EVALUATION OF SISO-OFDM AND MIMO-OFDM CHANNEL’S PERFORMANCE USING EXPERIMENT SET UP AND SIMULATIONS

BY

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ABSTRACT

Interference is an inevitable signal disruption in a wireless communication system. A high level of interference effect (Bit Error Rate (BER)) is experienced mostly in crowded urban areas and indoor environments. Interference caused by Additive White Gaussian Noise (AWGN), Rician and Rayleigh fading reduces the travelled distance and signal level. Additionally, systems employing single modulation techniques and antenna are more likely to be affected by interference. This is because they are incapable of adapting to the environment changes. As such, this research has proposed to evaluate a Single Input Single Output (SISO) Orthogonal Frequency Division Multiplexing (OFDM) capability in an indoor environment as well as apply adaptive modulation techniques and antenna diversity in a simulation experiment to mitigate interference-effect. The first objective of this research is to evaluate the SISO-OFDM channel's performance in an indoor environment against the cleanroom environment, acquired using an experimental setup. The second objective is to ascertain the improvement of SISO-OFDM channel performance when variable modulations are deployed, using the GNU Radio software platform. The third objective is to identify the channel performance's improvement when Multiple Input Multiple Output (MIMO)-OFDM System is deployed using the GNU Radio software. The performance's parameters assessed are the BER and Received Signal Strength Indicator (RSSI) in the case of the empirical testbed. Whereas, for the software simulation implementation, the parameter assessed is the BER. The methodologies adopted in the empirical study involved using SISO-OFDM with the Universal Software Radio Peripheral (USRP) hardware setup to conduct experiments in the laboratory and anechoic chamber environments. The distances between the transmitter and receiver were varied, and the collected measurements were compiled and recorded. The simulation experiment employing the SISO-OFDM system was carried out over various channel conditions, namely AWGN, Rician, and Rayleigh. The MIMO-OFDM system was simulated over different channel conditions, and the performance measurements were compared with that of the SISO-OFDM system. The most important research findings from the empirical study are the ability to identify the interference level at a specific site using the USRP. Based on the findings from the second objective, adaptive modulation can be said to mitigate the interference effect (BER) in a SISO-OFDM system. The key discovery found in the third objective is that the MIMO-OFDM system significantly reduces the interference effect (BER) level usually experienced over a multipath fading channel of a SISO-OFDM system. The major contribution of this research is the capability to share the method to identify interference level at a specific site using a standard radio frequency equipment with the USRP. Moreover, this research is one of the first to assess wireless channel performance in the anechoic chamber using the USRP N210 Software Defined Radio (SDR).

خلاصة البحث

التداخل هو اضطراب في الإشارة لا مفرّ منه في نظام الاتصالات اللاسلكية. يتّم في الغالب ملاحظة مستوى عالٍ من تأثير التداخل (معدل خطأ البت (BER)) في المناطق الحضرية المزدحمة والبيئات الداخلية. إنّ التداخل الناجم عن الضوضاء الغاوسية البيضاء المضافة (AWGN)، Rician و Rayleigh يؤدي إلى تقليل المسافة المقطوعة ومستوى الإشارة، بالإضافة إلى ذلك، من المرجح أن يؤثر التداخل على الأنظمة التي تستخدم تقنيات التشكيل الفردية والاستشعار الهوائي، وذلك لعدم قدرتهم على التكيف مع التغيرات البيئية. وعلى هذا النحو، اقترح هذا البحث تقييم قدرة تعدد الإرسال بتقسيم التردد المتعامد (OFDM) إلى مدخل منفرد ومخرج منفرد (SISO) في بيئة داخلية، بالإضافة إلى تطبيق تقنيات التعديل التكيفية وتنوع الهوائي في تجربة محاكاة لتخفيف تأثير التداخل. إنّ الهدف الأول من هذا البحث هو تقييم أداء قناة SISO-OFDM في بيئة داخلية بالمقارنة مع بيئة غرف الأبحاث باستخدام إعداد تجريبي. والهدف الثاني هو التحقّق من تحسين أداء قناة SISO-OFDM عند استخدام متغيرات التشكيل، باستخدام منصة برمجيات GNU Radio. والهدف الثالث هو تحديد تحسّن أداء القناة عندما يتم استخدام نظام الإدخال والإخراج المتعدد OFDM- (MIMO) باستعمال برنامج GNU Radio. كانت معلمات الأداء التي تم تقييمها هي BER ومؤشر قوة الإشارة المستقبلة (RSSI) في حالة الاختبار التجريبي، في حين أنه بالنسبة لتنفيذ محاكاة البرنامج، فإن المعلمة التي تم تقييمها هي BER. وتضمنت المنهجيات المعتمدة في الدراسة التجريبية استخدام SISO-OFDM مع إعداد الأجهزة بواسطة Universal Software Radio Peripheral (USRP) لإجراء التجارب في المختبر والغرف الكاتمة للصدى. تم تغيير المسافات بين المرسل والمستقبل، ومن ثمّ تجميع القياسات وتسجيلها. وتمّ إجراء تجربة المحاكاة باستخدام نظام SISO-OFDM في ظروف قناة مختلفة، وهي AWGN و Rician و Rayleigh. كذلك تمت محاكاة نظام MIMO-OFDM في ظروف قناة مختلفة، وتمت مقارنة قياسات الأداء مع نظام SISO-OFDM. كانت أهم نتائج البحث من الدراسة التجريبية هي القدرة على تحديد مستوى التداخل في موقع معين باستخدام USRP. واستنادًا إلى النتائج المستخلصة من الهدف الثاني، يمكن القول أنّ التشكيل التكيفي يخفف من تأثير التداخل (BER) في نظام SISO-OFDM. كما أنّ الاكتشاف الرئيسي من الهدف الثالث يشير إلى أنّ نظام MIMO-OFDM يقلل بشكل كبير من مستوى تأثير التداخل (BER) والذي يحدث عادةً عبر قناة الخبو (التضاؤل) متعددة المسارات لنظام SISO-OFDM. وتتمثل المساهمة الرئيسية لهذا البحث في القدرة على مشاركة طريقة لتحديد مستوى التداخل في موقع معين باستخدام جهاز تردد الراديو القياسي مع USRP. علاوة على ذلك، يعد هذا البحث من أوائل الأبحاث لتقييم أداء القناة اللاسلكية في الغرفة الكاتمة للصدى باستخدام برنامج USRP N210 Software Defined Radio (SDR).

APPROVAL PAGE

I certify that I have supervised and read this study and that in my opinion, it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a thesis for the degree of Master of Science (Communication Engineering)

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DECLARATION

I hereby declare that this thesis is the result of my 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.

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LIST OF ABBREVIATIONS

16QAM	Sixteen-state Quadrature Amplitude Modulation
64QAM	Sixty-Four-state Quadrature Amplitude Modulation
8PSK	Eight-state Phase Shift Keying
AMC	Adaptive Modulation and Coding
AMPS	Advanced Mobile Phone Service
AT&T	American Telephone and Telegraph Company
AWGN	Additive White Gaussian Noise
BER	Bit Error Rate
BPSK	Binary Phase Shift Keying
CDMA	Code Division Multiplexing Access
CO	Central Office
CR	Cognitive Radio
CRC	Cyclic Redundancy Check
CSI	Channel State Information
DFT	Discrete Fourier Transform
DSP	Digital Signal Processing
EMC	ElectroMagnetic Compatibility
FCC	Federal Communications Commission
FDMA	Frequency Division Multiplexing Access
FFT	Fast Fourier Transform
FPGA	Field-Programmable Gate Arrays
FSPL	Free Space Path Loss
GNU	GNU’s Not Unix

GRC	GNU Radio Companion
GSM	Global System Mobile Communication
ID	Identification
IDFT	Inverse DFT
IEEE	Institute of Electrical and Electronics Engineers
IFFT	Inverse Fast Fourier Transform
IMT	International Mobile Telecommunication
ISI	Inter-Symbol Interference
ITU	International Telecommunication Union
LOS	Line-of-Sight
LTE	Long Term Evolution
MIMO	Multiple-Input, Multiple-Output
NAMPS	Narrowband Analog Mobile Phone Service
NLOS	Non-Line-of-Sight
NMT	Nordic Mobile Telephone
NTT	Nippon Telegraph and Telephone
OFDM	Orthogonal Frequency Division Multiplexing
OOT	Out-of-Tree Modules
OS	Operating System
PCM	Pulse Code Modulation
PER	Packet Error Rate
PHY	Physical Layer
QAM	Quadrature Amplitude Modulation
QPSK	Quadrature Phase Shift Keying
RF	Radio Frequency

RSSI	Received Signal Strength Indicator
SDR	Software-Defined Radio
SISO	Single-Input, Single-Output
SMA	SubMiniature version A
SNR	Signal to Noise Ratio
STBC	Space-Time Block Code
TDMA	Time Division Multiplexing Access
UHD	USRP Hardware Driver
USRP	Universal Software Radio Peripheral
WLAN	Wireless Local Area Network

LIST OF SYMBOLS

H^{-1}	The Inverse of the Channel Mixing Matrix
h_{ij}	Complex Gaussian Random Variable
I_0	Zero-Order Modified Bessel Function
D	Minimum Far-Field Distance
Hz	Hertz
K	Rician Factor
L	Antenna Dimension
N	Packet Length
R	Bit Rate
bit/s	Bits per Second
dB	Decibels
dBm	Decibel-Milliwatt
m	Mean Value of AWGN
n	Channel Noise
r	Random Variable of Rician Fading Model
v	Peak Field Strength of the LOS Component
x	Grey Level Threshold of AWGN
λ	Centre Frequency's Wavelength
σ	Standard Deviation of AWGN

CHAPTER ONE

INTRODUCTION

1.0 HISTORICAL BACKGROUND

The modern telecommunications revolution began in 1838 when Samuel F.B. Morse invented the telegraph (Carr et al., 2001). The telegraph made communication between distant cities possible before Bell’s telephone was invented. On March 10, 1876, Alexander Graham Bell with his assistant Thomas A. Watson invented and tested the telephone in Court Street Boston (Carr et al., 2001). Progressively, the Bell Telephone made the required improvements, and the concept of a public telephone network then arrived by January 1878 in New Haven. In March 1885, the American Telephone and Telegraph Company (AT&T) was developed to control the sudden boom of the telephone network across the United States (Carr et al., 2001). James Clark Maxwell developed his theory of electromagnetism in 1864 with his first published paper (Schmitt, 2002). In 1887, Heinrich Rudolf Hertz confirmed Maxwell's theory by conducting an experiment in which he transmitted an electrical signal through the air (Schmitt, 2002). In 1896, Gugliemo Marconi demonstrated that telegraph messages can be sent and received wirelessly using electromagnetic waves (Schmitt, 2002). With this achievement, his fame rose when he was able to send a message across the Atlantic Ocean in 1901 (Schmitt, 2002). During this era, Nikola Tesla lost the patent on wireless transmission, but the court ruling was overturned in 1943 giving credit also to Tesla for his contribution to wireless transmission (Schmitt, 2002). The advancement of digital technology was soaring in the early 1900s. Within this period, in 1928, the general sampling theorem was first conceptualized by Harry Nyquist (Brittain, 2010). Claude

Shannon then further developed the sampling theorem and published a paper entitled "A Mathematical Theory of Communication" in 1948 (Brittain, 2010).

The telephone system consists of a local loop of two wires called "wire pair", and this connects to Central Office (CO) that contains switching equipment, signalling equipment, and batteries. The range of frequencies that are passband for voice channel is from 0 Hz up to 4000 Hz. Frequency Division Multiplexing Access (FDMA) was adopted for analog signals, as it was capable of assigning different frequencies for each transmission channel (Carr et al., 2001). Another means for transmission of voice in the telephone system is digital signals. The voice signal in its analog format is converted into a digital signal and converted back into an analog signal at the CO to retrieve the original transmitted voice. The digital transmission in the telephone system made use of Pulse Code Modulation (PCM), where binary code varies as the signal changes (Carr et al., 2001). Therefore, conversations are digitally encoded by PCM and digitally transmitted in series on the same channel or line by Time Division Multiplexing Access (TDMA).

In the United States (US), Advanced Mobile Phone Service (AMPS) system represents the first-generation (1G) cellular technology. It was developed in the 1970s and the early years of the 1980s. It was eventually released in 1983 (Carr et al., 2001). The AMPS was an analog system using FDMA radio technology operating at 800 MHz (Carr et al., 2001). Another feature of AMPS is the ability to use frequency reuse and cell splitting for seamless handoff operation between base stations (Carr et al., 2001). The Nippon Telegraph and Telephone (NTT) launched 1G in Japan in 1979. The Nordic Mobile Telephone (NMT), on the other hand, made 1G available throughout Europe in 1981 (Albreem, 2015). Before the debut of the second-generation (2G) system in Europe, Narrowband Analog Mobile Phone Service (NAMPS) operating at frequencies of 890 to 989 MHz was used to increase the performance of the 1G system (Carr et al., 2001). The era of 2G introduced Global System Mobile Communication (GSM) that solve low call capacity posed by the 1G cellular system. GSM was a digital system launched in 1991 which operates at a centre frequency of around 1800 MHz (Carr et al., 2001). A combination of narrowband voice processing with digital signalling allowed more channels to be accommodated in GSM. GSM uses TDMA and Code Division Multiplexing Access (CDMA-one) to solve the problem of low system capacity. TDMA systems are digitally modulated to provide several time slots over only one carrier signal (narrow frequency band), and only one mobile handset is assigned to each time slot.

The third-generation (3G) incorporates a more efficient CDMA technology. International Mobile Telecommunication-2000 (IMT-2000) launched 3G and set its operating frequencies around 2.1 GHz. The announcement was made during the World Administrative Radio Conference held in 1992 (Prasad & Velez, 2010). CDMA can encode the data stream to increase the number of bits within the bandwidth required for every carrier signal. Therefore, if another transmission takes place in the same frequency using a different code for the data stream, it does not affect the first transmission as the code is not recognized. The unique digital codes are shared by mobile phones and base stations. They are identified as pseudo-random code sequences also known as pseudo-noise. IMT-2000 and Universal Mobile Telecommunications System (UMTS) were the first technology to launch 3G radio access that offered enhanced data GSM environment (EDGE), wideband CDMA (WCDMA), and CDMA2000 (Elsen et al, 2001). The fourth-generation (4G) was readily welcomed as early as 2008 when IMT-Advanced requirements were approved by the International Telecommunication Union (ITU) (Prasad & Velez, 2010). 3rd Generation Partnership Project (3GPP) launched 4G and Long-Term Evolution (LTE) which employed