Chapter 1

Introduction

Introduction

Wireless communication has emerged as one of the largest sectors of the telecommunication industry, evolving from a niche business in the last decade to one of the most promising areas for growth in the 21st century [1]. To appreciate the growth of the wireless sector, it is worth noting that in 1990 there were only 10 million mobile subscribers worldwide. Today there are approximately 6 billion mobile subscribers worldwide [2]. Emerging demands for ubiquitous networks, high data rate multimedia based services and high spectral efficiency are the key drives for the continued technology evolution in wireless communications. Wireless communication is inherently limited by the available spectrum and impaired by signal fading, increasing interference and multi-path propagation. Hence, to achieve capacity needs for future wireless systems without increasing the required spectrum, accomplishment of implementation of advanced communication techniques is necessary. To satisfy the demand for next generation wireless communication networks, MIMO technology is mandatory.

MIMO wireless communication system constitutes a key technology for next generation wireless communication. It employs multiple antennas at both transmitter and receiver end of communication link. MIMO has emerged as one of the most promising approaches for high bit rates, small error rates and increased channel capacity without consuming extra bandwidth or transmit power [3]. MIMO concepts have been under development for many years for both wireless and wire-line systems. One of the earliest MIMO-to-wireless communication application came in 1984 with groundbreaking developments by Jack Winters of Bell Laboratories [4]. MIMO is now being integrated into many wireless standards like 3G and 4G wireless communication systems [5], IEEE 802.11n Wireless Local Area Network (WLAN) standard [6], IEEE 802.20 mobile broadband wireless access system [7] and the 3rd Generation Partnership Project(3GPP) LTE (Long Term Evolution) of Wide-band Code Division Multiple Access (W-CDMA) [8].

The 3GPP's LTE represents a major advance in cellular technology. LTE also called as Evolved-Universal Terrestrial Radio Access (E-UTRA) represents a radical new step towards 4G mobile to cope up with the increasing throughput requirements of the future wireless cellular systems [9]. MIMO schemes are now moving into mainstream communication systems. This has led to MIMO being standardized in 3GPP Rel-6 and Rel-7 of the UTRAN specifications [10]. Support for multi-antenna transmission was an integral part of LTE from the first release. MIMO technologies have been widely used to improve downlink peak rate, cell coverage, as well as average cell throughput. To achieve this diverse set of objectives, LTE adopted various MIMO transmission schemes such as

Transmit Diversity, Spatial Multiplexing (including Open-Loop Spatial multiplexing (OLSM) and Close-loop spatial multiplexing (CLSM)) and Beamforming [11].

LTE-A physical layer is highly efficient for conveying both data and control information between an Enhanced Base Station (eNB) and Mobile User Equipment (UE). The LTE Physical layer employs advanced technologies of wireless cellular systems. These includes multiplexing schemes: Orthogonal Frequency Division Multiplexing Access (OFDMA) and Single-Carrier Frequency Division Multiple Access (SC-FDMA), MIMO antenna schemes: 2x2, 4x4 upto 8x8, Adaptive modulation and coding (AMC) schemes, duplexing schemes: Time Division Duplexing (TDD) and Frequency Division Duplexing (FDD), and bandwidth flexibility [12]. Research and development of signal processing algorithms for Long Term Evolution (LTE) requires a realistic, flexible, and standard-compliant simulation environment [13]. In the development and standardization of LTE, as well as in the implementation process of equipment manufacturers, simulations are necessary to test and optimize algorithms and procedures [14]. MATLAB based Vienna LTE-A Link Level Simulator [15], has been used in the research work for investigation and analysis of channel estimation, MIMO Gains, MIMO Transmission Techniques and feedback for LTE-A Downlink Physical Link Layer.

Recently, various MIMO wireless testbed based on DSP and FPGA have been developed to verify the theoretical performance gains and to investigate practical issues in MIMO implementation [16, 17]. These systems are realized by computationally complex algorithms, requiring new digital hardware architectures to be developed. Embedded Processors are suitable for computation of extensive applications. Software simulations provide more flexibility, but the true performance of the system can only be known by developing a hardware wireless platform and performing measurements and tests in the target environment [18, 19].

Soft Computing with its roots in Fuzzy Logic (FL), Artificial Neural Network (ANN), and Evolutionary Computation has become one of the most important research and application fields for wireless communication in the last decade. Wireless communication systems are associated with much uncertainty and imprecision due to a number of stochastic processes such as time-varying characteristics of the wireless channel caused by the mobility of transmitters, receivers, objects in the environment and mobility of users. This reality has fueled numerous applications of Soft-Computing techniques in mobile and wireless communications [20].

1.1 Evolution of Wireless Access Technologies

Evolution of wireless access technologies is about to reach its Fourth Generation (4G). Looking at past, wireless access technologies have followed different evolutionary paths aimed at unified target: performance and efficiency in high mobile environment. The First Generation (1G) has fulfilled the basic mobile voice, while the Second Generation (2G) has introduced capacity and coverage. This is followed by the Third Generation (3G), which had quest for data at higher speeds, which is further realized by the 4G [21].

Over the years mobile technology have made breakthrough in the world of telecommunication and has become an indispensable equipment for everyone. On examining the revolutionary transformations from 1G to 4G, the technology has evolved with advanced features and usage patterns. The brief history of Generation of Wireless Technology from First Generation to Fourth Generation, with their respective Data Bandwidths, Services and Features are listed in Table 1.1.

Generation	1G	2G	2.5G	3G	3.5G	4G
Start	1970-1980	1991-2000	2001-2004	2004-2005	2006-2010	2011-Now
Data Bandwidth	2 Kbps	64 Kbps	144 Kbps	2 Mbps	$>$ 2Mbps	1 Gbps
Technology	Analog Cellular	Digital Cellular CDMA	GPRS, EDGE,	CDMA 2000, UMTS, Wi-Fi	WiMax-LTE	Wi-Fi LTE
Service	Voice	Digital Voice, SMS, Packet Size Data	SMS, MMS	Integrated High Quality Audio, Video & Data	High speed Internet application	Dynamic, Information access, Wearable Devices
Switching	Circuit	Circuit, Packet	Packet	Packet	All Packet	All Packet
Core Network	PSTN	PSTN	PSTN	Packet N/W	Internet	Internet

Table 1.1: Generations of Wireless Technology

1.2 Significance of research

Emerging trends for high data rate and high spectral efficiency are key drivers for the evolving technology in wireless communication. The major technical challenges to achieve high data rate and system performance, can be overcome by incorporating the advanced technical techniques in physical layer to enable truly ubiquitous network capabilities. The research work focuses on maximizing the Throughput of LTE-A Downlink Physical Layer.

The receiver in MIMO system, requires the knowledge of Channel State Information (CSI) in order to recover the transmitted signal properly. Channel estimation in MIMO systems is an active research area and challenging task. Several channel estimation methods have already been studied by different researchers for MIMO systems [22,23]. In wireless communications, the channel variability due to multi-path fading hardens the problem of channel estimation and optimization. Channel estimation by ANN has been deployed in MIMO-OFDM system, with different Neural Network architectures [24,25] . The research work proposes ANN based MIMO Channel Estimation Technique for LTE-A Downlink Physical Layer. Comparative analysis with traditional method, Least Square (LS) has been carried out as a part of research work. ANN based MIMO Channel Estimator is further tuned using Genetic Algorithm for optimization of Neural Network Weights to give better performance.

There exist trade-off between Spatial Multiplexing and Diversity Techniques [26]. Both the gains are not possible to achieve simultaneously. Hence switching algorithms are applied to MIMO system to get advantage of both the systems [27]. The condition number is a well known indicator of the spatial selectivity of a MIMO wireless channel [28]. In MIMO context, the condition number indicates the multipath richness of the channel. Many adaptive MIMO systems [29] that have been proposed employ the condition number as a criterion for choosing appropriate MIMO Scheme. This has motivated the author to design Fuzzy Logic Decision model for MIMO mode switching based on Channel Condition Number and Receive Signal-to-noise-ratio (SNR) for Throughput optimization of LTE-A Downlink Physical Layer.

During the last years, MIMO technology has attained great attractions in the area of wireless communications. The hardware implementation of MIMO algorithms becomes a challenging task as the complexity of the MIMO system increases. The developed Throughput Optimization algorithms for LTE-A Downlink Physical Layer are implemented and real-time close-loop verification has been carried out for performance analysis. The ANN based Channel Estimation Algorithm and the FL Decision model is implemented on FPGA using FPGA-in-the-Loop (FIL) Simulation and with DSP using Processor-in-the-Loop (PIL) Mode in close loop with LTE-A Link Level Simulator.

The features and discussions of research carried out in the thesis includes:

- Performance Analysis of MIMO Techniques and MIMO Channel capacity Analysis.
- Development of Conceptual Design and basic hardware architecture for MIMO Wireless System
- Design of GUI based MIMO-WS (Multi-Input Multi-Output Wireless Simulator) for Capacity and Performance Analysis of various MIMO Techniques.
- Comparative Performance Analysis of various MIMO Transmission modes in LTE-A Down-

link Physical Layer

- Design and simulation of ANN Based MIMO Channel Estimation for LTE-Advanced Downlink Physical Layer .
- Design and development of GA algorithm for Tuning ANN Network Parameters used in MIMO Channel estimation .
- Design and development of FL Decision model for MIMO mode switching for Throughput Optimization of LTE-A Downlink Physical Layer.
- Implementation of proposed algorithms on FPGA and DSP. Comparative performance analysis of software simulation and hardware implementation results.

1.3 Thesis Organization

The thesis is organized as follows:

Chapter: 1 This chapter provides an overview and the context for the remainder of the thesis. It also introduces the Evolution of Wireless Access Technologies. It presents the significance of research work to be carried out in the thesis.

Chapter: 2 Chapter gives theoretical background of MIMO wireless communication systems. It describes various MIMO performance gains and trade offs. MIMO capacity analysis for various antenna configuration is discussed. Various MIMO transmission schemes is discussed. MIMO Wireless Simulator (MIMO-WS) GUI developed for MIMO Capacity and transmission techniques analysis is briefly described.

Chapter: 3 This chapter discusses the conceptual design of MIMO wireless system. It describes the Design methodology for MIMO system and relevant decisions. It gives an overview of software development tools for analysis of DSP and FPGA implementation. Mathworks model based design for DSP and FPGA verification is discussed. A case study for wireless communication has been developed to study the wireless control of Mobile Robots. The Wireless module and the procedural steps has been briefly described.

Chapter: 4 The chapter discusses the Downlink Physical Layer of LTE-A systems in detail. It gives an overview of MIMO Transmission modes in LTE-A. Performance evaluation of MIMO Transmission modes is evaluated using MATLAB based Vienna LTE-A Link Level Simulator. Throughput and Block Error Rate (BLER) analysis for MIMO modes is carried out and discussed.

Chapter: 5 Chapter gives an concise overview and theoretical background of soft-computing techniques such as Fuzzy Inference System (FIS), ANN and GA. Applications of soft-computing techniques in various fields of wireless communication has been reviewed. Toolboxes available for deploying soft computing techniques in MATLAB and used in research work for the design and testing of proposed techniques are described in detail.

Chapter: 6

Channel estimation technique for LTE-A Downlink Physical Layer based on ANN and ANN trained by GA has been discussed in chapter. Comparative performance analysis of the proposed techniques with traditional Least Square (LS) method has been carried out. Also, channel estimators were designed using various Neural network Architecture: Back-propagation Neural Network (BPN), Layered Recurrent Neural Network (LRN), General Regression Neural Network (GRNN) and Radial Basis Function Neural Network (RBFN). Simulation parameters and result analysis for various ANN based MIMO channel estimators are discussed.

Chapter: 7

In this chapter, a Fuzzy Logic Decision model for MIMO mode switching that maximizes the throughput of LTE-A Downlink Physical Layer is briefly described. In particular two MIMO modes are considered: Transmit Diversity and Open Loop Spatial Multiplexing in LTE-A context. The decision for selection of MIMO mode is based on the Channel Condition Number and Receive SNR. The designed FL Decision model is verified using Vienna LTE-A Link Level Simulator. The simulation parameters and results are presented in the chapter. Analysis of Channel condition number has been studied and its effect on throughput and switching point for MIMO has been investigated in detail.

Chapter: 8 The chapter describes the implementation of the proposed algorithms described in Chapter 6 and 7, on embedded platforms using Software tools like Code Composer Studio (CCS) and Xilinx Development Suite. Real time Implementation of developed algorithms on FPGA using FIL Simulation and on DSP using PIL Mode is discussed in detail. Comparative performance analysis of MATLAB simulations, FPGA and DSP results is presented.

Chapter: 9 Conclusion and further developments has been elaborated in this chapter.

Chapter: 10 Thesis ends with Bibliography which includes the list of references used in each chapter.