{2} \text{ and } NL - \frac{N}{2} < k < NL$$

$$0, \text{ otherwise}$$
(4.5)

where

L is the oversampling factor

 Δf is the subcarrier spacing

N is the number of subcarriers

x(k) is the symbol carried by subcarrier k



Figure 4.4 Baseband signal Gaussian distribution [37]

Figure 4.4 shows the power spectral density and a histogram of the baseband signal without clipping and filtering. We can see the power density function shows a Gaussian distribution of the signal.



Figure 4.5 Clipped passband signal [37]

Clipping and filtering of OFDM has been studied; however; these techniques reduce PAPR at the expense of increased system complexity and a high peak re-growth. Figure 4.5 shows the level of out-of-band radiation of the clipped unfiltered passband signal. An OFDM transmitter emits out-of-band radiation when a set of subcarriers are modulated. Our results which were published in the International Journal of Computer Science show less out-of-band power emission compared to traditional OFDM by the use of the low complexity clipping and filtering technique [37].



Figure 4.6 Clipped and filtered passband signal [37]

The out-of-band radiation can be seen from Figure 4.5 and 4.6. It is clear that the out-of-band radiation increases after clipping; however; it decreases after filtering and shows a peak value beyond the clipping threshold implying a slight peak re-growth in PAPR after filtering as shown in Figure 4.6. To complete the evaluation of clipping and filtering then, we have to look at the BER performance when the clipping ratio varies. Clipping ratio is the ratio of the clipping level to the RMS power of the OFDM signal.



Figure 4.7 (a) PAPR distribution (b) BER performance [37]

We can see from Figure 4.7(a) that as the clipping ratio increases from right to left, the PAPR decreases dramatically after clipping and increases slightly after filtering. The simulation result in Figure 4.7 (b) shows that the performance of BER is better as the clipping ratio increases.

4.3 Partial Transmit Sequence (PTS) method

The Partial Transmit Sequence (PTS) technique suffers from the search complexity of finding the optimum set of phase vectors. We propose a suboptimal combination algorithm that reduces the search complexity. The number of commutations in the suboptimal combination algorithm is much lower than the required by the original PTS technique.

The PTS technique partitions the data block of N symbols into Z disjoint sublocks as follows:

$$X = [X^{0}, X^{1}, X^{2}, ..., X^{z-1}]^{T}$$
(4.6)

Where X^i are the subcarriers, which are of equal size and consecutively located. In the PTS technique, scrambling is applied to each subblock where in the selective mapping technique scrambling is applied to all subcarriers. Each subblock is multiplied by a phase factor $b^z = e^{j\phi z}, z = 1, 2, 3, ..., Z$, the IFFT becomes

$$x = IFFT\{\sum_{z=1}^{Z} b^{z} X^{z}\} = \sum_{z=1}^{Z} b^{z} IFFT\{X^{z}\} = \sum_{z=1}^{Z} b^{z} x^{z}$$
(4.7)



Figure 4.8—Block diagram of partial transmit sequence (PTS) technique for PAPR reduction [28]

Where x^{Z} is referred to as a partial transmit sequence. As shown in Figure 4.8 the phase vector is selected so that PAPR can be minimized as follows:

$$[\widetilde{b}^{1}, ..., \widetilde{b}^{Z}] = \underset{[\widetilde{b}^{1}, ..., \widetilde{b}^{Z}]}{\operatorname{argmin}} \{ \underset{n=0,1,...,N-1}{\max} \left| \sum_{z=1}^{Z} b^{z} . x^{z}[n] \right|$$

$$(4.8)$$

Then the time domain signal with the lowest PAPR vector can be expressed as follows:

$$\widetilde{x} = \sum_{z=1}^{Z} \widetilde{b}^{z} x^{z}$$
(4.9)

Figure 4.9 shows the Complementary Cumulative Distribution Function (CCDF) of PAPR for a QAM/OFDM system with PTS technique when the number of subblocks varies. It can be seen that the PAPR improves as the number of subblocks increases.



Figure 4.9 PAPR performance of a 16 QAM/OFDM system with PTS technique when the number of subblocks varies. [28]

So far, we analyzed the distribution of OFDM signal and the fact that PAPR worsens as the number of subcarriers increases. The PAPR characteristics of the OFDM

signal includes the distributions of the discrete time domain signal x[n] as well as the imaginary and real parts. Our simulation results show that the real and imaginary parts of discrete time signal x[n] follow a Gaussian distribution while the continuous time signal x[t] follows a Rayleigh distribution. Besides, we show when measuring the PAPR of a single-carrier system, we must take into consideration the carrier frequency of the passband signal.

The performance of PAPR with PTS is affected by the number of subblocks, the phase vector, and by the subblock partitioning. There are three different subblock partitioning schemes: interleaved, adjacent and pseudo-random.

4.4 Uplink: Orthogonal FDMA, Distributed FDMA and Localized FDMA

Unlike OFDM used for downlink transmission, SC-FDMA is utilized in the uplink transmission where subcarriers are separated and designated for several mobile units. Each unit utilizes a number of subcarriers, let N_{unit} denote the number of subcarriers assigned to each unit for uplink transmission. The effectiveness of reduction in PAPR is greatly influenced by the technique in the method utilized to assign N to each unit.

Discrete Fourier Transform (DFT) spreading technique is a promising solution to reduce PAPR because of its superiority in PAPR reduction performance compared to block coding, Selective Mapping (SLM), Partial Transmit Sequence (PTS) and Tone Reservation (TR). SC-FDMA and OFDMA are both multiple-access versions of OFDM. There are two subcarrier mapping schemes in single carrier frequency division multiple access (SC-FDMA) to allocate subcarriers between units: Distributed FDMA and Localized FDMA.



Figure 4.10. OFDM available bandwidth is divided into subcarriers that are mathematically orthogonal to each other. [38]

This simulation helps in evaluating the performance of PAPR with different mapping schemes and modulation techniques for uplink transmission. Figure 4.10 shows that in Localized Frequency Division Multiplexing Access (LFDMA) each user transmission is localized in the frequency domain where in the Distributed Frequency Division Multiplexing Access (DFDMA) each user transmission is spread over the entire frequency band making it less sensitive to frequency errors and diversifies frequency.



Figure 4.11(a) QPSK [38]

Figure 4.11 show the performance of PAPR while the number of subcarriers is 128 and the number of subcarriers assigned to each unit or mobile device is 32.



Figure 4.11(b) 16 QAM [38]

The three Figures of 4.11 show when the single carrier is mapped either by LFDMA or IFDMA, it outperforms OFDMA due to the fact that in an uplink transmission, mobile terminals work differently than a base station in terms of power amplification. In the uplink transmission PAPR is more of a significant problem then on the downlink due to the capability and type of the amplifiers used in base station and mobile devices. For instance, when a mobile circuit's amplifier operates in the non-linear region due to PAPR, the mobile devise would consume more power and become less power efficient whereas base stations do not suffer from this consequence. Therefore, OFDM works better in the downlink transmission in terms of PAPR.



Figure 4.11(c) 64 QAM [38]

Our results show the effect of using Discrete Fourier Transform spreading technique to reduce PAPR for OFDMA, LFDMA and OFDMA with N=128 and N=32. A comparison is shown in Figure 4.11a,b and c utilizing different modulation schemes. The reduction in PAPR is significant when DFT is used. For instance, Figure 4.11(b) shows the values of Orthogonal-FDMA, Localized-FDMA and Interleaved-FDMA as 5.9 dB, 9 dB and 11 dB, respectively. The reduction of PAPR in IFDMA utilizing the DFT-spreading technique compared to OFDMA without the use of DFT is about 53 percent. Such reduction is significant in the performance of PAPR. Based on the simulation results in Figure 4.9 we can see that single carrier frequency division multiple access systems with IFDMA and LFDMA perform better than OFDMA in the uplink transmission. Although IFDMA performs better than OFDMA and LFDMA is preferred because assigning subcarriers over the whole band of IFDMA is complicated while LFDMA does not require the insertion of pilots of guard bands.

4.5 Pulse shaping

The idea of pulse shaping is to find an efficient transmitter and a corresponding receiver waveform for the current channel condition. The raised-cosine filter is used for pulse shaping because it is able to minimize inter-symbol interference (ISI). In this section we show the effect of pulse shaping on the PAPR. Figure 4.12 (a,b) show the PAPR performance of both IFDMA and LFDMA, varying the roll-off-factor of the raised cosine filter for pulse shaping after IFFT. The roll-off-factor is a measure of excess bandwidth of the filter. The raised cosine filter can be expressed as:

$$p(t) = \frac{\sin(\pi t/T)}{\pi t/T} \cdot \frac{\cos(\pi \alpha t/T)}{1 - 4\alpha^2 t^2/T^2}$$
(4.10)

Where T is the symbol period and α is the roll-off factor.



IFDMA is more sensitive to pulse shaping than LFDMA which is shown in Figures 4.12 (a, b). The PAPR performance of the IFDMA is greatly improved by varying the roll-off factor from 0 to 1. On the other hand LFDMA is not affected so much by the pulse shaping.



It is important to note that IFDMA has a trade-off relationship between excess bandwidth and PAPR performance because any excess in bandwidth increases as the rolloff factor increases. Excess bandwidth of a filter is the bandwidth occupied beyond the Nyquist bandwidth.



Figure 4.13. PAPR performance of DFT-spreading technique when the number of subcarriers varies. [38]

The PAPR performance of the DFT-spreading technique depends on the number of subcarriers allocated to each user. Figure 4.13 shows the performance of DFTspreading for LFDMA with a roll-off factor of 0.5. The degraded performance by about 3.5 dB can be seen as the number of subcarriers increase from 4 to 128 subcarriers.

4.6 The challenge of scheduling user transmissions on the downlink of a Long-term-evolution (LTE) cellular communication system

WCDMA has extended into high-speed-downlink-packet-access (HSDPA) and high-speed uplink-packet-access (HSUPA). The next generation in cellular telecommunication proposed by 3GPP is named long-term-evolution (LTE) and marketed as 4G. The main goal of LTE is to offer high peak downlink and uplink rates by the use of OFDMA that attributes a very flexible multi-user bandwidth, high spectral efficiency and scalable bandwidth. The benefit of LTE is the fact that it offers higher data rates in both the uplink and downlink directions and enhances the services for the terminals. A notable fact is that several WiMAX projects have been reoriented toward Long Term Evolution (LTE), mainly aimed at increasing performance. In this section, the challenge of scheduling user transmissions on the downlink of LTE cellular communication system is discussed. Various results show that the system performance improves with increasing correlation among OFDMA subcarriers.

There have been substantial contributions to improve the downlink capacity of the universal mobile telecommunications system (UMTS) within the LTE group of the 3GPP

evolved UMTS terrestrial radio access network (E-UTRAN) standardization [39-41]. LTE-advanced offers high peak data rates of 300 Mb/s on the downlink and 75 Mb/s on the uplink for a 20 MHz bandwidth, allowing operation of up to 20 MHz [42]. Presently, improvements are being considered to offer considerable enhancements to LTE Release 8, allowing it to meet International Mobile Telecommunications- Advanced (IMT-A) requirements [43]. These improvements are being considered as part of LTE-Advanced (LTE-A, also known as LTE Release 10), which includes advanced uplink (UL) and downlink (DL) spatial multiplexing and carrier aggregation. LTE Release 8 is one of the main broadband technologies that use OFDM. OFDM is a modulation technique that is used in many communication systems such WiMAX, DSLs, WLANs [44], LTE cellular networks. OFDMA provides further flexibility in resource allocation and to take advantage of multiuser diversity. The issue of sub-carrier allocation in OFDMA systems and power has been investigated in [45], and [46]. LTE Release 8 presently is available commercially. The main advantages of LTE-advanced are to improve system capacity and coverage, flexible bandwidth operation, seamless integration with existing systems, high peak data rates, reduced operating costs, low latency and multi-antenna support [47]. LTE Release 10 considerably improves the existing LTE Release 8 and has the capability to sustain higher throughput and coverage, higher peak rates, and lower latencies. Moreover, LTE Release 10 will have the capability to support heterogeneous exploitations where remote radio heads and relays are located in a macro-cell layout. LTE Release 10 characteristics are able to exceed International Mobile Telecommunications-Advanced requirements. Besides, LTE Release 9 offers some slight improvement to LTE Release 8 in regard to the air interface. 3GPP goals for the Long Term EvolutionAdvanced have been stopped in June 2008 [48] and a review of the goals can be found e.g. in [48] which also shows the descriptions of the equipment included in the LTE-Advanced Release 9. the IMT-Advanced Radio Interface Technology (RIT) recommendation was released on February 2011 [49], which meets the targeted schedule of the LTE Release 10.

The challenges in communications when transmitting information signals over channels are reliability and efficiency. A successful approach to achieving high-speed data transmission is multicarrier modulation (MCM), often also called multitone modulation. OFDM has been accepted for several wireless network standards, such as IEEE802.11x [45] and IEEE802.16x [46]. OFDM is a form of multicarrier modulation. The carrier spacing is chosen so that every subcarrier is orthogonal to all the other subcarriers. OFDM speeds up the signal processing and it's modulation schemes will make the next generation wireless communication system possible. Recently, orthogonal frequency division multiplexing has been developed for wideband communication over mobile radio FM channels, asymmetric digital subscriber lines (ADSL), very high-speed digital subscriber lines (HDSL), digital video broadcasting (DVB), digital audio broadcasting (DAB), and High Definition Digital Television (HDTV) terrestrial broadcasting.

4.6.1 System model

Consider a single-cell OFDM downlink situation where U denotes the number of simultaneous users that communicate with a base station over L sub-carriers. Suppose

time-slotted transmission, in each transmit time interval (TTI) the information bits of each U are mapped to a complex data block in accordance with the way in which the transport format is chosen [50]. The complex data of each U is solely asserted to the subcarriers L that fits in to a subset $S_u \subseteq L$ Apparently, by the OFDMA limitation we have $S_u \cap S_{u'} = \varphi u \neq u'$. Writing $x_{u,l}$ for the complex data of user U on subcarrier L and ignoring both intercarrier and intersymbol interference, the equivalent established value $y_{u,l}$ is given by (4.11)

$$y_{u,l} = h'_{u,l} x_{u,l} + n_{u,l'} \forall l, u \in S_u$$
(4.11)

Where;

 $n_{u,l} \approx N_c(0,1)$ = the additive white Gaussian noise (AWGN) $h_u[I]$ = the *Ith* tap of the channel impulse response. D_u = the length of channel impulse response of user u = the number users. $h'_{u,l}$ = the complex channel gain

$$h'_{u,l} = \sum_{I=1}^{D_u} h_u[I] e^{-2nj(I-1)(l-1)/l/k}$$
(4.12)

Our simulation based on 3GPP simulation assumptions [51]. The channel can be modeled in a mix of Pedestrian A 1.8 mph, Pedestrian B 1.8 mph, Vehicular A 18 mph and Vehicular B 75 mph with a delay spread that is constantly slighter than the guard time of the OFDM symbol [52]. For instance, pedestrian B channel model has 29 taps modeled as random variables so that $h'_{u,l}[I] \approx N_C(0,1) \forall u,l$, at a sampling rate of 7.86 MHz and to communicate to a channel with significant frequency dispersion.

The complex channel gains $h'_{u,l}[I]$ are predicted by the user *u* by means of reserved pilot subcarriers. Subsequently, appropriate channel quality information (CQI) value of the predicted channel gains is generated and reported back to the base station through a feedback channel. Normally a very low code rate and a diminutive constellation size are utilized for the feedback channel. For example, BPSK modulation for HSDPA [53] and it is practical to presume an error free feedback channel.

The CQI values are then used by the scheduling entity in the base station that allocates the accessible resources between the users.

Now let's assume that $\Gamma: R_{+}^{l} \to R_{+}^{l}$ is a vector quantizer related to the channel gains $|h_{u,1}^{'}|, ..., |h_{u,l}^{'}|, \forall u$, and let the outcome of this mapping be $h_{u,1}, ..., h_{u,l}, \forall u$. The outcomes of this mapping are equivalent to the recorded channel gains $|h_{u,1}^{'}|, ..., |h_{u,l}^{'}|, \forall u$ because of the error free feedback channel. After that, the rate $r_{u,l}$ of user u and on sub-carrier l, and the power budget P_{l} on sub-carrier l within the transmit time interval is given by (3)

$$r_{u,l}(p_l, h_{u,l}) = N_s \cdot C_r(p_l, h_{u,l}) \cdot r_{\text{mod}}(p_l, h_{u,l})$$
(4.13)

where
The mapping of $C_r(p_l, h_{u,l})$ = the asserted code rate.

 $r_{\text{mod}}(p_l, h_{u,l})$ = the number of bits of the selected modulation scheme.

 $C_r(p_l, h_{u,l})$ and $r_{mod}(p_l, h_{u,l})$ are both dependent on the allocated power P_l and the channel state $h_{u,l}$.

Assuming that the channel is constant over one transmit time interval. The number of OFDM symbols is then denoted as $N_s \ge 1$ when the sub-carrier l is allocated to user u in this transmit time interval. With the aim of determining a suitable modulation scheme for a particular channel conditions, we ran a simulation to acquire the association between bit-error rate (BER) and signal-to-noise ratio ($SNR = p_l h_{l,u}$) for the channels [54].

It appeared that when the mobility is low to medium such as (Pedestrian A/B, 1.8 mph, and Vehicular A, 18 mph), the required SNR levels are approximately the same. Various SNR levels are shown in Table 4.2 (where the mobility is low to medium) and Table 4.3 (where the mobility is high). All the reported channel gains and powers are set in vectors $h \in \Re^{U,L}_+$ and $p \in \Re^{L}_+$, correspondingly.

BER	10 ⁻³	10 ⁻⁵
QPSK	9.7 dB	13.4 dB
16QAM	16.4 dB	19.4 dB
64QAM	22.4 Db	24.4 dB

Table 4.2 Essential signal-to-noise ratio levels for 3GPP Pedestrian A/B, 1.8 mph, and Vehicular A, 18 mph, channel for specific BER constraint.

BER	10 ⁻³	10 ⁻⁵
QPSK	10.5 dB	13.4 dB
16QAM	17.6 dB	21.1 dB
64QAM	23.7 dB	26.7 dB

Table 4.3 Essential signal-to-noise ratio levels for 3GPP Vehicular A, 75 mph channel for specific BER constraint.

It is worth mentioning that because the chosen transport format varies over the slots, control information has to be sent out in parallel to user's data in the downlink channel enclosing modulation scheme, code, and user identifiers. Notice that there are more than a few tradeoffs concerned here. For example, although a smaller ratio of computation to the amount of communication in the downlink channel enhances the flexible scheduling procedure, it also boosts the quantity of the essential control information and, for this reason, reduces the available capacity for the user data. Moreover, a great number of concurrently supported users may result in a higher multiuser gain, which affects the downlink capacity negatively.

4.6.2 Simulation Results

In support of frequency-selective scheduling the channel characteristic is consecutively distinguished in a particular time period. Evidently, the precision of the characteristic fundamentally relies on the length of the period. An extended period rise the feedback information which results into a false scheduling decisions. This false scheduling decisions cause a high retransmission rate. The throughput gain because of the enhanced loss and the feedback resolution caused by the increased retransmission rate is illustrated in Figure 4.14(a); where Maximum Information Rate (MIR) is at an update period of 4 transmit time intervals. These results are very close to results obtained by Gerhard Wunder et al. [44]. Figure 4.14 (a, b) have an average transmit SNR of 16dB.



Figure 4.14(a) Data throughput versus update period [55]



Figure 4.14 (b) Data throughput versus supported links [55]

Figure 4.14(a) shows the data throughput with respect to the update period for five users. In Figure 4.14(b) shows the data throughput with respect to the supported links.

The number of users supported simultaneously creates a multiuser gain on top of the enhanced quality of service. On the other hand, the essential signaling information rises with the number of supported links. Additional subcarriers have to be held in reserve for the high-speed shared control channel (HS-SCCH) instead of the high speedphysical downlink shared channel (HS-PDSCH). Consequently, the attained throughput gain is compensated by the raised signaling requirement. According to our simulation setup Figure 4.14(b) illustrates that the most desirable throughput is achieved at 5 links. To enhance the impediment performance for delay sensitive purposes, a larger number of links ought to be used sacrificing the data throughput loss. In section 4.6 we addressed the challenge of scheduling user transmissions on the downlink of LTE cellular communication systems, and provided a concise overview and description of the LTE-Advanced. The evolution from HSDPA to OFDM-HSDPA requires some essential modifications that have to be implemented in the physical layer and the data communication protocol sub-layer to facilitate the adaptation the OFDM technology to HSDPA. Realistic limitations such as user mobility, feedback capacity, and feed forward demand have a significant effect on the performance. We showed a flexible concept to resolve these issues. We conclude that OFDM-HSDPA offers an excellent performance and can be even put into practice by means of standard HSDPA uplink channels. HSDPA is an enormous achievement. Presently there are more than 300 commercially installed HSPA networks, serving subscribers in over 130 countries. LTE will make it possible to meet the demands of new and superior applications of the future.

Chapter 5

SUMMARY AND FUTURE WORK

5.1 Summary

Although clipping is the simplest method, in our method utilizing the soft limiter the signal to quantization noise ratio (SQNR) in the conversion from analog to digital is enhanced. SQNR is a measurement of the difference between the analog value and the quantized digital. As the clipping threshold increases, clipping distortion decreases at the expense of PAPR and quantization noise. On the other hand as the clipping threshold decreases, PAPR and quantization noise decrease at the expense of clipping distortion. Therefore, it is important to take into consideration this trade-off relationship between clipping distortion and quantization noise when picking the number of bits for quantization and the clipping threshold.

Clipping ratio is the ratio of the clipping level to the RMS power of the OFDM signal. It was shown that as the clipping ratio increases the PAPR decreases dramatically after clipping and increases slightly after filtering. It was also shown that the performance of Bit Error Rate (BER) is enhanced as the clipping ratio increases.

Clipping and filtering of OFDM has been studied; however; these techniques reduce PAPR at the expense of increased system complexity and a high peak re-growth. The level of out-of-band radiation increases as the OFDM signal passes through a nonlinear device. An OFDM transmitter emits out-of-band radiation when a set of subcarriers is modulated. Our result, which was published in the International Journal of Computer Science [37], showed less out-of-band power emission compared to traditional OFDM by the use of the low complexity clipping and filtering technique.

Unlike OFDM used for downlink transmission, SC-FDMA is utilized in the uplink transmission where subcarriers are separated and designated for several mobile units. Each unit utilizes a number of subcarriers, let N_{unit} denote the number of subcarriers assigned to each unit for uplink transmission. The effectiveness of reduction in PAPR is greatly influenced by the technique in the method utilized to assign N to each unit.

Discrete Fourier Transform (DFT) spreading technique is a promising solution to reduce PAPR because of its superiority in PAPR reduction performance compared to block coding, Selective Mapping (SLM), and Tone Reservation (TR). SC-FDMA and OFDMA are both multiple-access versions of OFDM. There are two subcarrier mapping schemes in single carrier frequency division multiple access (SC-FDMA) to allocate subcarriers between units: Distributed FDMA and Localized FDMA.

We have shown the distribution of OFDM signal and the fact that PAPR worsens as the number of subcarriers increases. The PAPR characteristics of the OFDM signal includes the distributions of the discrete time domain signal x[n] as well as the imaginary and real parts. Our simulation results showed that the real and imaginary parts of discrete time signal x[n] follow a Gaussian distribution while the continuous time signal x[t] follows a Rayleigh distribution. Also, we showed when measuring the PAPR of a single-carrier system, we must take into consideration the carrier frequency of the passband signal.

The PTS technique requires a number of Z IFFT operations for each block. The performance of PAPR with PTS is affected by the number of subblocks, the phase vector and by the subblock partitioning. There are three different subblock partitioning schemes: interleaved, adjacent and pseudo-random. We proposed a suboptimal combination algorithm. The number of commutations in the suboptimal combination algorithm is Z, which is much lower than the required by the original PTS technique. Finally yet importantly, our results show that PAPR improves as the number of subblocks increases.

5.2 Future work

5.2.1 Antenna diversity (MIMO-OFDM)

Multiple-Input-Multiple-Output is abbreviated as MIMO. MIMO-OFDM is an air-interface that combines both MIMO and OFDM for wideband transmission. The concept of MIMO is that each receiving antenna combines the transmitted signal from all the transmit antennas in a way where the BER or the data rate of transmission is Figure 5.1 shows the Time, frequency, space-time and space-frequency enhanced. diversity methods. When the frequency diversity method is applied, then data is transmitted at several bands to attain diversity gain. On the other hand, when the time diversity method is applied, then data is transmitted over several time periods. As shown in Figure 5.1(a) and (b), the frequency and time diversity methods demand more frequency and time resource, respectively. Nevertheless, space or antenna diversity methods do not necessitate any additional resources. Figure 5.1(c) demonstrates a concept of the space-time diversity that uses multiple transmit antennas, without adding more time resource compared to Figure 5.1(a). Correspondingly, Figure 5.1(d)demonstrates a concept of the space-frequency diversity that uses multiple transmit antennas, without adding more frequency resource compared to Figure 5.1(b). Even though two transmit antennas are demonstrated in Figure 5.1, the concept can be stretched to numerous antenna configurations. Some of the configurations are multiple input single outputs (MISO), single input multiple outputs (SIMO), and multiple input multiple output (MIMO) antenna.



Figure 5.1 Illustration of time, frequency, and space diversity techniques. [56]

List of Publications

<u>Journals:</u>

- 1. Alhasson B. and Matin M. A., "PAPR for OFDM signals with Partial Transmit Sequence", Journal of Communications-special issue, 2012 (Accepted).
- Alhasson B. and Matin M. A., "PAPR Performance Analysis of DFT-spread OFDM for LTE Uplink Transmission", International Journal of Computer Science and Information Security, Vol. 9, No. 10, pp 1-7, 2001, ISSN: 1947-5500.
- Alhasson B. and Matin M. A., "Reduction of PAPR for OFDM Downlink and IFDMA Uplink Wireless Transmissions", International Journal of Computer Science and Information Security, Vol. 9, No. 3, pp 6-13, 2011, ISSN: 1947-5500.

Proceedings:

- Alhasson B. and Matin M. A.: "PAPR Distribution Analysis of OFDM signals with Partial Transmit Sequence", ICCIT Proceedings, Sponsored by IEEE, 652-656, December 2011, ISBN: 978-1-61284-907-2.
- Alhasson B. and Matin M. A.: "The challenge of scheduling user transmissions on the downlink of a long-term evolution (LTE) cellular communication system", Proc. SPIE, Vol. 7797, 779719, 2010, DOI: 10.1117/12.863097.
- Alhasson B., Bloul A., and Matin M. A.: "Dispersion and Nonlinear Effects in OFDM-RoF system", SPIE, Vol. 7797, 779704, 2010, DOI: 10.1117/12.860948.
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Reduction of PAPR for OFDM Downlink and IFDMA Uplink Wireless Transmissions

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Abstract-- One of the major drawbacks of OFDM is the high peak-to-average power ratio (PAPR) of the transmitted signals. In this paper, we propose a novel low complexity clipping scheme applicable to Interleaved-FDMA uplink and OFDM downlink systems for PAPR reduction. We show the performance of PAPR of the proposed Interleaved-FDMA scheme is better than traditional OFDMA for uplink transmission system. Our reduction of PAPR is 53% when IFDMA is used instead of OFDMA in the uplink transmission. We also examine an important trade-off relationship between clipping distortion and quantization noise when the clipping scheme is used for OFDM downlink systems. Our results show that we were able to reduce the PAP ratio by 50% and reduce the out-of-band radiation caused by clipping for OFDM downlink transmission system.

Keywords-component-- Signal to quantization noise ratio (SQNR);Localized-frequency-division-multiple-access (LFDMA); interleaved-frequency-division-multiple-access (IFDMA); peakto-average power ratio (PAPR); clipping ratio (CR); single carrier frequency division multiple access (SC-FDMA).

I. INTRODUCTION

Wireless communication has experienced an incredible growth in the last decade. Two decades ago the number of mobile subscribers was less than 1% of the world's population [1]. In 2001, the number of mobile subscribers was 16% of the world's population [1]. By the end of 2001 the number of countries worldwide having a mobile network has tremendously increased from just 3% to over 90% [2]. In reality the number of mobile subscribers worldwide exceeded the number of fixed-line subscribers in 2002 [2]. As of 2010 the number of mobile subscribers was around 73% of the world's population which is around to 5 billion mobile subscribers [1].

In addition to mobile phones WLAN has experienced a rapid growth during the last decade. IEEE 802.11 a/b/g/n is a set of standards that specify the physical and data link layers in

ad-hoc mode or access point for current wide use. In 1997 WLAN standard – IEEE 802.11, also known as Wi-Fi, was first developed with speeds of up to 2 Mbps [2]. At present, WLANs are capable of offering speeds up-to 600 Mbps for the IEEE 802.11n utilizing OFDM as a modulation technique in the 2.4 GHz and 5 GHz license-free industrial, scientific and medical (ISM) bands. It is important to note that WLANs do not offer the type of mobility, which mobile systems offer. In our previous work, we modeled a mix of low mobility 1.8mph, and high mobility, 75mph with a delay spread that is constantly slighter than the guard time of the OFDM symbol

to predict complex channel gains by the user by means of reserved pilot subcarriers [3].

Orthogonal frequency division multiplexing (OFDM) is a broadband multicarrier modulation scheme. Research on multi-carrier transmission started to be an interesting research area [4-6]. OFDM modulation scheme leads to better performance than a single carrier scheme over wireless channels since OFDM uses a large number of orthogonal, narrowband sub-carrier that are transmitted simultaneously in parallel. We investigated the channel capacity and bit error rate of MIMO-OFDM [7]. The use of OFDM scheme is the solution to the increase demand for future bandwidth-hungry wireless applications [8]. Some of the wireless technologies using OFDM are Long-Term Evolution (LTE). LTE is the standard for 4G cellular technology, ARIB MMAC in Japan have adopted the OFDM transmission technology as a physical layer for future broadband WLAN systems, ETSI BRAN in Europe and Wireless local-area networks (LANs) such as Wi-Fi. Due to the robustness of OFDM systems against multipath fading, the integration of OFDM technology and radio over fiber (RoF) technology made it possible to transform the high speed RF signal to the optical signal utilizing the optical fibers with broad bandwidth [9]. Nevertheless, OFDM suffers from high peak to average power ratio (PAPR) in both the uplink and downlink which results in making the OFDM signal a complex signal [10].

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Figure.1 Fresnel diagram illustrating the PAPR issue

Figure.1 shows a constructive addition of subcarriers on a random basis which causes the peak-to-average power ratio problem. The outcome of high PAPR on the transmitted OFDM symbols results in two disadvantages high bit error rate and inference between adjacent channels. This would imply the need for linear amplification. The consequence of linear amplification is more power consumption. This has been an obstacle that limits the optimal use of OFDM as a modulation and demodulation technique [11-14]. The problem of PARP affects the uplink and downlink channels differently. On the downlink, it's simple to overcome this problem by the use of power amplifiers and distinguished PAPR reduction methods. These reduction methods can't be applied to the uplink due to their difficulty in low processing power devices such as mobile devices. On the uplink, it is important to reduce the cost of power amplifiers as well.

PAPR reduction schemes have been studied for years [15-18]. Some of the PAPR reduction techniques are: Coding techniques which can reduce PAPR at the expense of bandwidth efficiency and increase in complexity [19-20]. The probabilistic technique which includes SLM, PTS, TR and TI can also reduce PAPR; however; suffers from complexity and spectral efficiency for large number of subcarriers [21-22].

We perform an analysis on a low complexity clipping and filtering scheme to reduce both the PAPR and the out-of-bandradiation caused by the clipping distortion in downlink systems. It was also shown that a SC-FDMA system with Interleaved-FDMA or Localized-FDMA performs better than Orthogonal-FDMA in the uplink transmission.

II. SYSTEM MODEL



In complex baseband, an OFDM signal x(t) during time interval $mT_u \le t \prec (m+1)T_U$ can be expressed as

$$x(t) = \sum_{K=0}^{N_{c}-1} x_{k}(t) = \sum_{K=0}^{N_{c}-1} a^{m} e^{j 2\pi k \Delta f t}$$
(1)

Where $X_k(t)$ is the *kth* modulated subcarrier at a frequency $f_k = k \Delta f$. The modulation symbol $a_k^{(m)}$ is applied to the *kth* subcarrier during the *mth* OFDM interval which is $mT_u \leq t \prec (m+1)T_U$. Therefore, during each OFDM symbol interval transmission, N_C modulation symbols are transmitted in parallel. The modulation symbols are dependent on the use of this technology and can be any form of modulation such as 16QAM, 64QAM or QPSK. The choice of which modulation scheme to implement varies

depending on the environment and application.



Figure 3 OFDM modulation valid for time interval $mT_{u} \le t \prec (m + 1)T_{u}$.

Subcarriers spacing range hundreds of kHz to a small number of kHz depending on the environment of operation. Once the spacing between subcarriers has been specified, then the choice of how many subcarriers to be transmitted in parallel has to be done. It is important to note that allocation of the number of subcarriers is dependent on the transmission bandwidth. For instance, LTE uses 15 kHz as the basic spacing with a 600 subcarriers assuming the operation is in the 10 MHZ spectrum.

Let us consider two modulated OFDM subcarriers $x_{k1}(t)$ and

 $x_{k2}(t)$. The two signals are *orthogonal* over the time period $mT_u \le t \prec (m+1)T_{ti}$

$$\int_{mT_{u}}^{(m+1)T_{u}} x_{k1}(t) x_{k2}^{*}(t) dt$$

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$$\implies \int_{mT_u}^{(m+1)T_u} a_{k2}^* e^{j2\pi k_1 \Delta f} e^{-j2\pi k_2 \Delta f} dt = 0$$

for $k_1 \neq k_2$ (2)

Therefore, OFDM transmission can be expressed as the modulation of a set of orthogonal functions $\varphi_k(t)$, where

$$\varphi_{k}(t) = \mathcal{C} \stackrel{j \ 2 \ \pi \ k \ \Delta \ ft}{0 \le t \prec T_{u}},$$

$$0 \text{ otherwise} \qquad (3)$$



Figure 4. OFDM available bandwidth is divided into subcarriers that are mathematically orthogonal to each other

III. DISTRIBUTION of THE PAP RARIO

The complex baseband signal for one OFDM symbol can be rewritten as:

$$x(t) = \frac{1}{\sqrt{N}} \sum_{n=1}^{N} a_n \exp(j\omega_n t)$$
⁽⁴⁾

Where N is the number of subcarriers and a_n are the modulating symbols. From the central limit theorem, we can assume that the real and imaginary parts of the time domain complex OFDM signal x(t) have a Gaussian distribution for a large number of subcarriers. Therefore, the amplitude of the OFDM signal x(t) follows a Rayleigh distribution, whereas power follows a central chi-square distribution with the cumulative distribution expressed as:

$$F(z) = 1 - e^z \tag{5}$$

OFDM system with a certain number of subcarriers suffers from maximum power which arises when all of the subcarriers add up coherently with identical phases. The largest PAPR happens randomly with a very low probability. The main interest is actually in the probability of the occurrence of high signal power. This high signal power is out of the linear range of high power amplifiers. The probability PAPR is below a certain threshold can be expressed as:

$$P(PAPR \le z) = F(z)^{N} = (1 - \exp(-z))^{N}$$
(6)

Equation (6) holds for samples that are mutually uncorrelated; however; when over sampling is applied then it doesn't hold. This is due to the fact that a sampled signal doesn't certainly include the maximum point of the original continuous time signal. Nevertheless, it is important to note that it is difficult to derive the exact cumulative distribution function for the peak power distribution. The following simplified proposed PAP distribution will be used:

$$F(z)^{N} \approx (1 - \exp(-z^{2}))^{\alpha N}$$
⁽⁷⁾

Where α has been found by fitting the theoretical CDF into the actual one. From our simulation, it was shown that $\alpha = 2.8$ is suitable for adequately a large number of subcarriers.

The theoretical and simulated curves are plotted in Figure 5 for different number of subcarriers. As N decreases, the deviation between the obtained simulation and theoretical results increases, which indicates that equation (7) is quite accurate for N>256. It is worth noting that equation (6) is more accurate for large CDF values as shown in Figure 5.



Figure 5 OFDM system with N-point FFT. CCDFs of signal PAP ratio with N=16, 32, 64, 128 and 1024. Solid lines are calculated; dotted lines are simulated.

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IV. CLIPPING AND SIGNAL TO QUANTIZATION NOISE RATIO

An OFDM signal has the tendency to have a large peak to average power ratio when each subcarrier by chance has the highest amplitude and identical phases at the same time. The likelihood of such event is rare yet it does occur. As the number of subcarriers increase, the maximum power increases as shown in Figure 5. The probability of that maximum power signal actually decreases as N increases. This is due to the statistical magnitude distribution of the time-domain OFDM signal.

The simplest approach to reduce the PAP ratio is to clip the amplitude of the signal to a desired maximum level. Although clipping is the simplest method, in our method it enhances the signal to quantization noise ratio (SQNR) in the conversion from analog to digital.

As the clipping threshold increases, clipping distortion decreases at the expense of PAPR and quantization noise. On the other hand as the clipping threshold decreases, PAPR and quantization noise decrease at the expense of clipping distortion. Therefore, it is important to take into consideration this trade-off relationship between clipping distortion and quantization noise when picking the number of bits for quantization and the clipping threshold.

Figure 6 shows the SQNR values of OFDM signal quantized with 5, 6, 7, 8 bits against the clipping threshold and N=128. The optimal clipping threshold to maximize the signal to quantization noise ratio fluctuates with the quantization level; however; we can see that the maximum points are approximately around 3.5 of the normalized clipping threshold. Clipping distortion is more significant to the left of the maximum points due to the low threshold of clipping whereas the clipping distortion is not as significant to the right of the maximum points where the clipping threshold is higher.



Figure 6 Clipping threshold against SQNR of quantized OFDM signal. N=128

The performance of any PAPR reduction scheme is evaluated based on out-of-band radiation, in-band ripple, distribution of PAPR and the BER performance [23].

V. SIMULATION AND RESULTS

To evaluate the performance of the clipping and filtering method used in our simulation, the following parameters were used to in the simulation.

Table I. Simulation parameters

Ν	256
Clipping Ratio	1.4
Carrier frequency	5 MHz
Modulation	QPSK
Sampling frequency	10 MHz
Bandwidth	1MHz
Guard interval samples	32



Figure 7 Baseband signal

Figure 7 shows the power spectral density of oversampled baseband signal. This is the output of IFFT. Let x(s) be the output of IFFT. Then the output of IFFT can be expressed mathematically as:

$$x(s) = \frac{1}{\sqrt{L.N}} \sum_{k=0}^{L.N-1} X(k) \cdot e^{2\pi j s \Delta j k / L.N}, s = 0, 1, \dots NL - 1$$

With
$$X(k) = X(k), \text{ for } 0 \le k \le N/2 \text{ and } NL-N/2 \le k \le NL$$

0, otherwise (8)

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Where L, Δf , N and $\chi(k)$ represent the oversampling factor, the subcarrier spacing, the number of subcarriers and the symbol carried by subcarrier k, respectively.



Figure 8 shows the power spectral density and a histogram of the baseband signal without clipping and filtering. We can see the power density function shows a Gaussian distribution of the signal.



Clipping and filtering OFDM has been studied [23]; however; these techniques reduce PARP at the expense of increased system complexity and a high peak re-growth. Figure 9 shows the level of Out-of-band radiation increases as the OFDM signal passes through a nonlinear device. An OFDM transmitter emits out-of-band radiation when a set of subcarriers are modulated. Our results show less out-of-band power emission compared to traditional OFDM by the use of the low complexity clipping and filtering technique.



The out-of-band radiation can be seen from Figure 9 and 10. It is clear that the out-of-band radiation increases after clipping; however, it decreases after filtering and shows a peak value beyond the clipping threshold implying a slight peak regrowth in PAPR after filtering as shown in Figure 10. To complete the evaluation of clipping and filtering then we have to look at the BER performance when the clipping ratio varies.



Figure 11 (a) PAPR distribution (b) BER performance

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It can be seen from Figure 11(a) as the clipping ratio increases from right to left, the PAPR decreases dramatically after clipping and increases slightly after filtering. The simulation result in Figure 11 (b) shows that the performance of BER is better as the clipping ratio increases. Unlike OFDM used for downlink transmission, SC-FDMA is utilized in the uplink transmission where subcarriers are separated and designated for several mobile units. Each unit utilizes a number of subcarriers, let $\frac{N}{unit}$ denote the number of subcarriers assigned

to each unit for uplink transmission. The effectiveness of reduction in PAPR is greatly influenced by the technique in the method utilized to assign N to each unit [24].

Discrete Fourier Transform (DFT) spreading technique is a promising solution to reduce PAPR because of it's superiority in PAPR reduction performance compared to block coding, Selective Mapping (SLM), Partial Transmit Sequence (PTS) and Tone Reservation (TR) [25-26]. SC-FDMA and OFDMA are both multiple-access versions of OFDM. There are two subcarrier mapping schemes in single carrier frequency division multiple access (SC-FDMA) to allocate subcarriers between units: Distributed FDMA and Localized FDMA.



Figure 12 show the performance of PAPR while the number of subcarriers is 128 and the number of subcarriers assigned to each unit or mobile device is 32. This simulation helps in evaluating the performance of PAPR with different mapping schemes and modulation techniques. In LFDMA each user transmission is localized in the frequency domain where in the DFDMA each user transmission is spread over the entire frequency band making it less sensitive to frequency errors and diversifies frequency.



The three figures of 12 show that when the single carrier is mapped either by LDMA or DFDMA, it outperforms OFDMA due to the fact that in an uplink transmission, mobile terminals work differently then a base station in terms of power amplification. In the uplink transmission PAPR is more of a significant problem then on the downlink due to the type and capability of the amplifiers used in base station and mobile devices. For instance, when a mobile circuit's amplifier operates in the non-linear region due to PAPR, the mobile devise would consume more power and become less power efficient whereas base stations don't suffer from this consequence. Therefore, OFDM works better in the downlink transmission in terms of PAPR.



Our results show the effect of using Discrete Fourier Transform spreading technique to reduce PAPR for OFDMA, LDMA and OFDMA with N=128 and N =32. A comparison unit

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is shown in Figure 12 a,b and c utilizing different modulation schemes. The reduction in PAPR is significant when DFT is used. For instance, Figure 12(b) where Orthogonal-FDMA, Localized-FDMA and Interleaved-FDMA have the values of 5.9 dB, 9 dB and 11 dB, respectively. The reduction of PAPR in IFDMA utilizing the DFT-spreading technique compared to OFDMA without the use of DFT is about 53 percent. Such reduction is significant in the performance of PAPR. Based on the simulation results in Figure 12 we can see that single carrier frequency division multiple access systems with Interleaved-FDMA and Localized-FDMA perform better than OFDMA in the uplink transmission. Although Interleaved-FDMA performs better than OFDMA and LFDMA, LFDMA is preferred due to the fact that assigning subcarriers over the whole band of IFDMA is complicated while LFDMA doesn't require the insertion of pilots of guard bands.

VI. CONCLUSION

We have shown the importance of the trade-off relationship between clipping distortion and quantization noise. Our results show that as the clipping threshold increases, clipping distortion decreases at the expense of PAPR and quantization noise. On the other hand as the clipping threshold decreases, PAPR and quantization noise decrease at the cost of clipping distortion. Therefore, it is important to take into consideration this trade-off relationship between clipping distortion and quantization noise when picking the number of bits for quantization and the clipping threshold. We showed that clipping decreases the amplitude to a desired maximum power level and the outcome signal suffers from out-of-band radiation as a result of clipping distortion which is eliminated by filtering at the expense of a slight peak re-growth in amplitude due to filtering. It was also shown that a SC-FDMA system with Interleaved-FDMA or Localized-FDMA performs better than Orthogonal-FDMA in the uplink transmission where transmitter power efficiency is of great importance in the uplink.

LFDMA and IFDMA result in lower average power values, due to the fact that OFDM and OFDMA map their input bits straight to frequency symbols where LFDMA and IFDMA map their input bits to time symbols. We conclude that single carrier-FDMA is a better choice on the uplink transmission for cellular systems. Our conclusion is based on the better efficiency due to low PAPR and on the lower sensitivity to frequency offset since SC-FDMA has a maximum of two adjacent users.

VII. FUTURE WORK

We would like to further investigate the effect of PAPR in MIMO-OFDM systems.

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PAPR Performance analysis of DFT-spread OFDM for LTE Uplink transmission

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Abstract— 3rd Generation Partnership Project (3GPP) LTE has adopted SC-FDMA as the uplink multiple access scheme which use single carrier modulation and frequency domain equalization. In this paper, we show that the PAPR performance of DFT-spreading technique with IFDMA can be significantly improved by varying the roll-off factor from 0 to 1 of the RC (Raised-Cosine) filter for pulse shaping after IFFT. Our PAPR reduction is 30% of DFT with IFDMA utilizing QPSK and varying the roll-off factor. We show pulse shaping does not affect LFDMA as much as it affects IFDMA. Therefore, IFDMA has an important trade-off relationship between excess bandwidth and PAPR performance since excess bandwidth increases as the rolloff factor increases. Our simulation indicates that the performance of PAPR of DFT spreading technique is dependent on the number of subcarriers assigned to each user. The effect of PAPR dependency on the method used to assign the subcarriers to each terminal is also simulated.

Index terms— Long-term-evolution (LTE); Discrete Fourier Transform (DFT); Orthogonal frequency division multiplexing (OFDM);Localized-frequency-division-multiple-access (LFDMA);Interleaved-frequency-division-multiple-access (IFDMA); peak-to-average power ratio (PAPR); single carrier frequency division multiple access (SC-FDMA).

I. INTRODUCTION

Wireless communication has experienced an incredible growth in the last decade. Two decades ago the number of mobile subscribers was less than 1% of the world's population [1]. In 2001, the number of mobile subscribers was 16% of the world's population [1]. By the end of 2001 the number of countries worldwide having a mobile network has tremendously increased from just 3% to over 90% [2]. In reality the number of mobile subscribers worldwide exceeded the number of fixed-line subscribers in 2002 [2]. As of 2010 the number of mobile subscribers was around 73% of the world's population which is around to 5 billion mobile subscribers [1].

In addition to mobile phones WLAN has experienced a rapid growth during the last decade. IEEE 802.11 a/b/g/n is a set of standards that specify the physical and data link layers in adhoc mode or access point for current wide use. In 1997 WLAN standard – IEEE 802.11, also known as Wi-Fi, was first developed with speeds of up to 2 Mbps [2]. At present,

WLANs are capable of offering speeds up-to 600 Mbps for the IEEE 802.11n utilizing OFDM as a modulation technique in the 2.4 GHz and 5 GHz license-free industrial, scientific and medical (ISM) bands. It is important to note that WLANs do

not offer the type of mobility, which mobile systems offer. In our previous work, we analyzed a low complexity clipping and filtering scheme to reduce both the PAPR and the out-ofband-radiation caused by the clipping distortion in downlink systems utilizing OFDM technique [3]. We also modeled a mix of low mobility 1.8mph, and high mobility, 75mph with a delay spread that is constantly slighter than the guard time of the OFDM symbol to predict complex channel gains by the user by means of reserved pilot subcarriers [4]. SC-FDMA is the modified version of OFDMA. SC-FDMA is a customized form of OFDM with comparable throughput performance and complexity. The only dissimilarity between OFDM and SC-FDMA transmitter is the DFT mapper. The transmitter collects the modulation symbols into a block of N symbols after mapping data bits into modulation symbols. DFT transforms these symbols in the time domain into frequency domain. The frequency domain samples are then mapped to a subset of M subcarriers where M is greater than N. Like OFDM, an M point IFFT is used to generate the time-domain samples of these subcarriers

OFDM is a broadband multicarrier modulation scheme where single carrier frequency division multiple access (SC-FDMA) is a single carrier modulation scheme.

Research on multi-carrier transmission started to be an interesting research area [5-7]. OFDM modulation scheme leads to better performance than a single carrier scheme over wireless channels since OFDM uses a large number of orthogonal, narrowband sub-carrier that are transmitted simultaneously in parallel; however; high PAPR becomes an issue that limits the uplink performance more than the downlink due to the low power processing terminals. SC-FDMA adds additional advantage of low PAPR compared to OFDM making it appropriate for uplink transmission.

We investigated the channel capacity and bit error rate of MIMO-OFDM [8]. The use of OFDM scheme is the solution to the increase demand for future bandwidth-hungry wireless applications [9]. Some of the wireless technologies using OFDM are Long-Term Evolution (LTE). LTE is the standard

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for 4G cellular technology, ARIB MMAC in Japan have adopted the OFDM transmission technology as a physical layer for future broadband WLAN systems, ETSI BRAN in Europe and Wireless local-area networks (LANs) such as Wi-Fi. Due to the robustness of OFDM systems against multipath fading, the integration of OFDM technology and radio over fiber (RoF) technology made it possible to transform the high speed RF signal to the optical signal utilizing the optical fibers with broad bandwidth [10]. Nevertheless, OFDM suffers from high peak to average power ratio (PAPR) in both the uplink and downlink which results in making the OFDM signal a complex signal [11].

The outcome of high PAPR on the transmitted OFDM symbols results in two disadvantages high bit error rate and inference between adjacent channels. This would imply the need for linear amplification. The consequence of linear amplification is more power consumption. This has been an obstacle that limits the optimal use of OFDM as a modulation and demodulation technique [12-15]. The problem of PARP affects the uplink and downlink channels differently. On the downlink, it's simple to overcome this problem by the use of power amplifiers and distinguished PAPR reduction methods. These reduction methods can't be applied to the uplink due to their difficulty in low processing power devices such as mobile devices. On the uplink, it is important to reduce the cost of power amplifiers as well.

PAPR reduction schemes have been studied for years [16-19]. Some of the PAPR reduction techniques are: Coding techniques which can reduce PAPR at the expense of bandwidth efficiency and increase in complexity [20-21]. The probabilistic technique which includes SLM, PTS, TR and TI can also reduce PAPR; however, suffers from complexity and spectral efficiency for large number of subcarriers [22-23].

We show the effect of PAPR dependency on the method used to assign the subcarriers to each terminal. PAPR performance of DFT-spreading technique varies depending on the subcarrier allocation method.

II SYSTEM CONFIGURATION OF SC-FDMA and OFDMA



Fig.1. Transmitter and receiver structure of SC-FDMA

The transmitters in Figure 1 and 2 perform some signalprocessing operations prior to transmission. Some of these operations are the insertion of cyclic prefix (CP), pulse shaping (PS), mapping and the DFT. The transmitter in Figure 1 converts the binary input signal to complex subcarriers. In a SC-FDMA, DFT is used as the first stage to modulate subcarriers. DFT produce a frequency domain representation of the input signal. **OFDMA:**



Figure 2 illustrates the configuration of OFDMA transmitter and receiver. The only difference between SC-FDMA and OFDMA is the presences of the DFT and IDFT in the transmitter and receiver respectively of SC-FDMA. Hence, SC-FDMA is usually referred to as DFT-spread OFDMA.



Fig. 1. OFDM available bandwidth is divided into subcarriers that are mathematically orthogonal to each other [3]

II. SYSTEM MODEL



Fig. 2.DFT-spreading OFDM single carrier transmitter

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One of the major drawbacks of OFDM is the high peak-toaverage power ratio (PAPR) of the transmitted signals, i.e., the large variations in the instantaneous power of the transmitted signal. This would require linear amplification. The result of such linear amplification would imply more power consumption. This is significant on the uplink, due to the low mobile-terminal power consumption and cost. Therefore, wide-band single-carrier transmission is an alternative to multi-carrier transmission, particularly for the uplink. One of such single-carrier transmission scheme can be implemented using DFT-spread OFDM which has been selected as the uplink transmission scheme for LTE allowing for small variations in the instantaneous power of the transmitted uplink signal.

The main advantage of DFTS-OFDM, compared to OFDM, is the reduction of variations in the instantaneous transmit power, leading to the possibility for increased power-amplifier efficiency.

DFT spreading technique is a promising solution to reduce PAPR because of it's superiority in PAPR reduction performance compared to block coding, Selective Mapping (SLM), Partial Transmit Sequence (PTS) and Tone Reservation (TR) [24-25]. SC-FDMA and OFDMA are both multiple-access versions of OFDM. There are two subcarrier mapping schemes in single carrier frequency division multiple access (SC-FDMA) to allocate subcarriers between units: Distributed FDMA and Localized FDMA.



Fig. 3.Subcarrier allocation methods for multiple users (3 users, 12 subcarriers, and 4 subcarriers allocated per user).

III SIMULATION AND RESULTS

Before examining the reduction of PAPR, let us consider a single-carrier system where N=1. Figure 4 shows both the baseband QPSK-modulated signal and the passband signal with a single carrier frequency of 1 Hz and an oversampling factor of 8. Figure 4a shows that the baseband signal's average and peak power values are the same that is PAPR is

0dB.



Fig. 4. (a) Baseband signal

On the other hand, Figure 4b shows the passband signal with a PAPR of 3,01 dB.



Note that the PAPR varies in the passband signal depending on the carrier frequency. As a result, when measuring the PAPR of a single-carrier system, then we must be taken into consideration the carrier frequency of the passband signal.

A. Interleaved, Localized and Orthogonal-FDMA

There are two channel allocation schemes for SC-FDMA systems; i.e., the localized and interleaved schemes where the subcarriers are transmitted subsequently, rather than in parallel. In the following simulation results, we compared

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different allocation schemes of SC-FDMA systems and their PAPR. These types of allocation schemes are subject to intersymbol interference when the signal suffers from sever multipath propagation. In SC-FDMA this type of interference can be substantial and usually an adaptive frequency domain equalizer is placed at the base station. This type of arrangement makes sense in the uplink of cellular systems due to the additional benefit that SC-FDMA adds in terms of PAPR. In this type of arrangement, i.e, single carrier system the burden of linear amplification in portable terminals is shifted to the base station at the cost of complex signal processing, that is frequency domain equalization.



Fig. 4. (a) QPSK

Figure 4 show the performance of PAPR while the number of subcarriers is 256 and the number of subcarriers assigned to each unit or mobile device is 64. This simulation helps in evaluating the performance of PAPR with different mapping schemes and modulation techniques. In LFDMA each user transmission is localized in the frequency domain where in the DFDMA each user transmission is spread over the entire frequency band making it less sensitive to frequency errors and diversifies frequency.



The three figures of 4 show that when the single carrier is mapped either by LFDMA or DFDMA, it outperforms OFDMA due to the fact that in an uplink transmission, mobile terminals work differently then a base station in terms of power amplification. In the uplink transmission PAPR is more of a significant problem then on the downlink due to the type and capability of the amplifiers used in base station and mobile devices. For instance, when a mobile circuit's amplifier operates in the non-linear region due to PAPR, the mobile devise would consume more power and become less power efficient whereas base stations don't suffer from this consequence. Therefore, OFDM works better in the downlink transmission in terms of PAPR.



Our results show the effect of using Discrete Fourier Transform spreading technique to reduce PAPR for OFDMA, LFDMA and OFDMA with N=256 and N =64. A comparison unit is shown in Figure 4 a,b and c utilizing different modulation schemes. The reduction in PAPR is significant when DFT is used. For example, Figure 4(b) where Orthogonal-FDMA, Localized-FDMA and Interleaved-FDMA have the values of 3.9 dB, 8.5 dB and 11 dB, respectively. The reduction of PAPR in IFDMA utilizing the DFT-spreading technique compared to OFDMA without the use of DFT is 6.1 dB. Such reduction is significant in the performance of PAPR. Based on the simulation results in Figure 2 we can see that single carrier frequency division multiple access systems with Interleaved-FDMA and Localized-FDMA perform better than OFDMA in the uplink transmission. Although Interleaved-FDMA performs better than OFDMA and LFDMA, LFDMA is preferred due to the fact that assigning subcarriers over the whole band of IFDMA is complicated while LFDMA doesn't require the insertion of pilots of guard bands.

B. Pulse shaping

The idea of pulse shaping is to find an efficient transmitter and a corresponding receiver waveform for the current channel

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condition [26]. The raised-cosine filter is used for pulse shaping because it is able to minimize intersymbol interference (ISI). In this section we show the effect of pulse shaping on the PAPR. Figure 4 a and b show the PAPR performance of both IFDMA and LFDMA, varying the rolloff-factor of the raised cosine filter for pulse shaping after IFFT. The roll-off-factor is a measure of excess bandwidth of the filter. The raised cosine filter can be expressed as:

$$p(t) = \frac{\sin(\pi t/T)}{\pi t/T} \cdot \frac{\cos(\pi \alpha t/T)}{1 - 4\alpha^2 t^2/T^2}$$

Where T is the symbol period and α is the roll-off factor.



Fig. 5. (a) QPSK

Figures 5 a and b imply that IFDMA is more sensitive to pulse shaping than LFDMA. The PAPR performance of the IFDMA is greatly improved by varying the roll-off factor from 0 to 1. On the other hand LFDMA is not affected so much by the pulse shaping.



It is important to note that IFDMA has a trade-off relationship between excess bandwidth and PAPR performance because any excess in bandwidth increases as the roll-off factor increases. Excess bandwidth of a filter is the bandwidth occupied beyond the Nyquist bandwidth.



Fig. 6. PAPR performance of DFT-spreading technique when the number of subcarriers vary

The PAPR performance of the DFT-spreading technique depends on the number of subcarriers allocated to each user. Figure 5 shows the performance of DFT-spreading for LFDMA with a roll-off factor of 0.5. The degraded performance by about 3.5 dB can be seen as the number of subcarriers increase from 4 to 128 subcarriers.

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V. CONCLISION

We have shown the importance of the trade-off relationship of IFDMA between excess bandwidth and PAPR performance due to the fact that any excess in bandwidth increases as the roll-off factor increases. Our results show The PAPR performance of the IFDMA is greatly improved by varying the roll-off factor. On the other hand LFDMA is not affected so much by the pulse shaping. It was also shown that a SC-FDMA system with Interleaved-FDMA or Localized FDMA performs better than Orthogonal-FDMA in the uplink transmission where transmitter power efficiency is of great importance in the uplink. LFDMA and IFDMA result in lower average power values due to the fact that OFDM and OFDMA map their input bits straight to frequency symbols where LFDMA and IFDMA map their input bits to time symbols. We conclude that single carrier-FDMA is a better choice on the uplink transmission for cellular systems. Our conclusion is based on the better efficiency due to low PAPR and on the lower sensitivity to frequency offset since SC-FDMA has a maximum of two adjacent users. Finally yet importantly, the PAPR performance of DFT-spreading technique degrades as the number of subcarriers increase.

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Appendix B



PAPR Distribution Analysis of OFDM signals with Partial Transmit Sequence

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Abstract

Third Generation Partnership Project (3GPP) LTE has adopted OFDMA as the uplink multiple access scheme. One of the major drawbacks is the high PAPR. Not only is the performance of PAPR with PTS technique influenced by the number of subblocks and the phase vector but also by the subblock partitioning. The Partial Transmit Sequence (PTS) technique suffers from the search complexity of finding the optimum set of phase vectors. We propose a suboptimal combination algorithm that reduces the search complexity. The number of commutations in the suboptimal combination algorithm is much lower than the required by the original PTS technique. In this paper, we propose a suboptimal combination algorithm to reduce the searching complexity of finding the optimum set of vectors to minimize PAPR. The performance of PAPR utilizing the PTS technique improves by the use of the proposed suboptimal combination algorithm.

Keywords— Partial Transmit Sequence (PTS); Longterm-evolution (LTE); Orthogonal frequency division multiplexing (OFDM); peak-to-average power ratio (PAPR).

I. INTRODUCTION

Wireless communication has experienced an incredible growth in the last decade. Two decades ago, the number of mobile subscribers was less than 1% of the world's population and in 2001, the number of mobile subscribers was 16% of the world's population [1]. By the end of 2001 the number of countries worldwide having a mobile network has tremendously increased from just 3% to over 90% and the number of mobile subscribers in 2002 [2]. As of 2010, the number of mobile subscribers was around 73% of the world's population, which is around to 5 billion mobile subscribers [1].

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The maximum data rate that can be attained over a given channel is determined by the capacity and bit error rate of that channel. We investigated the channel capacity and bit error rate of MIMO-OFDM [8]. The use of OFDM scheme is the solution to the increase demand for future bandwidth-hungry wireless applications [9]. Some of the wireless technologies using OFDM are Long-Term Evolution (LTE) which is the standard for 4G cellular technology, ARIB MMAC in Japan have adopted the OFDM transmission technology as a physical layer for future broadband WLAN systems, ETSI BRAN in Europe and Wireless local-area networks (LANs) such as Wi-Fi. Due to the robustness of OFDM systems against multipath fading, the integration of OFDM technology and radio over fiber (RoF) technology made it possible to transform the high-speed RF signal to the optical signal utilizing optical fibers with broad bandwidth [10]. Nevertheless, OFDM suffers from high peak to average power ratio (PAPR) in both the uplink and downlink which results in making the OFDM signal a complex signal [11].

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PAPR reduction schemes have been studied for years [16]-[19]. Some of the PAPR reduction techniques are Coding techniques which can reduce PAPR at the expense of bandwidth efficiency and increase in complexity [20]-[21]. The probabilistic technique which includes SLM, TR and TI can also reduce PAPR; however, suffers from complexity and spectral efficiency for large number of subcarriers [22]-[23].

II. DISTURBUTION OF OFDM SIGNAL

Fig. 1 illustrates the block diagram of an OFDM system. The discrete time signal after IFFT can be expressed as:

$$x[n] = \frac{1}{N} \sum_{k=0}^{N-1} X[k] e^{j\frac{2\pi}{N}kn} \qquad \dots$$

For a sequence of modulated data symbols, X[k]. The

discrete time domain signal x[n] is the addition of N

different time domain signals $e^{j\frac{2\pi}{N}kn}$ where each signal corresponds to different orthogonal subcarriers.



Fig. 2(a) shows the individual time domain QPSK modulated subcarrier signals for N=8. The PAPR of the continuous time signal x[t]. The PAPR worsens as the number of subcarriers increases.



Fig. 2(a)-Time domain OFDM signals for N=16

Fig. 2 (b) shows the PAPR characteristics of the OFDM signal which includes the distributions of x[n] as well as the imaginary and real parts for N=16. Fig. 2(b) shows that

the real and imaginary parts of x[n] follow a Gaussian distributions while x[t] follow a Rayleigh distribution.



Fig. 2(b)—Magnitude distribution of OFDM signal for N=16

Before examining the reduction of PAPR, let us consider a single-carrier system where N=1. Fig. 4 shows the passband signal with a single carrier frequency of 1 Hz and an oversampling factor of 8. The baseband signal's average and peak power values are the same that is PAPR is 0 dB ,however, the passband signal's PAPR is 3.01 dB as shown in Fig. 3.



Note that the PAPR varies in the passband signal depending on the carrier frequency. As a result, when measuring the PAPR of a single-carrier system, then we must be taken into consideration the carrier frequency of the passband signal.

III. SYSTEM MODEL

The PTS technique partitions the data block of N symbols into Z disjoint sublocks as follows:

$$X = [X^0, X^1, X^2, ..., X^{z-1}]^T$$
 ...2

Where X^i are the subcarriers, which are of equal size and consecutively located. In the PTS technique, scrambling is applied to each subblock where in the selective mapping technique scrambling is applied to all subcarriers. Each subblock is multiplied by a phase factor $b^z = e^{j\phi z}$,

subblock is multiplied by a phase factor $b^2 = e^{j\varphi z}$, z = 1, 2, 3, ..., Z, the IFFT becomes

$$x = IFFT\{\sum_{z=1}^{Z} b^{z} X^{z}\} = \sum_{z=1}^{Z} b^{z} IFFT\{X^{z}\} = \sum_{z=1}^{Z} b^{z} x^{z} \dots 3$$



Fig. 4—Block diagram of partial transmit sequence (PTS) technique for PAPR reduction

Where x^{Z} is referred to as a partial transmit sequence. The phase vector is selected so that PAPR can be minimized as follows:

$$[\widetilde{b}^{1},\ldots\widetilde{b}^{Z}] = \operatorname*{arg\,min}_{[\widetilde{b}^{1},\ldots\widetilde{b}^{Z}]} \{ \max_{n=0,1,\ldots,N-1} \left| \sum_{z=1}^{Z} b^{z} \cdot x^{z}[n] \right| \qquad \ldots 4$$

1.7
Then the time domain signal with the lowest PAPR vector can be expressed as follows:

$$\widetilde{x} = \sum_{z=1}^{Z} \widetilde{b}^{z} x^{z} \qquad \dots 5$$

Original PTS technique. Fig. 5 shows the CCDF of PAPR for a QAM/OFDM system with PTS technique when the number of subblocks varies. It can be seen that the PAPR improves as the number of subblocks increases.



Fig. 5—PAPR performance of a 16 QAM/OFDM system with PTS technique when the number of subblocks vary

IV. CONCLISION

We have shown the distribution of OFDM signal and the fact that PAPR worsens as the number of subcarriers increases. The PAPR characteristics of the OFDM signal includes the distributions of the discrete time domain signal x[n] as well as the imaginary and real parts. Our simulation results show that the real and imaginary parts of discrete time signal x[n] follow a Gaussian distribution while the continuous time signal x[t] follows a Rayleigh distribution. Besides, we show when measuring the PAPR of a single-carrier system, we must take into consideration the carrier frequency of the passband signal.

The PTS technique requires Z IFFT operation for each block. The performance of PAPR with PTS is affected by the number of subblocks, the phase vector and by the subblock partitioning. There are three different subblock partitioning schemes: interleaved, adjacent and pseudo-random. We proposed a suboptimal combination algorithm. The number of commutations for equation (2) in the suboptimal combination algorithm is Z, which is much lower than the required by the original PTS technique. Finally yet importantly, our results show that PAPR improves as the number of subblocks increases.

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Dispersion and nonlinear effects in OFDM-RoF system

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ABSTRACT

The radio-over-fiber (RoF) network has been a proven technology to be the best candidate for the wireless-access technology, and the orthogonal frequency division multiplexing (OFDM) technique has been established as the core technology in the physical layer of next generation wireless communication system, as a result OFDM-RoF has drawn attentions worldwide and raised many new research topics recently.

At the present time, the trend of information industry is towards mobile, wireless, digital and broadband. The next generation network (NGN) has motivated researchers to study higher-speed wider-band multimedia communication to transmit (voice, data, and all sorts of media such as video) at a higher speed. The NGN would offer services that would necessitate broadband networks with bandwidth higher than 2Mbit/s per radio channel. Many new services emerged, such as Internet Protocol TV (IPTV), High Definition TV (HDTV), mobile multimedia and video stream media. Both speed and capacity have been the key objectives in transmission. In the meantime, the demand for transmission bandwidth increased at a very quick pace. The coming of 4G and 5G era will provide faster data transmission and higher bit rate and bandwidth.

Taking advantages of both optical communication and wireless communication, OFDM Radio over Fiber (OFDM-RoF) system is characterized by its high speed, large capacity and high spectral efficiency. However, up to the present there are some problems to be solved, such as dispersion and nonlinearity effects. In this paper we will study the dispersion and nonlinearity effects and their elimination in OFDM-radio-over-fiber system.

Keywords: The radio-over-fiber (RoF), orthogonal frequency division multiplexing (OFDM), multicarrier modulation (MCM), and next generation network (NGN).

1.0 INTRODUCTION

There is an increasing demand for people to communicate with each other and have suitable and timely access to information in spite of the location of the each individuals or the information. This increase in demand for wireless communication systems have led scientists to better understand the fundamental issues in communication theory and electromagnetic for the design of wireless systems that is highly capable.

The integration of RoF technology and OFDM technology emerged the opportunity of cost-effective wireless networks, and made it possible to transform the high speed RF signal to the optical signal utilizing the optical fibers with broad bandwidth. Nevertheless, the nonlinear effects can negatively impact the performance of RoF and OFDM system Nonlinear distortion effects have turned out to be a significant parameter to consider for Orthogonal Frequency Division Multiplexing (OFDM) since OFDM is subjected to high Peak to Average Power Ratios (PAPR) [1]. On the other hand, OFDM showed its robustness against time-dispersive impairments, and that made OFDM become a universally adopted modulation schemes for broadband wireless deployments Radio over Fiber (RoF) is a planned solution for network architecture [1].

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The idea of sending radio signals over optical fiber (RoF) has been around for over two decades [2]. Radio over Fiber (RoF) is a technology where light is modulated by a radio signal and transmitted over an optical fiber link to make wireless access possible. The Radio-Over-Fiber technology converts the high RF (Radio Frequency) signal to an optical signal. In a RoF system, the majority of the signal processing takes place at the CS (Central Station). As a result, BS (Base Station) becomes cost-effective. Subsequently, RoF technology is a vital technology in the next generation mobile communication system [3-4].

This writeless-access technology has experienced an extraordinary development in recent years such as the video phones, and high-definition television (HDTV), remote medical monitoring and security surveillance [5]. Besides, conference centers, hotels, shopping malls and airports also have experienced an extraordinary development recently. For example, "smart airports". A passenger-sensing, self-organizing unified network to track the location of every passenger and bag in the terminal will feature in future airports. It's being developed by scientists from the University of Cambridge, University College London, and the University of Leeds, and it is in the process to be deployed at London Heathnow airport which handles more international passengers than any other airport in the world [6].

Optical writeless networking connectivity can normally be achieved by means of radio frequency (RF). The RF range is overcrowded, and the provision of broadband services in new bands is complicated. Optical writeless networking provides an enormous free bandwidth that can be manipulated by mobile terminals to set up high speed multimedia services. Diffuse optical writeless networking systems can be considerably impaired by multipath propagation. Therefore; resulting in pulse dispersion and inter symbol interference. Researchers showed a lot of interest in studying the area of RoF technology because of the advantages that RoF technology offers such as low attenuation, low complexity, lower cost and future proof.

2.0 PRINCIPLE OF OFDM

The challenges in communications, when transmitting information signals over channels, are reliability and efficiency. A successful approach to achieving high-speed data transmission is multicarrier modulation (MCM), often also called multitone modulation OFDM has been accepted for several wireless network standards, such as IEEE802.11x [7] and IEEE802.16x [8]. OFDM can be described as a form of multicarrier modulation (MCM), often also called multitone modulation. The carrier spacing is chosen so that every subcarrier is orthogonal to all the other subcarriers. OFDM speeds up the signal processing and it's a modulation schemes will make the next generation wireless communication system possible.

Recently, orthogonal frequency division multiplexing has been developed for wideband communication over mobile radio FM channels, asymmetric digital subscriber lines (ADSL), very high-speed digital subscriber lines (VHDSL), highspeed digital subscriber lines (HDSL), digital video broadcasting (DVB), digital audio broadcasting (DAB), and HDTV terrestrial broadcasting.



Fig.1 OFD M subcarriers in frequency domain

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2.1 System model of OFDM:

OFDM forms one of the best options to lessen multipath effects. The complex baseband OFDM signal can be expressed as:

$$s(t) = \frac{1}{\sqrt{N}} \sum_{K=0}^{N-1} X(k) e^{j\frac{2\pi}{T}kt}, 0 \le t \le T$$
(1)

The frequency separation between any two adjacent subcarriers is 1/T, where T = The OFDM symbol duration. N = The total number of subcarriers <math>X(k) = The modulated data symbol for the k-th subcarrier.

To simplify, we can imagine that there is no frequency lap between different OFDM symbols and no cyclic prefix in OFDM symbols. Therefore, the discrete form of complex baseband OFDM signal can be represented as:

$$s(m) = \sum_{K=0}^{N-1} X(k) e^{j\frac{2\pi}{N}km}, m = 0, \dots N - 1$$
⁽²⁾

where, N is the size of IFFT.

2.2 OFDM nonlinearity:

OFDM offers high data rate, allows simultaneous low-data-rate transmission from several users and pulsed carrier can be avoided. Besides, OFDM signal is robust against impulsive noise and multipath fading. However, OFDM is subjected to large Peak-to-Average Power Ratio (PAR) and require large dynamic range. This large dynamic signal range creates sensitivity to nonlinear distortions.

The transmitter high-power-amplifier (HPA) causes nonlinear distortions. The nonlinear effects on the transmitted OFDM signal are spectral-spreading of the OFDM signal, warping of the signal constellation in each sub channel and intermodulation effects on the subcarriers. The power spectra of both the transmitted signal and the distortion are computed. They are then used to evaluate the system bit-error rate (BER) [9].

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2.3 OFDM transmitter and receiver chains:



Fig.2 OFDM transmitter chain



Fig.3 OFDM receiver chain

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3.0 ROF ARCHITECTURE



Fig.4 Basic RoF architecture

3.1 Advantages of Radio-over-Fiber:

➢ Low Attenuation

The use of optical fiber will eliminate the need of repeaters.

> Low Complexity

The majority of the signal processing takes place at the CS. As a result, BS consists of (O/E) and (E/O) converters where the optical signal is converted into an electrical signal and vice versa, amplifiers and the antenna.

➢ Lower Cost

The simple structure of the base stations results in a lower cost of infrastructure, lower power consumption by devices. Besides, maintenance will be easier.

➢ Future Proof

RoF can handle high speeds proposed by future NGN since the radio signals are piped into fiber optics that can handle terabytes speeds.

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4.0 SIMULATION RESULTS

The simulation parameters used to investigate the nonlinearity comparison of various schemes are shown in Table 1. The nonlinearity effect of different OFDM schemes is shown in Fig.5. The high peak to average power ratio of the OFDM signal creates the vulnerability to nonlinear distortions as the signal peaks might sporadically push into the saturation state of the power amplifier. The outcome is a performance degradation that needs optimization of the back-off with the aim to balance cautiously the contradictory requirements of power efficiency and signal distortion.

Carrier Frequency	900 MHz
Speed	20 m/s
Frame size (excluding guard time)	64 subcarriers
Symbol rate Number of 64-QAM symbols per second	256 ksymbol/sec
<i>f_{sub}</i> Subcarrier spacing	4000 HZ
<i>f</i> _{Doppler} Doppler spread.	60 HZ

Table 1 simulation parameters



The obtained results show symbol error rate (SER) performance degradation as function of nonlinear distortions in QAM/OFDM and QPSK/OFDM systems. Comparison of the different schemes shows that the QPSK modulation scheme is less sensitive to amplifier nonlinearity as a result of the lower amplitude of the constellation states. On the other hand, QAM signal is susceptible to nonlinearity due to its high crest factor.

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5.0 CONCLUSION

RoF technology has been a proven technology to be the best candidate for the wireless-access technology because of its low attenuation, complexity and cost. The integration OFDM technology and RoF technology facilitate the transformation of high speed RF signal to the optical signal; to make use of optical fibers with broad bandwidth. Our simulation results of OFDM-ROF system show the effect of nonlinearity on OFDM-QPSK and OFDM-QAM signal. OFDM-QAM signal is susceptible to nonlinearity due to its high crest factor. We confirmed, by computer simulations, that the SER degradation due to nonlinearity tend to be more sever at the receiver because of the transmitter nonlinearity. Last but not least, Ultra-wideband radio over fiber (UROOF) is a promising novel technology that will change the way we think about short-range communication applications.

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LTE-advanced MIMO uplink for mobile system

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ABSTRACT

By increasing multimedia communications, mobile communications are expected to reliably support high data rate transmissions. To provide higher peak rate at a better system efficiency, which is necessary to support broadband data services over Wireless links, we need to employ long term evolution Advanced (LTE-A) Multiple-input multiple-output MIMO uplink. The outline of this paper is to investigate and discuss the Long Term Evolution (LTE) for broadband wireless technologies and to discuss its functionality. We explore how LTE uses the inter-technology mobility to support a variety of access technology.

This paper investigates the channel capacity and bit error rate of MIMO-OFDM system. In addition, it introduces various MIMO technologies employed in LTE and provide a brief overview on the MIMO technologies currently discussed in the LTE-Advanced forum.

1.0 INTRODUCTION

LTE-A is the cutting edge standard in the mobile network technology. Mobile broadband is going to be a reality, as the internet generation grows with broadband access. It is expected that by the year of 2012 there will be approximately 2 billion people who will have broadband, some two-thirds will be mobile broadband consumers. Also the majority of these will be provided by High Speed Packet Access. (HSPA) and Long Term Evolution, (LTE) networks. With LTE, the user experience will be even better, because the users can already browse the Internet or send huge data using HSPA. These technologies will enhance advanced games, video blogging, interactive TV and professional services [1]. There are some essential advantages of LTE for users and operators such as capacity, wide range of terminals, and performance. Furthermore, some applications like radio communications systems need high data rates related to mobile radio networks such as wireless radio networks like WLAN and 3GPP UMTS, or provide wide bandwidths. This can be accomplished by using multiple antenna systems MIMO [2]. In addition, there are some different ranges of modes that are used to make radio communications more robust. The technology tolerates for speeds over 200Mb/s and there is some company's already established LTE peak rates up to150Mb/s. In fact LTE more than any other technology already meets the requirements of 4G requirements. In wide range of terminals for mobile phones, there are several computer and end user electronic machines, like gaming devices, notebooks and ultra-portables, will include LTE implanted modules. While LTE supports hand-over and wandering to existing mobile networks, all these machines can have everywhere mobile broadband coverage from day one. As we can say that the operators can introduce LTE flexibly to match their existing network, like spectrum and business objectives for mobile broadband and multimedia services [3].

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Fig. 1 Future of MIMO

Multiple-input multiple-output (MIMO) communication techniques is an important area to study for the next-generation wireless systems based to increased diversity, interference suppression, and high capacity. MIMO has some purposes like wireless WANs, LANs, and some communication technologies, MIMO systems has been organized in environments where a single base must communicate with many users consecutively. Current radio communication types or more bandwidth are incomplete, there are methods of using the transmission channel must be used. Multiple antenna systems (Multiple Input, Multiple Output – MIMO) to get a considerable improvement to channel capacity and data rate [4].

The 3rd Generation Partnership Project (3GPP) is at this time identifying the system requirements for the upcoming Long Term Evolution Advanced, (LTE-A) systems, meaning at target peak data rates of 100 Mb/S in wide areas and 1 Gb/S in local areas . Whereas in the earlier only single transmit antenna systems have been the same for the uplink, MIMO methods are estimated to be deployed to meet these determined requirements. Orthogonal Frequency Division Multiplexing, (OFDM) has been chosen for the downlink suitable to its high strength to multipath as well as its flexibility, letting to easily share resources among users while keeping full intra-cell orthogonally [5]. Even though its benefits, OFDM endures from high Peak to Average Power Ratio (PAPR) of the transmitted signals, which is need higher power back off in the transmitter to keep away from distortions, and therefore leading to lower power efficiency. This is principally serious in uplink because of the power consumption limit in the end user. Then, Single Carrier Frequency Division Multiplexing (SC-FDM) has been chosen for the uplink in LTE [1]. This modulation method develops the same advantages in terms of multipath improvement and elasticity as OFDM. On the other hand, the information symbols are sent successively in the time domain, leading to a reliable reduction of the PAPR [6]. However, the alternative of the uplink modulation method for LTE-A until now is not decided [5]. That composes the performance of SC-FDM same as to OFDM. In our work, we expand the earlier job to a double stream Single User MIMO method for the forthcoming LTE-A systems. This application note gives an introduction to basic MIMO concepts and terminology and explains how MIMO is implemented in different radio communications standards.

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2.0 MULTIPE-ANTENNA TECHNIQUES for WIRELESS COMMUNICATIONS

By the use of multi-antenna transmission techniques, the requirements by the LTE system can be met. The multi-antenna transmission techniques can facilitate an enhanced system performance such as increasing the data rate per user as well as the capacity. Three are three ways of employing the multi-antenna techniques which are Spatial, Diversity Beamforming, and Spatial multiplexing (SM).

 <u>Beam-forming</u> This technique enhances the received signal power by having the base station direct the beam toward a specific user [7.

 <u>Multiple-input and multiple-output (MIMO) or Spatial multiplexing (SM)</u>: Independent parallel channels are used to transmit different data streams which provide high data rate. This can be possible by the use of multiple-input and multiple-output, without increasing the total transmitted power or the channel bandwidth[7].

 <u>Spatial Diversity</u>. The objective of the spatial diversity technique is to produce a number of self-sufficient paths. This technique transmits and receives with low fading which allows higher gain at the receiver side [7].

LTE adopted a range of multi-antenna techniques such as single user (SU)-MIMO, multiuser (MU)-MIMO, beamforming and transmit diversity [7].

2.1 Principle of MIMO:

MIMO (Multi-input Multi-output) communication is developed to provide more advantageous performance for current communication system. It uses multiple antennas at both the transmitter and receiver, thus offers a significant increase in capacity gains without additional bandwidth or transmit power. Examples of wireless standards employing MIMO include the draft IEEE 802.11 n WLAN, the IEEE 802.16e WiMAX and all future 4th generation (4G) cellular systems.

MIMO system transmits two or more data streams in the same channel at the same time, it consists of N transmits and M receives, or N parallel channels. The parallel channels support AWGN (Additive White Gaussian Noise) with a noise level of σ^2 . The received data over N channels is the input data plus noise.

According to Shannon's Law, the capacity of the channel, denoted by C, is the maximum rate at which reliable

communication can be performed in a specified bandwidth:

 $C = B\log_2\left(1 + \frac{S}{N}\right)$

The capacity of the channel can be characterized by the mutual information transmitting between the input and the output. The mutual information of one channel is defined as:

 $I(x, y) = \int_{S_{x,y}} f(x, y) \log\left(\frac{f(x, y)}{f(x)f(y)}\right) dx dy$

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In the above equation, f(x), f(y), and f(x, y) are the probability distribution functions of the random input variable X and output variable Y [8].

The Shannon channel capacity gives the limitation to MIMO system. The capacity increases as a logarithmic function with a base of 2 at high SNR, and linearly at low SNR. This characteristic leads to the development of the water filling algorithm, that the overall capacity can be increased by applying power to weaker channels, which describes the optimal power allocation scheme on transmission channels [9]. If there are N channels with effective noise power of each σ^2

channel $\overline{h_n}$ (h_n is the nth fading channel), and the water level is μ , then water is filled on each channel to reach the water level μ , in a result more energy will be allocated to channels with lower noise to reach μ whereas less energy is

allocated to channels with large noise power. Thus, water filling measures the energy that is allocated on each channel. For example, some channels have such a large noise power which exceeds the water level that it could not accommodate any allocated energy. Such channels should be abandoned because transmitting any information on them is a waste of energy. The sum of the allocated energy and the effective noise power is a constant [9]. To increase the overall capacity the energy should be transmitted on the channel which is in a good condition, i.e. the channel has a large energy containment; however, if the channel characteristic at the transmitter is known, the best energy distribution is to equally spread the energy between all channels. Thus the capacity is described as:

$$C = \sum_{n=1}^{N} \log_2 \left(1 + \frac{E_s}{N\sigma^2} \right),$$

where E_{s} is the energy of the transmitter which is allocated across N channels.

2.2 Capacity Analysis:

When the characteristic of the channel is known to both the transmitter and receiver, the SNR for the n_{rh} subchannel is

 $\sigma_n = \tau_n \frac{P_n}{\sigma_N^2}$, where which P_n is the allocated power of the π_{th} subchannel, π_n is the π_{th} eigenvalue, and σ_N^2 is the noise. Assuming that $\sigma_{N}^{A} = 1$, the maximum capacity of N parallel subchannels is:

$$\mathcal{L} = \sum_{n=1}^{N} \log_2 \left(1 + \tau_n \frac{P_n}{M} \right),$$

which is also defined as the capacity of the MIMO system. In the above equation, M is the number symbols. Fig 5 and 7 show the Channel capacity Lowerbound.

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3.0 MIMO AND SISO SYSTEMS



Fig. 2 The difference between smart antennas (MIMO) and SISO

The Smart antenna technology (MIMO) has a multiple in element / feature, and it is a device that sends at least two signals through multiple sending antennas. The multiple in element/feature is reached by link endurance and by an improved efficiency of spectral. In today's world, the MIMO technology has contributed to the wireless communication industry like (4G) and (WiFi).

In MIMO, "multiple in" means a WLAN device simultaneously sends two or more radio signals into multiple transmitting antennas. "Multiple out" refers to two or more radio signals coming from multiple receiving antennas.

MIMO is one of several forms of smart antenna technology. MIMO offers a considerable boost in data throughput and link range not requiring additional transmit power or bandwidth. It attains this by higher spectral efficiency and diversity. MIMO is an vital part of modern wireless communication standards such as IEEE 802.11n (Wifi), 4G, 3GPP Long Term Evolution, WiMAX and HSPA+.

3.1 Advantages of MIMO:

The main advantage of MIMO is the use of multiple antennas which receives more signal and transmits more signal. Another advantage is on the receive side fig.3, for instance, when employing multiple receivers, the receive power increases and the multipath issues aren't as significant when combining the received signals for each frequency component independently.

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Fig. 3 Signals are collected from multiple antennas/receivers and combined in a manner that considerably improves signal strength.

This process has an advantage of increasing overall gain of the system; multipath environments are most benefited by the process. In these environments, signals are sent to various objects that reflect the signals so that signals with different characteristics reach the two receiving antennas.

Number of TX & RX Antennas	2 x 4	
Pilot pattern	Orthogonal	
Symbol Constellation	16QAM	
Number of channel taps	3	
Iterations	50	
Optimal PDPR =	2.3	
Ata – tone – power data – tone – power		

4.0 SIMULATION RESULTS of MIMO-OFDM SYSTEM

Table 1.1 Simulation parameters for a 2x4 antennas



Fig.4 BER



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Number of TX & RX Antennas	4 x 4
Pilot pattern	Orthogonal
Symbol Constellation	16 Q A M
Number of channel taps	3
Iterations	50
Optimal PDPR =	2.29
Pilot – tone – power	
data – tonc – power	

Table 1.2 Simulation parameters for a 4x4 antennas



The channel state information is crucial in MIMO-OFDM systems to be able to detect the received signal at the receiver side. The more channels the system has then the more diversity there is. Therefore the channel is very significant to the execution of schemes. As a result, with the intention of reaching precise channel state information at the receiver side, pilot-symbol-aided channel assessment have to be employed to trace the deviations of the frequency selective fading channel. Power assignment is associated with the precision of the channel assessment use in MIMO systems. Pilot symbols smooth the progress of channel estimation. Nevertheless, they diminish the transmitted energy for data symbols per OFDM symbol and consume bandwidth. Therefore, there is a tradeoff between the precision of the channel assessment and the system capacity in MIMO-OFDM systems,

We ran our simulation when the number of TX & RX Antennas is 2x4 and 4x4, and obtained the above figures. We can see from Fig 4 and 5 that as the bit error rate for the transmission decreases, the signal to noise ratio increases. Also, we can see from figure 5 and 8 that as the number of bits/sec/Hz increases, the signal to noise ratio increases as well.

5.0 CONCLUSION

We addressed the performance of various MIMO technologies employed in LTE and provided a brief overview on the MIMO technologies currently discussed in the LTE-Advanced forum. Our simulation results showed the BER and the channel capacity of the MIMO-OFDM system.

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The challenge of scheduling user transmissions on the downlink of a long-term evolution (LTE) cellular communication system

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ABSTRACT

Wideband code division multiple access (WCDMA) is currently being extended into high-speed downlink access (HSDPA) and high-speed uplink packet access (HSUPA). The continuing research of next generation communication proposed by 3GPP is named long term evolution (LTE). The main goal of LTE Release is to offer high peak downlink and uplink rates by the use of Orthogonal Frequency-Division Multiple Access (OFDMA) that attributes a very flexible multi-user bandwidth, high spectral efficiency and scalable bandwidth. The benefit of LTE is the fact that it offers higher data rates in both uplink and downlink and enhances the services for the terminals.

A notable fact is that several WiMAX projects have been reoriented toward Long Term Evolution (LTE), mainly aimed at increasing performance. In this paper the challenge of scheduling user transmissions on the downlink of LTE cellular communication system is discussed. Various results show that the system performance improves with increasing correlation among OFDMA subcarriers.

Keywords: Long term evolution (LTE), high-speed downlink access (HSDPA), high-speed uplink packet access (HSUPA), and Orthogonal Frequency Division Multiple Access (OFDMA).

1.0 INTRODUCTION

There have been substantial contributions to improve the downlink capacity of the universal mobile telecommunications system (UMTS) within the LTE group of the 3GPP evolved UMTS terrestrial radio access network (E-UTRAN) standardization [1-3].

Universal Mobile Telecommunications System (UMTS) Long Term Evolution (LTE) Release offers high peak data rates of 300 Mb/s on the downlink and 75 Mb/s on the uplink for a 20 MHz bandwidth, allowing operation of up to 20 MHz [4]. Presently, improvements are being considered to offer considerable enhancements to LTE Release 8, allowing it to meet International Mobile Telecommunications- Advanced (IMT-A) requirements [5]. These improvements are being considered as part of LTE-Advanced (LTE-A, also known as LTE Release 10), which includes advanced uplink (UL) and downlink (DL) spatial multiplexing and carrier aggregation.

LTE Release 8 is one of the main broadband technologies that uses orthogonal frequency division multiplexing (OFDM) which is a great modulation technique that is used in many communication systems such WiMAX, DSLs, WLANs [6], and Long Term Evolution (LTE) cellular networks.

Orthogonal Frequency Division Multiple Access (OFDMA) can be used to provide further flexibility in resource allocation and to take advantage of multiuser diversity. The issue of sub-carrier allocation in OFDMA systems and power has been investigated by [7], and [8].

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LTE Release 8 presently is available commercially. The main advantages of LTE Release are to improve system capacity and coverage, flexible bandwidth operation, seamless integration with existing systems, high peak data rates, reduced operating costs, low latency and multi-antenna support [9].

LTE Release 10 considerably improves the existing LTE Release 8 and has the capability to sustain higher throughput and coverage, higher peak rates, and lower latencies. Moreover, LTE Release 10 will have the capability to support heterogeneous exploitations where remote radio heads and relays are located in a macro-cell layout.

LTE Release 10 characteristics are able to exceed International Mobile Telecommunications- Advanced requirements. Besides, it should be mentioned that LTE Release 9 offers some slight improvement to LTE Release 8 in regard to the air interface. 3GPP goals for the Long Tenn Evolution-Advanced have been stopped in June 2008 [10] and a review of the goals can be found e.g. in [10] which also shows the descriptions of the equipment included in the LTE-Advanced Release 9. IMT-Advanced Radio Interface Technology (RIT) recommendation should be done in February 2011 [11] which meets the targeted schedule of the LTE Release 10.

2.0 PRINCIPLE OF OFDM

The challenges in communications, when transmitting information signals over channels, are reliability and efficiency. A successful approach to achieving high-speed data transmission is multicarrier modulation (MCM), often also called multitone modulation. OFDM has been accepted for several wireless retwork standards, such as IEEE802.11x [7] and IEEE802.16x [8]. OFDM can be described as a form of multicarrier modulation (MCM), often also called multitone modulation. The carrier spacing is chosen so that every subcarrier is orthogonal to all the other subcarriers. OFDM speeds up the signal processing and it's a modulation schemes will make the next generation wireless communication system possible.

Recently, orthogonal frequency division multiplexing has been developed for wideband communication over mobile radio FM channels, asymmetric digital subscriber lines (ADSL), very high-speed digital subscriber lines (VHDSL), high-speed digital subscriber lines (HDSL), digital video broadcasting (DVB), digital audio broadcasting (DAB), and HDTV terrestrial broadcasting.



Fig.1 OFDM subcarriers in frequency domain

OFDM forms one of the best options to lessen multipath effects. The complex baseband OFDM signal can be represented as:

$$s(t) = \frac{1}{\sqrt{L}} \sum_{k=0}^{L-1} X(k) e^{j\frac{2\pi}{T} - k}, 0 \le t \le T$$
(1)

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The frequency separation between any two adjacent sub-carriers is 1/T; where

T = The OFDM symbol duration.

L = The number of subcarriers

X(k) = The modulated data symbol for the k-th subcarrier.

To simplify, we can imagine that there is no frequency lap between different OFDM symbols and no cyclic prefix in OFDM symbols. Consequently, the discrete form of complex baseband OFDM signal can be **represented as**:

$$s(u) = \sum_{k=0}^{N-1} X(k) e^{j\frac{2\pi}{N}km}, u = 0, \dots N - 1$$
(2)

Where *N* is the size of IFFT.

3.0 SYSTEM MODEL

Consider a single-cell OFDM downlink situation where U denotes the number of simultaneous users that communicates with base station over L which denotes the number of sub-carriers. Let $U = \{1, ..., U\}$ be the set of users in the cell, and $L = \{1, ..., L\}$ be the set of available subcarriers. Suppose time-slotted transmission, in each transmit time interval (TTI) the information bits of each U are mapped to a complex data block in accordance with the way in which the transport format is chosen [12]. The complex data of each U is solely asserted to the subcarriers L that fits in to a subset $S_u \subseteq L$. Apparently, by the OFDMA limitation we have $S_u \cap S_{u'} \equiv \varphi . u \neq u'$. Writing $x_{u,i}$ for the complex data of user U on subcarrier L and ignoring both intercarrier and intersymbol interference, the equivalent established value $y_{u,i}$ is given by (1):

$$y_{u,l} = h'_{u,l} x_{u,l} + n_{u,l'} \forall l, u \in S_u$$
⁽³⁾

Where;

 $n_{u,l} \approx N_c$ (0,1) = the additive white Gaussian noise (AWGN).

 $h_u[I]$ = the *Ith* tap of the channel impulse response.

 D_u = the length of channel impulse response of user.

u = the number users.

 $h'_{u,l}$ = the complex channel gain which is given by (2)

$$h'_{u,l} = \sum_{I=1}^{D} h_{u} [I] e^{-2\eta i (I-1)(I-1)/I/k}$$
(4)

Our simulation is based on 3GPP simulation assumptions [13]. The chancel can be modeled in a mix of low mobility 1.8mph, high mobility HM18, 18mph and high mobility HM75, 75mph with a delay spread that is constantly slighter than the guard time of the OFDM symbol [14].

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For instance, low mobility channel model has 28 taps modeled as random variables so that $h'_{u,l}[I] \approx N_C(0,1) \forall u, l$, at a sampling rate of 7.86 MHz and communicate to a channel with significant frequency dispersion.

In this paper the complex channel gains $h'_{u,i}[I]$ are predicted by the user u by means of reserved pilot subcarriers. Subsequently appropriate channel quality information (CQI) value of the predicted channel gains is generated and reported back to the base station through a feedback channel. Normally a very low code rate and a diminutive constellation size are utilized for the feedback channel. For example, BPSK modulation for HSDPA [15] and it is practical to presume an error free feedback channel. At last, the CQI values are then used by the scheduling entity in the base station that allocates the accessible resources between the users.

Now let's assume that $\Gamma: R_+^l \to R_+^l$ is a vector quantizer related to the channel gains $|\dot{h}_{u,1}|, ..., |\dot{h}_{u,j}|, \forall u$, and let the outcome of this mapping be $h_{u,1}, ..., h_{u,j}, \forall u$. The outcomes of this mapping are equivalent to the recorded channel gains $|\dot{h}_{u,1}|, ..., |\dot{h}_{u,j}|, \forall u$ because of the error free feedback channel. After that, the rate $r_{u,l}$ of user u on sub-carrier l, and the power budget P_l on sub-carrier l within the transmit time interval is given by (5):

$$r_{u,l}(p_l, h_{u,l}) = N_s \cdot C_r(p_l, h_{u,l}) \cdot r_{mod}(p_l, h_{u,l})$$
(5)

Where;

The mapping of $C_r(p_l, h_{u,l})$ = the asserted code rate.

 $r_{mod}(p_i, h_{u,i})$ = the number of bits of the selected modulation scheme. $C_r(p_i, h_{u,i}) \& r_{mod}(p_i, h_{u,i})$ are both dependent on the allocated power p_i and the channel state $h_{u,i}$.

Assuming that the channel is constant over one transmit time interval. The number of OFDM symbols is then denoted as $N_s \ge 1$ when the sub-carrier l is allocated to user u in this transmit time interval.

With the aim of determining a suitable modulation scheme for a particular channel conditions, we ran a simulation to acquire the association between bit-error rate (BER) and signal-to-noise ratio ($SNR \equiv p_i h_{i,u}$) for the channels [16].

It appeared that when the mobility is low to medium such as (low mobility, 1.8mph, high mobility HM18, 18mph, high mobility HM75, 75mph), the required SNR levels are approximately the same.

Various SNR levels are shown in Table 1.1 (where the mobility is low to medium) and Table 1.2 (where the mobility is high). All the reported channel gains and powers are set in vectors $h \in \mathfrak{R}^{U,L}_+$ and $p \in \mathfrak{R}^{L}_+$, correspondingly.

BER	10^-3	10^-5
QPSK	9.7 dB	13.4 dB
16QAM	16.4 dB	19.4 dB
64QAM	22.4 dB	24.4 dB

Table 1.1: Essential signal-to-noise ratio levels for 3GPP low mobility, 1.8mph, and high mobility HM18, 18mph, channel for specific BER constraint.

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BER	10^-3	10^-5
QPSK	10.5 dB	13.4 dB
16QAM	17.6 dB	21.1 dB
64QAM	23.7 dB	26.7 dB

 Table 1.2: Essential signal-to-noise ratio levels for 3GPP high mobility HM75,

 75mph, channel for specific BER constraint.

It is worth mentioning that because the chosen transport format varies over the slots, control information has to be sent out in parallel to user's data in the downlink channel enclosing modulation scheme, the used coding, and user identifiers. Notice that there are more than a few tradeoffs concerned here. For example, although a smaller ratio of computation to the amount of communication in the downlink channel enhances the flexible scheduling procedure, it also boosts the quantity of the essential control information and, for this reason, reduces the available capacity for the user data. Moreover, a great number of concurrently supported users may result in a higher multiuser gain which affects the downlink capacity negatively.

4.0 SIMULATION RESULTS

In support of frequency-selective scheduling the channel characteristic is consecutively distinguished in a particular time period. Evidently, the precision of the characteristic fundamentally relies on the length of the period. In contrast, an extended period rise the outdate ratio in the feedback information which results into a false scheduling decisions. This false scheduling decisions cause a high retransmission rate. The throughput gain because of the enhanced loss and the feedback resolution caused by the increased retransmission rate is illustrated in Fig.2a; the where Maximum Information Rate (MIR) is at an update period of 4 transmit time intervals. These results are very close to results obtained by GerhardWunder et al.[8]. Figure 2a&b have an average transmit SNR of 16dB.



Fig.2a shows the data throughput with respect to the update period for five users who are supported at the same time, and in Fig.2b shows the data throughput with respect to the supported links with a feedback period of 4 transmit time intervals. The number of users that are supported simultaneously creates a multiuser gain on top of the enhanced quality of service. On the other hand the essential signaling information rises with the number of supported links. Additional

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subcarriers have to be held in reserve for the high-speed shared control channel (HS-SCCH) instead of the high speedphysical downlink shared channel (HS-PDSCH). Consequently, the attained gain is given back by the raised signaling obligation. According to our simulation setup Fig.2b illustrates that the most desirable throughput is achieved at 5 links. It should be mentioned that to enhance the impediment performance for delay sensitive purposes, a larger number of links ought to be used sacrificing the data throughput loss.

5.0 CONCLUSION

This paper concentrates on the issues of scheduling user transmissions on the downlink of the long term evolution cellular communication system, and provides a concise overview and description of the LTE-Advanced. The evolution from HSDPA to OFDM-HSDPA requires some essential modifications that have to be implemented in physical layer and the data communication protocol sub-layer to facilitate the adaptation the OFDM technology to HSDPA. Realistic limitations such as user mobility and feedback capacity have a significant effect on the behavior of the system. We show a flexible concept to resolve these issues. We conclude that OFDM-HSDPA offers an excellent performance and can be even put into practice by means of standard HSDPA uplink channels. HSPA is an enormous achievement. Presently there are more than 300 commercially installed HSPA networks, serving subscribers in over 130 countries. LTE will make it possible to meet the demands of new and superior applications of the future.

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