REDUCTION IN PEAK AVERAGE POWER RATIO FOR MIMO-OFDM SYSTEM

BY

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ABSTRACT

Orthogonal frequency division multiplexing (OFDM) technology was adopted as the downlink and single-carrier FDMA (SC-FDMA) for uplink in the fourth-generation (4G) whereas as downlink and uplink transmission schemes for the fifth-generation (5G) communication systems. The high peak average power ratio (PAPR) value is of particular concern for all communication systems incorporating OFDM technology as their multiplexing and modulation methods. With cyclic prefixes, time-domain all the N subcarriers are added up constructively; they produce a peak power by systems incorporating OFDM, causing the increase of PAPR value. Reducing the PAPR has become a daunting task for developers of the 4G and 5G cellular communication systems. Due to the high PAPR value, the system requires exclusively higher power amplifiers (PA), increasing the systems' price. The main objective of the research is to assess and identify some techniques that can make up a system capable of experiencing the lowest possible overall PAPR value. The study's objectives are At this juncture, conventional OFDM systems use the transform algorithms, namely the inverse fast Fourier transform (IFFT) and fast Fourier transform (FFT), in the transmit and receive side, respectively. The research objective also includes investigating the number of subcarriers used and its effect on the PAPR value. Another objective is to determine which transform algorithm, including its associated family, experiences the lowest PAPR value and inspect what type of modulation experienced the lowest PAPR value. The study also examines the best multiple-input multiple-output (MIMO) antenna diversity configuration and observes the effect on several channel model conditions. The research methodology entails the replacement of the conventional transform algorithm inverse discrete Fourier transform (IDFT) and discrete Fourier transform (DFT) with inverse discrete Wavelet transform (IDWT) and discrete Wavelet transform (DWT) in the transmitter and receiver, respectively. Similar assessments had also been carried out for the discrete cosine transform (DCT) algorithm. Most members of the Wavelet family had been inspected. Three variations of the subcarrier, namely 64, 128, and 256, had been appraised. The PAPR values were thoroughly assessed based on five modulations: the QPSK, 8-PSK, 16-QAM, 32-QAM, and 64-QAM. The research undertakings also encompass PAPR value determination observed at the receiver involving MIMO antenna configurations. Three configurations, such as MIMO 2x2, MIMO 4x4, and MIMO 8x8, had been examined. Also, three channel-model conditions, such as AWGN+Rayleigh, AWGN+Rician, and AWGN+Nakagami, were evaluated. All simulations in determining the PAPR values were carried out using pseudocode and MATLAB programming language. This study can observe that a lower number of subcarriers instigates a lower PAPR value. It can be concluded that the deployment of transform algorithm '*bior 1.1*' of the Wavelet family and 16-QAM modulation with 64 subcarriers and MIMO 4x4 are the best configuration capable of establishing the lowest PAPR values. The application of MIMO somehow did not exhibit a significant reduction of PAPR values. The overall results imply that a Wavelet-based OFDM system with QAM modulation and MIMO-OFDM will experience the lowest PAPR value. In a nutshell, it had been identified that a PAPR value of 6.77 *dB* lower than a conventional OFDM system could be established at the transmitter, whereas a PAPR value of 3.62 *dB* lower can be formed at the receiver.

خلاصة البحث

لقد تبنت تقنية تعدد الإرسال بتقسيم التردد المتعامد (OFDM) على أساس أنها عبارة عن وصلة هابطة وناقلة واحدة FDMA (SC-FDMA) للوصلة الصاعدة في الجيل الرابع (G4)، في حين أنها تشكل مخططات نقل للوصلة الهابطة والوصلة الصاعدة لأنظمة الاتصال من الجيل الخامس (G5). وتمثل قيمة نسبة الذروة العالية لمتوسط القدرة (PAPR) مصدر قلق خاص لجميع أنظمة الاتصالات التي تتضمن تكنولوجيا OFDM كأساليب تعدد وتعديل. مع البادئات الدورية تتم إضافة جميع الموجات الحاملة الفرعية N بشكل بناء وهي تنتج طاقة ذروة عن طريق أنظمة تتضمن OFDM، مما يؤدي إلى زيادة قيمة PAPR. وقد أصبح الحد من PAPR مهمة شاقة بالنسبة لمطوري نظم الاتصالات الخلوية 4G و5G. ونظراً لارتفاع قيمة PAPR، فإن النظام يتطلب حصراً تضخيم طاقةأعلى (PA)، الأمر الذي يزيد من سعر الأنظمة. ويتمثل الهدف الرئيسي للبحوث في تقييم وتحديد بعض التقنيات التي يمكن أن تشكل نظاماً قادراً على الحصول على أدنى قيمة ممكنة لـ PAPR. تتلخص أهداف الدراسة في هذا المنعطف في استخدام أنظمة OFDM التقليدية خوارزميات التحويل، أَيْ تحويل فورييه السريع المعكوس (IFFT) وتحويل فورييه السريع (FFT) في جانبي الإرسال والاستقبال على التوالي. ويشمل هدف البحث أيضا التحقيق في عدد الحاملات الفرعية المستخدمة وتأثيرها على قيمة PAPR. الهدف الآخر هوتحديد خوارزمية التحويل بما في ذلك العائلة المرتبطة بها التي تواجه أدنى قيمة لـ PAPR وفحص نوع التعديل الذي شهد أدنى قيمة لـ PAPR. تفحص الدراسة أيضًا أفضل تكوين تنوع هوائي متعدد المدخلات ومخرجات (MIMO) وتلاحظ التأثيرعلى العديد من الشروط لنمط القناة. وتنطوي منهجية البحث على استبدال خوارزمية التحول التقليدية المنفصل عكسيا (IDFT) وتحويل فورييه المنفصل (DFT) بتحويل الموجات المنفصلة عكسيا (IDWT) وتحويل الموجات المنفصلة في جهاز الإرسال والمستقبل على التوالي. كما تم إجراء تقييمات مماثلة لخوارزمية تحويل جيب التمام المنفصل (DCT). تم فحص معظم أفراد عائلة Wavelet. وتم تقييم ثلاثة أشكال مختلفة من الناقل الفرعي، وهي 64 و128 و256. تم تقييم قيم PAPR بدقة بناءً على خمسة تعديلات: QPSK و8-PSK و16-QAM و32-QAM و64-QAM. وتشمل عمليات البحث أيضا تحديد قيمة PAPR التي لوحظت في جهاز الاستقبال والتي تنطوي على تصميم هوائيات MIMO. تم فحص ثلاثة تصميمات مثل MIMO 2x2 MIMO 4x4 و8x8 MIMO. كما تم تقييم ثلاثة شروط من نماذج القنوات مثل

AWGN + Rayleigh، AWGN + Rician وAWGN + Nakagami. وقد أجريت جميع عمليات المحاكاة في تحديد قيم PAPR باستخدام الكود المزيف(السودوكود) ولغة برمجة MATLAB . وفي هذه الدراسة يمكن ملاحظة أن عددًا أقل من الحاملات الفرعية يحرض على قيمة PAPR أقل. يمكن استنتاج أن نشر خوارزمية التحويل 'bior 1.1' لعائلة Wavelet وتعديل 16-QAM مع 64 حاملة فرعية و4x4 MIMO هي أفضل تكوين قادر على إنشاء أقل قيم PAPR. وأيضا تطبيق MIMO بطريقة ما لم يظهر انخفاض كبير في قيم PAPR. تشير النتائج الإجمالية إلى أن نظام OFDM القائم على الموجة مع تعديل QAM وMIMO-OFDM سيشهد أقل قيمة PAPR من هذا النظام. باختصار تم تحديد أن قيمة PAPR التي تقل 6.77 dB عن نظام OFDM التقليدي يمكن أن تنشأ في جهاز الإرسال في حين أن قيمة PAPR التي تقل 3.62 dB يمكن أن تتكون عند جهاز الاستقبال.

APPROVAL PAGE

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DECLARATION

I hereby declare that this thesis is the result of my own investigations, except where otherwise stated. I also declare that it has not been previously or concurrently submitted as a whole for any other degrees at IIUM or other institutions.

Sofia Pinardi

Signature .... Date: October 16th, 2021..................

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To :

My Husband, My Parents (Alm), My parent in law, My Children, and My Sister & brother

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LIST OF ABBREVIATIONS

1G	First Generation
2G	Second Generation
3G	Third Generation
4G	Fourth Generation
5G	Fifth Generation
16QAM	Sixteen Quadrature Amplitude Modulation
32QAM	Thirty-Two Quadrature Amplitude Modulation
64QAM	Sixty-Four Quadrature Amplitude Modulation
8PSK	Eight Phase-Shift Keyings
3GPP-LTE	Third Generation Partnership Project-Long Term Evolution
ADC	Analog To Digital Converter
ADC	Analog-Digital Converter
ASK	Amplitude Shift Keying
AWGN	Additive White Gaussian Noise
BER	Bit Error Rate
BS	Base Station
CCDF	Complementary Cumulative Distribution Function
CDMA	Code Division Multiple Access
CFO	Carrier Frequency Offset
CP	Cyclic Prefix
CWT	Continuous Wavelet Transform
DAC	Digital To Analog Converter
DAC	Digital-Analog Converter
DB	Decibel
DCT	Discrete Cosine Transform
DFT	Discrete Fourier Transform
DSB	Double Sideband
DWT	Discrete Wavelet Transform
e.g	Example
EDGE	Enhanced Data Gsm Environment
FDMA	Frequency Division Multiple Access
FFT	Fast Fourier Transform
FMT	Filtered Multitone
FSK	Frequency-Shift Keying
GI	Guard Interval
HPA	Higher Power Amplifier
HPF	High Pass Filter
IBO	Input Back Off
ICI	Inter-Channel Interference
ICI	Inter-Carrier Interference
IDFT	Inverse DFT
IDWT	Inverse Discrete Wavelet Transform
IFFT	Inverse Fast Fourier Transform
IMT 2000	International Mobile Telephone 2000

IP	Internet Protocol
ISI	Inter Symbol Interference
ITU-R	International Telecommunication Union-Radio
Labview	Laboratory Virtual Instrument Engineering Workbench
LOS	Line Of Sight
LPF	Low Pass Filter
Mbps	Mega Bit Per Second
MIMO	Multiple Input Multiple Output
M-PSK	Mary-Phase Shift Keying
M-QAM	Mary-Quadrature Amplitude Modulation
MRC	Maximal Ratio Combining
MS	Mobile Station
N-LOS	Non-Line Of Sight
OBO	Output Back Off
OFDM	Orthogonal Frequency Division Multiplexing
PA	Power Amplifier
PAPR	Peak Average Power Ratio
PSD	Power Spectral Density
PSK	Phase-Shift Keying
QAM	Quadrature Amplitude Modulation
QPSK	Quadrature Phase-Shift Keying
R8	Release 8
R9	Release 9
R10	Release 10
Rx	Receiver
S/P	Serial To Parallel
SC-FDMA	Single-Carrier Fdma
SD	Selection Diversity
SISO	Single Input Single Output
SQNR	Signal-To-Quantization Noise Ratio
SSB	Single Sideband
STBC	Space-Time Block Coding
TDMA	Time Division Multiple Access
Tx	Transmitter
UMTS-HSPA	Universal Mobile Telecommunication System-High Speed Packet
USRP	Universal Software Radio Peripheral
UWB	Ultra-Wideband
WB-PAN	Wireless BroadBand-Personal Area Networks
WGAN	Wireless Global Area Network
WLAN	Wireless Local Area Networks
WOFDM	Wavelet OFDM
WPAN	Wireless Personal Area Networks
WWAN	Wireless Wide Area Networks
ZP	Zero-Padded

LIST OF SYMBOLS

ψ (t)	Wavelet Function
∞	Infinity
ϕ (t)	Scaling Function
α	Fading Amplitude
F_{Δ}	Minimum Frequency Spacing
$\hat{\psi}(\omega)$	Fourier Transform

CHAPTER ONE

INTRODUCTION

1.1 BACKGROUND

Wireless technology has become know-how that keeps on growing non-stop in the forthcoming years. The popular technologies are namely the wireless global area network (WGAN), wireless wide area networks (WWAN), wireless local area networks (WLAN), wireless personal area networks (WPAN), and wireless broadBand-personal area networks (WB-PAN). Early-stage mobile communication systems were made up of high-power transmitters, employing analog frequency modulation techniques. The first generation (1G) system was analog using frequency division multiple access (FDMA) technology. The main weakness of analog systems is that they are not robust enough to endure interferences. After successfully addressing the fragile aspect of 1G systems where digital technology was adapted, a new era called second-generation (2G) started in most countries worldwide, as illustrated in Figure 1.1. Digital messaging services to improve security and possibly standard protocols to allow international services using time division multiple access (TDMA) and FDMA technology. The 1G systems launched in 1980 satisfied the need for essential mobile voice services. The evolution was followed by the 2G systems that were established in 1990. The 2G systems realized the additional capacity and services requirements. The third-generation (3G) systems were introduced in 2000. The 3G systems offer fundamental packet data with a higher speed of up to 2Mbps. The International Mobile Telephone 2000 (IMT 2000) project is responsible for establishing 3G technology standards. The system was expected to offer 144 kbps downlink throughput for mobile data during travel, 384 kbps while stationary or at pedestrian speed, and 2 Mbps in the indoor environment (Mshvidobadze, 2012). Among the superior 3G technologies are universal mobile telecommunication system-high speed packet access (UMTS-HSPA), code division multiple access (CDMA) 2000, and enhanced data GSM environment (EDGE).

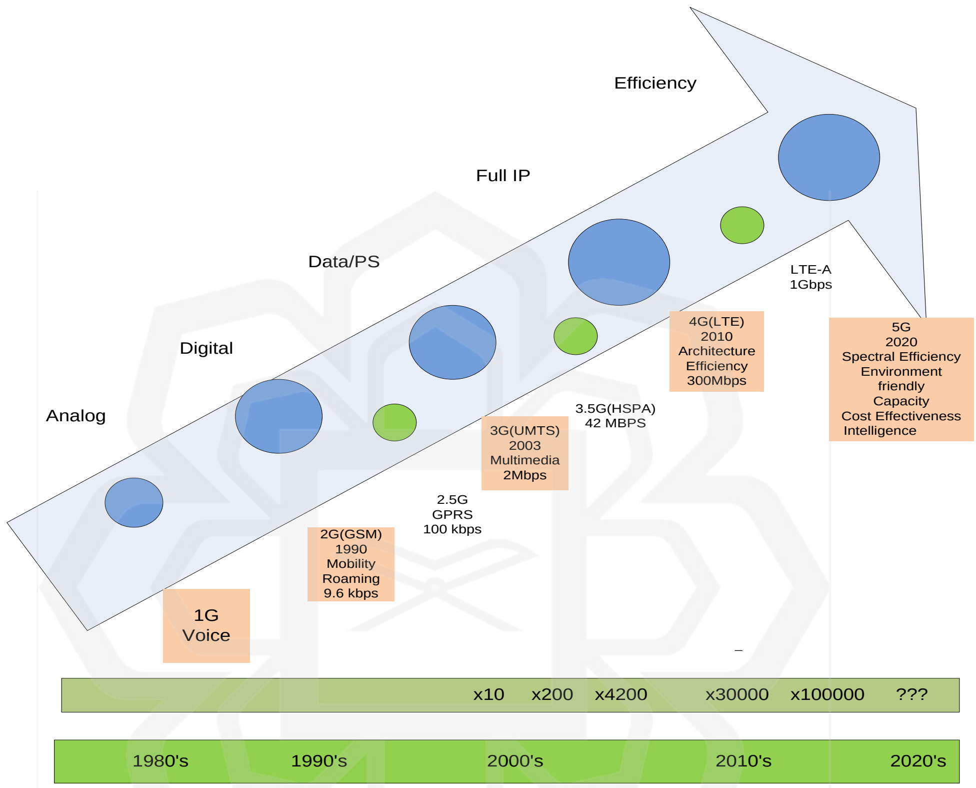

Figure 1.1: Evolution of Wireless Mobile Communication

The fourth-generation (4G) systems were expected to present much more significant bandwidth than the previous 3G systems. In 2008, the international telecommunication union-radio (ITU-R) specified the requirement for 4G standards. The peak throughput requirement for 4G service is supposed to be at least 100 Mbps for the device in high mobility environments such as trains or cars. For a low mobility environment, communication throughput was expected to be at least 1 Gbps. Mobile

4G networks worldwide are using a transmission with a center frequency of about 2.6 GHz. The third generation partnership project, the long-term evolution (3GPP-LTE) technology, is often branded as "4G-LTE". Downlink speeds of up to 100 Mbps and uplinks up to 50 Mbps are anticipated for LTE technology bitrate with bandwidth 20 MHz. Higher rates are expected to be achieved by implementing a multiple-input multiple-output (MIMO) antenna configuration (Reddy & Boppana, 2014). Internet protocol (IP) was then incorporated as part of the 4G network evolution. The packet technology was being migrated into IP technology for cost reduction and to increase efficiency. Release 8 (R8) defines the LTE system as a break from the past. It marks the start of the transition of 4G technologies and networks. Release 9 (R9) offers enhancements to LTE, including home eNodeBs, for improved coverage. Release 10 (R10) recommendation for LTE advanced is a full-featured 4G system, including the MIMO 8x8 antenna configuration.

In the cellular communication system on 4G and 5G technology, Orthogonal Frequency Division Multiplexing (OFDM) is a promising multi-carrier modulation. OFDM is used for the downlink direction in LTE telecommunication, whereas single-carrier FDMA (SC-FDMA) is used for the uplink. The LTE signal format based on OFDM comprises 15 kHz resource elements across different channel bandwidths varying from 1.4 MHz to 20 MHz. The LTE system can adapt to the number of bits transmitted between the cell site and mobile stations. The difference of bits is that different types of modulation, i.e., QPSK, 16-QAM, 64-QAM, are employed or scheduled based on the quality of the received signal by a mobile station. The multiple transmission streams between the cell side and mobile station incorporate the adaption of MIMO arrays, where it might involve MIMO 2x2 and MIMO 4x4. As for the LTE advanced, the MIMO 8x8 configuration had been proposed.

In an OFDM system, the transmission channel is divided into sub-channel in which each sub-channel is assigned a subcarrier. When a signal is transmitted through a non-line of sight (N-LOS) channel, inter symbol interference (ISI) will occur such that the system performance is degraded. The cyclic prefix (CP) is added to each symbol to inhibit inter symbol interference (ISI) between adjacent OFDM symbols and ensures orthogonality between sub-carriers by keeping the OFDM symbol periodic over the extended symbol duration. However, the cyclic prefix also introduces ripples in the power spectral density (PSD) of the ultra-wideband (UWB) signal, thus resulting in a transmit power backoff (Deshmukh; Hasan & Singh, 2012b). The inverse Fourier Transform (IFFT) and FFT are employed to modulate and demodulate the N subcarrier into quadrature amplitude modulation (QAM) information symbols at transmitter and receiver. The Fourier-based implementation is vulnerable to inter-channel interference (ICI) (Abdullah, Sadik, & Hussain, 2009).

OFDM modulated signal comprises many independently modulated subcarriers, resulting in a large peak average power ratio (PAPR) when added up coherently. With N number of the same phase signal added together, the result will be an N peak power times the average power. The method used to add the subcarrier components occurs during the fast Fourier transform (FFT) operation. High PAPR poses a severe limitation in an OFDM system because it reduces the signal-to-quantization noise ratio (SQNR) of the analog-digital converter (ADC) and the digital-analog converter (DAC). PAPR also reduces the efficiency of the transmit power amplifier due to the generated access heat. Therefore as the PAPR value increases, the average power decreases, which reduces the coverage area. To avoid the large clipping amplitude of OFDM, so an extensive dynamic range of high power amplifier (HPA) and digital to analog converter (DAC) is needed. Causes of increasing PAPR values due to power consumption from the dynamic range of HPA and DAC (Mohammed, Shehata, Nassar, & Mostafa, 2019).

1.2 PROBLEM STATEMENT

The OFDM technique in 4G and 5G technology is causing a high peak average power ratio (PAPR), which leads the amplifier to operate in the nonlinear region. The downlink and uplink processes also employ OFDM modulation. OFDM involves a cyclic prefix used as a guard interval (GI), whose length should exceed the maximum exceed delay of the multipath propagation channel. The use of a high number of subcarriers of OFDM symbols that are out of phase with each other will cause high PAPR values. When many independent modulated subcarriers, the cyclic prefix in the time domain, are added, they produce a peak power that is N time greater than a signal's average power, which will have a high PAPR. A significant value of PAPR can cause the transmitters' power amplifier (PA) to run within the nonlinear operating region. The instance causes significant signal distortion at the output of the power amplifier. Also, the high PAPR can cause saturation at the digital-to-analog converter (DAC), leading to saturation of the PA. The linearity refers to the ability of an amplifier to produce signals that are accurate copies of the input. Load impedance, supply voltage, input base current, and power output capabilities can affect the amplifier's efficiency. The damages to the amplifier can cause expensive repair expenditures. The PAPR experienced by an OFDM system grouped under the IEEE 802.11a specifications with 52 subcarriers has been identified to be around 17dB (Prasad, 2004).