UNIVERSITI PUTRA MALAYSIA

CONCATENATED RS-CONVOLUTIONAL CODES FOR MIMO-OFDM OVER MULTIPATH FADING CHANNEL

GHASAN ALI HUSSAIN

CONCATENATED RS-CONVOLUTIONAL CODES FOR MIMO-OFDM OVER MULTIPATH FADING CHANNEL

GHASAN ALI HUSSAIN

MASTER OF SCIENCE
UNIVERSITI PUTRA MALAYSIA
2013

CONCATENATED RS-CONVOLUTIONAL CODES FOR MIMO-OFDM OVER MULTIPATH FADING CHANNEL

By

GHASAN ALI HUSSAIN

Thesis Submitted to the School of Graduate Studies, University Putra Malaysia, in Fulfilment of the Requirements for the Degree of Master of Science

July 2013

COPYRIGHT

DEDICATION

This thesis is dedicated to:

My Country Iraq,

All my family who have supported me in all ways since the beginning of my studies

My wife and Kids who have been a great source of motivation and inspiration

Abstract of thesis presented to the Senate of University Putra Malaysia in fulfilment of the requirement for the degree of Master of Science

CONCATENATED RS-CONVOLUTIONAL CODES FOR MIMO-OFDM OVER MULTIPATH FADING CHANNEL

By

GHASAN ALI HUSSAIN

July 2013

Chairman: Makhfudzah bt. Mokhtar, PhD

Faculty: Engineering

The enormous developments through recent years in the wireless communications applications have led to important needs for increasing the data bandwidth and channel reliability (the probability of correct reception at the receiver) which are required to support several multimedia applications. Orthogonal Frequency Division Multiplexing (OFDM) has become the common method for services that need high data rate and robust to the inter-symbol interference (ISI). On the other hand, high data rate transmission needs more bandwidth. This problem gives a great motivation to use Multiple Input Multiple Output (MIMO) technique as a solution to increase the spectral efficiency**.** Therefore, the combination of OFDM with MIMO systems will allow higher data throughput while increasing the bandwidth efficiency at the same time. However, the channel coding technique is still required in MIMO-OFDM system in order to improve error performance by protecting the data transmission and decreasing the Bit

Error Rate (BER) over fading and noisy channel. Therefore, this thesis proposes a concatenated Reed-Solomon\Convolutional code for MIMO-OFDM system as a channel coding technique, so that the bandwidth efficiency and the channel reliability can be increased. The performance of MIMO-OFDM using concatenated Reed-Solomon and Convolutional Codes is investigated over Rayleigh fading channel with Additive White Gaussian Noise (AWGN), and Rician fading channel with AWGN. The simulation works have been carried out using MATLAB software. The channel reliability improvements are performed by the curve of Bit Error Rate (BER) against Signal-to-Noise Ratio (SNR). The performance of MIMO-OFDM system with concatenated code has also been compared with other possible concatenated systems over Rayleigh and Rician fading channel. Using the proposed system, a coding gain up to 16dB at 10^{-3} of BER has been obtained over Rayleigh fading channel with AWGN, while 11dB of coding gain at 10^{-3} of BER has been achieved over Rician fading channel with AWGN, compared to uncoded MIMO-OFDM system also it performs better than other concatenated MIMO-OFDM systems. The results show that the proposed code rate is performed better than other code rates with MIMO-OFDM system over both of Rayleigh and Rician fading channel with AWGN. Lastly, the burst error has been analyzed in our proposed system for both of interleaving process and Reed-Solomon Codes.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Master Sains

TURUTAN KOD RS-PELINGKARAN BAGI SISTEM PELBAGAI KELUARAN PELBAGAI MASUKAN-PEMULTIPLEKS BAHAGIAN FREKUENSI ORTOGONAL ATAS LALUAN PELBAGAI ARAH SALURAN PUDAR

Oleh

GHASAN ALI HUSSAIN

July 2013

Pengerusi: Makhfudzah bt. Mokhtar, PhD

Fakulti: Kejuruteraan

Perkembangan yang besar bagi abad terkini dalam aplikasi komunikasi wayarles menyebabkan berlakunya keperluan yang mendesak untuk meningkatkan lebar jalur data dan kebolehpercayaan (saluran kebarangkalian penerimaan yang betul pada penerima) yang diperlukan untuk menyokong beberapa aplikasi multimedia. Pemultipleks Frekuenci Ortogonal (OFDM) merupakan kaedah biasa untuk perkhidmatan yang memerlukan kadar data yang tinggi dan lasak terhadap gangguan antara simbol (ISI). Sebaliknya, penghantaran data berkelajuan tinggi memerlukan lebar jalur yang besar. Masalah ini telah memberi motivasi kepada penggunaan teknik Pelbagai Masukan Pelbagai Keluaran (MIMO) sebagai penyelesaian kepada kecekapan spektrum. Oleh yang demikian, gabungan teknik OFDM dan MIMO dapat membantu penghasilan data yang tinggi di samping meningkatkan kapasiti. Akan tetapi, pengkodan saluran yang

cekap masih diperlukan dalam sistem MIMO-OFDM untuk memperbaiki prestasi hingar pada jalur lebar yang tinggi dengan melindungi penghantaran data dan mengurangkan kadar ralat bit (BER) yang melalui saluran pemudaratan dan berhingar. Oleh itu, tesis ini mencadangkan kod turutan Reed Solomon dan pelingkaran bagi meningkatkan kecekapan lebar jalur dan kebolehpercayaan saluran. Prestasi MIMO-OFDM menggunakan kod turutan Reed Solomon dan pelingkaran diuji melalui saluran pemudaratan Rayleigh dengan Hingar Tambahan Putih Gaussian (AWGN), dan saluran pemudaratan Rician dengan AWGN. Kerja simulasi dijalankan dengan menggunakan perisian MATLAB. Penambahbaikan kebolehpercayaan saluran ditunjukkan oleh lengkungan kadar ralat bit (BER) melawan nisbah isyarat-kepada-hingar (SNR). Di samping itu, prestasi antara pemudaratan Rayleigh dan Rician turut dibandingkan. Dengan menggunakan sistem yang dicadangkan, gandaan kod sebanyak 16dB pada 10^{-3} kadar ralat bit dihasilkan bagi saluran pemudaratan Rayleigh, manakala 11dB gandaan kod pada 10^{-3} kadar ralat bit pula diperoleh bagi saluran pemudaratan Rician, berbanding sistem MIMO-OFDM yang tiada pengkodan. Keputusan menunjukkan bahawa kadar kod yang dicadangkan adalah prestasi yang lebih baik daripada kadar kod lain dengan sistem MIMO-OFDM atas kedua-dua daripada Rayleigh dan saluran pudar Rician dengan AWGN. Akhir sekali, kesilapan pecah telah dianalisis dalam sistem cadangan kami untuk kedua-dua proses interleaving dan Kod Reed-Solomon.

I certify that a Thesis Examination Committee has met on 3 July 2013 to conduct the final examination of Ghasan Ali Hussain on his thesis entitled "Concatenated Rs-Convolutional Codes for Mimo-Ofdm Over Multipath Fading Channel" in accordance with the Universities and University Colleges Act 1971 and the Constitution of the Universiti Putra Malaysia [P.U.(A) 106] 15 March 1998. The Committee recommends that the student be awarded the Master of Science.

Members of the Thesis Examination Committee were as follows:

Salasiah binti Hitam, PhD
Associate Professor
Faculty of Engineering
Universiti Putra Malaysia
(Chairman)

Ahmad Shukri bin Muhammad Noor, PhD
Senior Lecturer
Faculty of Engineering
Universiti Putra Malaysia
(Internal Examiner)

Ratna Kalos Zakiah binti Sahbudin, PhD
Senior Lecturer
Faculty of Engineering
Universiti Putra Malaysia
(Internal Examiner)

Sharifah Kamilah binti Syed Yusof, PhD
Associate Professor
University of Technology Malaysia
Malaysia
(External Examiner)

NORITAH OMAR, PhD
Assoc. Professor and Deputy Dean
School of Graduate Studies
Universiti Putra Malaysia

Date: 2 August 2013

This thesis was submitted to the Senate of Universiti Putra Malaysia and has been accepted as fulfilment of the requirement for the degree of Master of Science. The members of the Supervisory Committee were as follows:

Makhfudzah bt. Mokhtar, PhD
Senior Lecturer
Faculty of Engineering
Universiti Putra Malaysia
(Chairman)

Raja Syamsul Azmir Bin Raja Abdullah, PhD
Associate Professor
Faculty of Engineering
Universiti Putra Malaysia
(Member)

BUJANG KIM HUAT, PhD
Professor and Dean
School of Graduate Studies
Universiti Putra Malaysia

Date:

DECLARATION

I declare that the thesis is my original work except for quotations and citations, which have been duly acknowledged. I also declare that it has not been previously, and is not concurrently, submitted for any other degree at Universiti Putra Malaysia or at any other institution.

GHASAN ALI HUSSAIN

Date: 3 July 2013

TABLE OF CONTENTS

LIST OF FIGURES

Figure **Page**

LIST OF ABBREVIATIONS

AWGN	Additive White Gaussian Noise
BER	Bit Error Rate
CC	Convolutional Code
COFDM	Coded Orthogonal Frequency Division Multiplexing
CP	Cyclic Prefix
Eb/No	Energy per Bit Noise Ratio
ICI	Inter Carrier Interference
ISI	Inter Symbol Interference
LOS	Line of Sight
LDPC	Low Density Parity Check
MIMO	Multiple Input Multiple Output
OFDM	Orthogonal Frequency Division Multiplexing
RS	Reed-Solomon
SISO	Single Input Single Output
SNR	Signal to Noise Ratio
UWB	Ultra Wide Band

CHAPTER 1

INTRODUCTION

1.1 Background

The Orthogonal Frequency Division Multiplexing (OFDM) has been becoming one of the successful methods in mobile wireless channels in mitigating the delay spread of multipath channel and improving the system capacity [1]. The OFDM has capability to resist inter-symbol interference (ISI), thus it becomes a strong candidate to be a standard for digital (video and audio) broadcasting, as well as for indoor broad-band wireless systems [2].

In practice, an OFDM is a transmission technology which can be used for both wire (e.g. via copper cables) and wireless communication systems. It is considered as a particular case of the common technique of Frequency Division Multiplexing (FDM) which modulates the digital or analogue data onto a number of carriers transmitted in parallel through the same medium of transmission. The significant reason for utilizing (FDM) is because it depends on the parallel data transmission in a frequency domain. Using this technique, each channel will occupy a short frequency band. Thereby, the frequency selective fading will be reduced.

High spectral efficiency is an attractive property in the OFDM technique compared to FDM. The FDM has limited spectral efficiency due to the selectivity of the band-pass filter required for demodulation system. In designing an OFDM, several carriers are orthogonal pairs, which suppress the Inter Symbol Interference (ISI). The orthogonality in OFDM is obtained by putting the RF carriers on a certain frequency grid and considering the rectangular pulse shaping [3].

Generally, high robustness versus frequency selective fading and a narrowband interference is a significant reason to utilize an OFDM system. In contrast, the interference or the single fade may cause a complete link to fail for single carrier systems, while the subcarriers in multicarrier systems will be slightly affected. The errors that may occur in subcarriers can be corrected by using coding techniques [4].

In fact, in any wireless communication signals, the signal will be passed via a number of several paths (multipath) during the transmission from the transmitter to the receiver. The propagation of the signal power drops off due to three effects: macroscopic fading, path loss and microscopic fading. The diversity technique can be used to mitigate the fading. In the diversity, the signal is propagating via multiple separated fading paths (frequency, time or space) then being combined constructively at the receiver. Therefore, the Multiple Input Multiple Output (MIMO) technique is an appropriate choice because it uses the spatial diversity through different antennas at the transmitter and the receiver [5].

1.2 Problem Statement

The OFDM system became a common method for the services of wireless indoor short-range like video networking at homes that needs a high data rate, high quality of service systems and low of power consumption with the addition to the low cost [6].

Typically, several wireless applications require a high data rate, while the high data rate transmission needs more bandwidth. On the other hand, it is difficult to increase the bandwidth because it is very expensive and it is spectrally limited. By using multiple antennas at transmitter and receiver (known as MIMO), the system capacity can be increased. The combination of OFDM technique with MIMO systems would allow high data rate, as well as increasing the system capacity [9]. However, in multipath fading environments, the performance of OFDM degraded due to the increment of Bit Error Rate (BER) [6]. To improve the BER, coding techniques have been proposed to be implemented in OFDM system [7][8]. These coding techniques could improve the system performance by correcting the errors and then decreasing the BER. However, using concatenated code gives extra robust for channel coding and performs better than using single code [6]. Therefore, this work is aimed to investigate the improvement of MIMO-OFDM system using concatenated Reed Solomon and convolutional coding due to it is considered a relatively coding gain [22]. This concatenated coding will be tested at various code rates and its performance will be compared to other possible concatenated codings.

1.3 Motivations

The motivations of this thesis are as follow:

- To achieve high data rate and increase the system capacity, we applied the combination of OFDM and MIMO systems.
- To improve the error performance or in other words, to increase the channel reliability over fading and noisy channel, we propose using concatenated Reed-Solomon with Convolutional codes as a channel coding of MIMO-OFDM system to obtain a robust error control system rather than any other concatenated coding.

1.4 Research Objectives

Based on our study, it has been found that most of researchers discussed the issue of degradation for OFDM performance which occurs in multipath fading environments and they suggested a lot of methods like using several coding techniques and/or using MIMO channel. To the best of our knowledge, an investigation or study on improving the OFDM using MIMO system and concatenated Reed Solomon and convolutional codes has not been reported yet.

Therefore the following are the objectives of this study:

(i) To develop a reliable MIMO-OFDM system using concatenated Reed Solomon and convolutional codes.

(ii) To design and evaluate MIMO-OFDM system performance over Rician and Rayleigh fading with AWGN at different code rates.

(iii) To compare the developed system with other concatenated codes of MIMO-OFDM system.

1.5 Research Contribution

This research has proposed a reliable and high capacity of channel transmission in OFDM system by applying MIMO system and a proper concatenated technique, i.e. Reed Solomon and convolutional codes with optimum code rates of (1/7) and (1/2) respectively . Coding gain up to 16dB at 10^{-3} of Bit Error Rate (BER) is achieved using the proposed OFDM system over Rayleigh fading channel compared to uncoded MIMO-OFDM systems. Meanwhile, up to 11dB of coding gain is obtained at 10^{-3} of BER for the proposed system over Rician fading channel with AWGN, compared to uncoded MIMO-OFDM systems. It also performs better BER rather than other concatenated MIMO-OFDM systems.

1.6 Scope of Work

As mentioned earlier, the OFDM system is a very important technique that is used in wireless systems, such as indoor and outdoor broadcasting systems. These systems are mainly affected by the Rayleigh and Rician fading. Concatenated techniques are a very good method in providing strong reliable systems. Thus, our works will concentrate on concatenated coding over these fading channels to improve the reliability of channel transmission. The combination between OFDM and MIMO systems will be used with concatenated technique in our design system to increase the system capacity. Figure 1.1 illustrates the scope of this thesis.

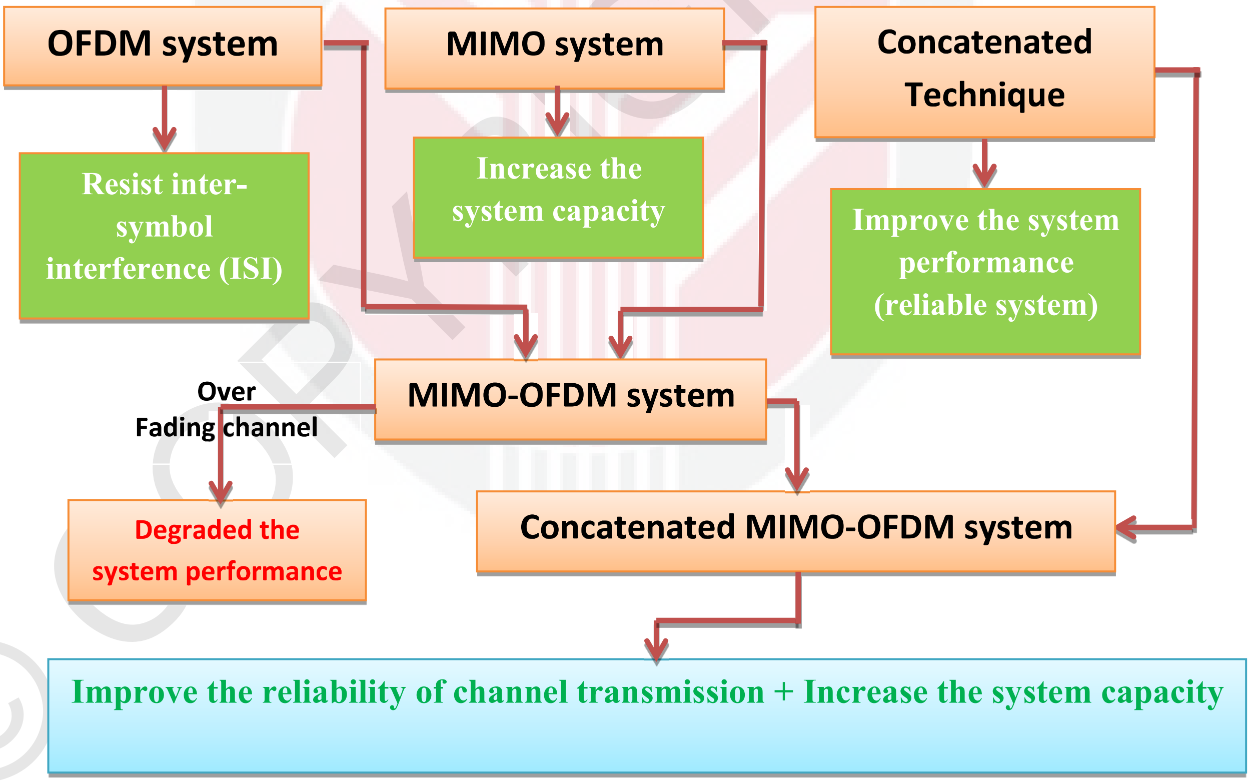

Figure 1.1: Thesis Scope

1.7 Thesis Organization

The structure of this thesis is as follows:

(i) **Chapter one** presents the introduction and general information on OFDM systems, as well as the MIMO configuration. Then, the problem statement, objectives, and contributions of the research are also presented.

(ii) **Chapter two** presents the overview of an OFDM system and the techniques that have been used to improve the performance. This chapter also analyzes the system performance to show the advantages and disadvantages of each case. This overview includes the explanation of channel coding techniques and MIMO system.

(iii) **Chapter three** explains the methodology of the proposed technique that designs the concatenated RS-Convolutional codes of MIMO-OFDM system over multipath fading channel with AWGN. It also provides a description of the system model and parameters that have been used.

(iv) **Chapter four** describes the simulation results and their analysis.

(v) **Chapter five** draws the conclusion and future work.

References

[1] Senol, H., Cirpan, H.A.and Panayirci, E. (2006). Linear expansions for frequency selective channels in OFDM. *International Jornal of Electronics and Communications (AEU)* 60: 224 – 234.

[2] Shin, M., Lee, H. and Lee, Ch. (2004). Enhanced Channel-Estimation Technique for MIMO-OFDM Systems. *IEEE Transactions on Vehicular Technology* 53(1): 261-265.

[3] Rosenkranz, W., Leibrich, J., Serbay, M. and Ali, A. (2007). Orthogonal Frequency Division Multiplexing (OFDM) and other Advanced Options to achieve 100Gb/s Ethernet Transmission. *Transparent Optical Networks, ICTON '07. 9th International Conference on* 1:12-15.

[4] Hara, S. and Prasad, R. (2003). Multicarrier Techniques for 4G Mobile Communications 27-28. London: Artech House. ISBN 1-58053-482-1.

[5] Jaya, k. J. (2010). MIMO-OFDM for 4G Wireless Systems. *International Journal of Engineering Science and Technology* 2(7): 2886-2889.

[6] Nyirongo, N., Malik, W. Q. and Edwards, D. J. (2006). Concatenated RS-Convolutional Codes for Ultrawideband Multiband-OFDM. *IEEE International Conference on Ultra-Wideband*, pp. 137-142

[7] Lin, L., Cimini, L. J. and Chuang, J. C. (2000). Comparison of Convolutional and Turbo Codes for OFDM with Antenna Diversity in High-Bit-Rate Wireless Applications. *IEEE Communication Letters* 4 (9): 277-279.

[8] Meerbergen, G. V., Moonen M. and Man H. D. (2006). Reed-Solomon Codes implementing a Coded OFDM scheme for Rayleigh fading channels. *Global Telecommunications Conference ,GLOBECOM '06. IEEE*, pp. 1-6.

[9] Li, Y. G., Winters, J. H. and Sollenberger, N. R. (2002). MIMO-OFDM for Wireless Communications: Signal Detection With Enhanced Channel Estimation. *IEEE Transactions on Communications* 50(9): 1471 -1477.

[10] Hwang, W. and Kim, K. (1998). Performance Analysis of OFDM on the Shadowed Multipath Channels. *IEEE Transactions on Consumer Electronics* 44(4): 1323-1328.

[11] Ke, Z., Yang, L., Wei, Z. and Heejong, S. (2008). The Study of Multi-user Diversity technology over the MIMO-OFDM System. *Wireless Communications, Networking and Mobile Computing,* 4th International Conference, pp. 1-4.

[12] Bourdoux, A., Horlin, F., Estraviz, E. L. and Perre, L. V. (2006). Practical Channel Estimation for OFDM in time-varying channels. *Global Telecommunications Conference, 2006. GLOBECOM '06. IEEE*, pp. 1-5.

[13] Tran , X. N. and Fujino, T. (2005). Groupwise Successive ICI Cancellation for OFDM Systems in Time-Varying Channels. *IEEE International Symposium on Signal Processing and Information Technology,* pp. 489-494.

[14] Tang, Z., Cannizzaro, R. C., Leus, G. and Banelli, P. (2007). Pilot-Assisted Time-Varying Channel Estimation for OFDM Systems. *IEEE Transactions on Signal Processing* 55(5): 2226-2238.

[15] Kim, Y. H., Song, I., Kim, H. G., Chang, T. and Kim, H. M. (1999). Performance Analysis of a Coded OFDM System in Time-Varying Multipath Rayleigh Fading Channels. *IEEE Transactions on Vehicular Technology* 48(5): 1610-1615.

[16] Chang, M. X. and Su, Y. T. (2002). Performance Analysis of Equalized OFDM Systems in Rayleigh Fading. *IEEE Transactions on Wireless Communications* 1(4): 721-732.

[17] Floch, B. L., Alard, M. and Berrou, C. (1995). Coded Orthogonal Frequency Division Multiplex. *Proceedings of the IEEE* 83(6): 982-996.

[18] Thibault, L. and Le, M. T. (1997). Performance Evaluation of COFDM for Digital Audio Broadcasting Part I: Parametric Study. *IEEE Transactions on Broadcasting* 43(1): 64-75.

[19] Ahmed, K. M., Majumder, S. P. and Rahman, B.K.M. M. (2009). Performance Analysis of an OFDM Wireless Communication system with Convolutional coding. *Advanced Communication Technology, 2009. ICACT 2009. 11th International Conference on* 2: 1078-1083

[20] Forney, G. D. (1966). Concatenated Codes. Cambridge, MA : M. I. T. Press.

[21] Kasami, T., Takata, T., Yamashita, K., Fujiwara, T. and Lin, S.(1997). On Bit-Error Probability of a Concatenated Coding Scheme. *IEEE Transactions on Communications* 45(5): 536-543.

[22] Li, Y. and Salehi, M. (2009). An Efficient Decoding Algorithm for Concatenated RS-Convolutional Codes. *Information Sciences and Systems,. CISS 2009. 43rd Annual Conference on* , pp. 411-413.

[23] Cideciyan, R. D., Eleftheriou, E. and Rupf, M. (1997). Concatenated Reed–Solomon/Convolutional Coding for Data Transmission in CDMA-Based Cellular Systems. *IEEE Transactions on Communications* 45(10): 1291- 1302.

[24] Sato, H., Ohtsuki, T, Kashima, T. and Jarot, S. (2007). MultiBand-OFDM System with Concatenated Coding Scheme. *Vehicular Technology Conference, VTC2007-Spring. IEEE 65th,* pp. 2165-2169.

[25] Zou, G., Zhang, S., Wang, L., Wang, Y. and Li, M. (2007). MIMO-OFDM Channel Modeling and Simulation for Application in Ocean Exploring. *Wireless, Mobile and Sensor Networks, (CCWMSN07). IET Conference on*, pp. 588 – 591.

[26] Shin, Ch., Heath, R. W. and Powers, E. J. (2007). Blind Channel Estimation for MIMO-OFDM Systems. *IEEE Transactions on Vehicular Technology* 56(2): 670-685.

[27] Stuber, G. L. and Barry, J. R. (2004). Broadband MIMO-OFDM Wireless Communications. *Proceeding of The IEEE* 92(2): 271-294.

[28] Park, K. W. and Cho, Y. S.(2005). An MIMO-OFDM Technique for High-speed Mobile Channels*. IEEE Communications Letters* 9(7): 604-606.

[29] Lu, B., Yue, G. and Wang X. (2004). Performance Analysis and Design Optimization of LDPC-Coded MIMO OFDM Systems. *IEEE Transactions on Signal Processing* 52(2): 348-361.

[30] Yomo, H., Nguyen, C. H., Kyritsi, P., Nguyen, T. D., Chakraborty, S. S. and Prasad, R. (2005). PHY and MAC Performance Evaluation of IEEE 802.11a WLAN over Fading Channels. *Journal of the Institution of Electronics and Telecommunication Engineers* 51: 83-94.

[31] Bahai, A. R. S. and Saltzberg, B. R. (2002). Multi-Carrier Digital Communications Theory and Applications of OFDM. New York: Kluwer Academic Publishers. ISBN 0-306-46296-6.

[32] Abdu-Ragheff, M. A. (2007). Introduction to CDMA Wireless Communications. Academic Press: 1 edition, ISBN 978-0-75-065252-0.

[33] Sweeney, P. (2002). Error Control Coding From Theory to Practice. England: John Wiley & Sons, Ltd. ISBN 0 470 84356 X.

[34] Alard, M. and Lassalle, R. (1987). Principles of modulation and channel coding for digital broadcasting for mobile receivers. *EBU REVIEW-Technical* 224: 168-190.

[35] Bossert, M. (1999). Channel Coding for Telecommunications. New York NY: John Wiley and Sons.

[36] Chan, F. and Haccoun, D. (1997). Adaptive Viterbi Decoding of Convolutional Codes over Memoryless Channels. *IEEE Transactions on Communications* 45(11): 1389- 1400.

[37] Sklar, B. (2001). Digital Communications: Fundamentals and Applications. USA: Prentice-Hall, Second Edition, ISBN 0-13-084788-7.

[38] Masakawa, T. and Ochiai, H. (2007). Design of Reed-Solomon Codes for OFDM Systems with Clipping and Filtering. *Wireless Communications and Networking Conference. WCNC 2007. IEEE* , pp. 1361 - 1366

[39] Ling, Q. and Xing, D. Y. (2010). Study of Multi-Pulse Position Modulation System for Reed-Solomon Codes. *Optics Photonics and Energy Engineering (OPEE), 2010 International Conference on* 1: 240-242.

[40] Han, Y., Harliman, P., Kim, S. W., Kim, J. K. and Kim, Ch. (2010). A Novel Architecture for Block Interleaving Algorithm in MB-OFDM Using Mixed Radix System. *IEEE Transactions on (VLSI) Systems* 18(6): 1020-1024.

[41] Wesolowski , K. (2002). Mobile Communication Systems. First Edition: Wiley , ISBN: 978-0-471-49837-7.

[42] Free Tech Exams, Burst Error. http://www.freetechexams.com/computers-tips/computer-tips/burst-error.html

[43] Beek, J. J., Sandell, M. and Borjesson P. O. (1997). ML Estimation of Time and Frequency Offset in OFDM Systems. *IEEE transactions on signal Processing* 45(7): 1800-1805.

[44] Langton Ch. and Sklar, B. (2011). Tutorial 27 - Finding MIMO. *www.complextoreal.com*.

[45] JPL's Wireless Communication Reference Website, Wireless Channels, Propagation Mechanisms. *http://www.wirelesscommunication.nl/reference/chaptr03/fading/fading.htm*

[46] Prabhu, G. S. and Shankar, P. M. (2002). Simulation of Flat Fading Using MATLAB for Classroom Instruction. *IEEE Transactions On Education* 45(1): 19-25.

[47] Block Interleaver Design for RS codes. http://www.gaussianwaves.com/2010/10/block-interleaver-design-for-rs-codes-2/