CHAPTER 2

LITERATURE REVIEW

The motivation to undertake research work on Direct Sequence Code Division Multiple Access (DS-CDMA) communication systems is based on advantages that DS-CDMA has inherent property of better noise immunity, common pool of shared radio channels available to all users, wide bandwidth, higher system capacity, and improved service quality, higher level of privacy, increased security and higher throughput. The 3G & 4G mobile system is evolving fast and will provide much higher data rates as in Clarke & de Lamare (2011). It is based on integration of existing wireless communication systems with increased frequency range and decreased cell radius of base station. The 3G & 4G communication will need specifically designed and miniaturized patch antenna to meet bandwidth needs and power ratings as explained by Hamad Ameen & Widad Binti Ismail (2011).

This research work is focused on an antenna element design for uplink, downlink and dual band for future 4G communications standards for DS-CDMA. The antennas, specifically strips or patches types, are very important element and are critical for high speed data rates. There are not many thoughtful designs of antenna dedicated to DS-CDMA. The direct sequence code division multiple accesses (DS-CDMA) based mobile communication system has been optimized for various performance parameters. Intelligent and smart antenna systems were developed with adaptive properties and use of digital signal processing. This has led to the higher directional gain and efficiency. Analysis includes users at different
power level at different direction of arrival. We have implemented DS-CDMA system using adaptive linear (ADALINE) neural networks to improve efficiency. Here, our focus is on reducing BER and improving MAI cancellation. We observed that channel efficiency is improved considerably. The throughput has been improved by numerous approaches by forming smart beams for mobile applications at high speed. This may be attributed to the constraints of system dependency and frequency limitations. Adaptive techniques are far superior to many other techniques for variable conditions. Minimal trellis module based on convolutional codes has been observed with an efficiency improvement in the OFDM-CDMA based mobile radio communications. The research indicates an improved system capacity. A novel way of software based design implemented on FPGA for CDMA mobile communications system has observed higher speed with low complexity involved. It also indicated for better channel utilization. The problem definition for the above mentioned motivation is outlined as follows:

2.1 OUTLINE OF PROBLEM DEFINITION

The advantages mentioned above may be further enhanced, if it is implemented meticulously on hardware which supports critical parameters such as low area on chip, parallel processing, easy to implement, low cost, low power consumption and fast enough to support high speed communications. In general DS-CDMA allows a number of transmitters to transmit simultaneously on the same channel, resulting in sharing of bandwidth or multiple accesses by many users. Each user of the system gets interference from many other users attempting multiple accesses. This is called Multiple Access Interference (MAI). CDMA system capacity is limited by the amount of MAI presence. MAI presence also degrades many other parameters of DS-CDMA communications. It is, therefore, very critical to reduce or suppress the amount of MAI to a minimum possible level as found
CDMA based mobile radio communications is fast emerging mobile service in recent times. One of the challenges in Orthogonal Frequency Division Multiplexing (OFDM) based DS-CDMA is channel coding for easy detection and correction of errors and same time keeping Bit Error Rate (BER) at lower levels. Intelligent and efficient coding can also protect data while in transmission through channel.

The third and fourth generation (3G and 4G) communications require increased bandwidth as the quantum of data transfer is huge and is ever increasing furthermore. Thus, there is a need for an antennae system of higher efficiency to facilitate data transfer at high speed. The challenge is to design and characterize compact and light weight patch antennae for uplink, down link and dual band for DS-CDMA wireless communications, in Fakoukkakis et al (2006). The antennae design further requires producing a highly directional beam to maximize the power transfer in ultra high frequency range. In brief, the problem consists of finding solutions or improving of above mentioned parameters of DS-CDMA communication system and subsequently optimization of the same.

2.2 METHODOLOGY STEPS FOR RESEARCH WORK

The methodologies adopted for design, implementation, characterization and analyses of DS-CDMA communication system are explained in the following steps.

2.2.1 Design of DS-CDMA and Implement on FPGA

A 60 bit input word based DS-CDMA communication system is implemented on Field Programmable Gate Array (FPGA). The simulation programs are written in Very High Speed Integrated Circuits Hardware Description Language (VHDL) the same are simulated on ISE® Series 11
software from XILINX. A 15 bit chip rate Pseudo Noise (PN) sequence is generated based on the principles of minimal polynomial mathematical model. The Quadrature Phase Shift Keying (QPSK) modulation technique is implemented on MATLAB® 5. Random input data are used for testing the performance of the DS-CDMA communication system. Performance parameters of FPGA utilization and fan out etc. are analyzed for further validating suitability of the design (www.origin.xilinx.com).

2.2.2 Novel Techniques for MAI Suppression

The system designed above is optimized for MAI suppression based on successive interference cancellation using Adaptive Linear Neuron (ADALINE) algorithm. The architecture for successive interference and ADALINE algorithm are designed and optimized by carrying out simulation tests on MATLAB® 5 platforms with C++ programming. A model of 90 users simultaneously accessing the communication over DS-CDMA channel is tested for Bit Error Rate (BER) analysis. The simulation tests are also carried out to test optimality of the design using mathematical modeling for error theory at 40% of users’ interference cancellation level and 6 dB of signal to noise ratio.

2.2.3 Channel Coding

Channel coding is performed using low complexity generalized punctured convolutional codes and the system is tested by simulating it for mobile radio communication application. Mathematical model based on minimal generator polynomial. A minimal trellis module is designed trellis complexity is determined. The channel coding is validated based on BER performance of the Nan Chang & Jyun-Ming Lin (2011), (http://english.turkcebilgi.com/Convolutional+code).
2.3 SMART PATCH ANTENNA DESIGN FOR 3G AND 4G SYSTEMS

Patch antennae for uplink, downlink and dual link communications are designed, characterized and analyzed for performance analyses on Advanced Design Systems (ADS) software. A physical design is laid down with material selection for substrate and patch. The dimensions of patch features are optimized by trial methods in conformity with physical principles and mathematical models to achieve required bandwidth, return loss, efficiency and directivity in Garg et al (2001). Simulations on ADS are carried out to validate design for chosen frequency range. Performance evaluation is done to validate and critically examine the designed patch antenna for DS-CDMA communications (http://www.antenna-theory.com/phpbb2/viewtopic).

The research work is concentrated on the design as well as systems development in wireless mobile communication that requires low cost, nominal weight and antennas that are capable of high performance in addition to a wide band of spectrum frequencies. The each step of the design procedure - graphic capture, layout, time-domain, frequency-domain circuit simulation, and electromagnetic field simulation, characterize and optimize a design exclusively for DS-CDMA is very important. Therefore, technique based on ADS software is used to design a Micro strip Patch Antenna with better gain and bandwidth. Advanced Design System (ADS) give freedom to design a patch antenna for wireless radio communication. The length of the antenna is virtually half the wavelength in the dielectric, a very significant limit, which rules the resonant frequency of the antenna. In an observation of design, choice of the patch width and length are the most important parameters. The patch antenna design was simulated on ADS simulator program.
The Figure 2.1 shows schematic for sequential steps for methods adopted to accomplish research work. It also shows various components of methods and steps for design of the DS-CDMA system.

![Figure 2.1 Architecture of DS-CDMA communication transceiver system for the research work](image)

**2.4 RESEARCH CHALLENGES IN DS-CDMA**

- The research work reported here is a comprehensive report about designing, characterizing and evaluating DS-CDMA communication systems especially for wireless mobile applications.
• The design is optimized and implemented on FPGA for efficient area and gate count utilization. DS-CDMA communication system has interference problems inherently present.

• Different types of adaptive techniques are applied to suppress the MAI.

• Channel coding is performed keeping in mind the security of data while transmitting. BER error analyses are evaluated in detail to conclude the validation of the design.

• LMS algorithm and Filtered X-LMS algorithm has performed well for adaptation to varying channel conditions. Finally different patch antenna and arrays of antenna are tested for the DS-CDMA communication system.

• The design characterization and performance analysis of antennae systems for uplink, down link and dual band applications have performed well on simulation tests performed.

• The system is expected to be suitable for recently developing technologies such as 3G and 4G mobile applications.

2.5 REVIEW OF LITERATURE

The proposed system has inherent property of better noise immunity and other advantages. The signal processing for communication systems is performed in modern times almost entirely in digital domain which requires high throughput. One such example is CDMA communication system. It requires an efficient design and testing of its subsystems of PN-sequence generator, spectrum spreading and de-spreading digital circuits and digital modulator and demodulator modules which give high throughput. Keeping high processing speed is another big challenge for developing such a
system. Such a design of multistage detector and low complexity multistage detectors is particularly useful as found in Cottatellucci et al (2010). Simpler and dedicated hardware circuits can only provide the high speed processing capability to meet these contrasting requirements, in Do & Feher (1996).

The parallel processing capability of FPGA based Programmable Logic Devices (PLDs) makes them ideally suitable for baseband / Radio Frequency (RF) digital signal processing in CDMA applications in Boukadourn et al (2005). The choice of CDMA is based on the fact that allocating channel resources using spread spectrum techniques have number of advantages compared to Frequency Division Multiple Access (FDMA) or Time Division Multiple Access (TDMA) schemes in Clarke & de Lamare (2011).

By spreading the spectrum of the data to be transmitted with orthogonal codes, the receiver can decode each user’s data uniquely, even though many users share the same spectral and temporal channel resources in Vishwas Sundaramurthy & Joseph Cavallaro (1999). The problem is, therefore, to design hardware based CDMA communication system which works on the principles of direct sequence spread spectrum technology. The design must be easy to use, better in performance and highly efficient. The high speed and simplicity of circuits are always desirable in digital systems in Uuanbin Guo et al (2004). This makes them suitable for low power applications and has simpler and smaller circuit size. The design solution should also provide high throughput and high speed data transfer which can be directly used for providing quality of service to cellular mobile communication in Correal et al (1999).

A design modeled by using VHDL and FPGA often has both speed and area advantages over a functionally equivalent software based designs that does not use actual hardware for experiments and tests. It, therefore, is
very important to further implement on FPGA during research period of such
designs for above mentioned digital systems and circuits in Tomaso Erseghe
& Antonio Maria Cipriano (2011). Also, the same design may be
implemented for low power applications with different approach but same
concept through scalable technology for Ultra Wide Band (UWB). Different
types of cellular systems employ various schemes to achieve this multiple
access. The traditional analog cellular systems use Frequency Division
Multiple Access (FDMA) and Time Division Multiple Access (TDMA).
TDMA and FDMA systems divides each carrier into time slots and frequency
slots (channels) and then only one subscriber at a time is assigned to each
time slot or channel respectively in Rappaport (2010).

The CDMA, therefore, increases the level of privacy and security.
Spreading is the key to increasing the security level in communication
systems, as the code of information can be spread over the entire carrier,
which is very hard to detect or intercept in Min Shi D’Amours & Yongacoglu
(2010). CDMA system, like any other real time system, has limitations as
well. These may include that there is a need for very efficient power control
to ensure uniform signal strength at the receiving antenna. Failure to this may
result in one user swamping all others. Channel pollution may occur when
equally dominant signals from many base stations are present at receiving
antenna in Magaa et al (2007). The digital data is first spread by means of PN
sequence and then modulated using digital modulation schemes such as
Quadrature Phase Shift Keying (QPSK) and RF carrier signal. The signal is
then transmitted through channel where it may have noise attenuation and
other distortions. A distorted signal is then received at receiver. At receiver
the signal is first demodulated and then de-spread by using PN codes. Finally
original and undistorted signal is reconstructed and received. QPSK has a
scheme of self cancellation of inter-carrier-interference, which makes it very
robust against noise related distortion in the channel in Alaka Barik & Asutosh Kar (2011).

The original bandwidth has to be expanded by a factor of about 1.9246 to compensate for the reduction in the channel SNR. It can be noted that increasing the transmission bandwidth will increase the amount of the input noise power in a wideband receiver. This is normally countered by using a narrowband receiver to limit input noise. The spread-spectrum idea has been developed from the principle of Shannon’s theorem. The data is transmitted at higher rate over a channel occupying a bandwidth of much greater length. In the receiver, the received signal is multiplied again by the same (synchronized) PN code. This operation completely removes the code from the signal and the original data-signal is recovered. This implies that the de-spread operation is the same as the spread operation. Space Time Block Codes (ST-BC) have also been used for DS-CDMA system for producing hybrid sequence in Shiunn-Jang Chern & Ming-Kai Cheng (2010). These schemes are used for user verification and signature purposes. Frequency Hoping CDMA systems are good for band jamming purposes in Haichang Sui & Zeidler (2007).

The fundamental issues of MAI is based on the fact that in CDMA communication system a number of users use same frequency and bandwidth separated at receiver only due to presence of different spreading codes in Hassan Moradi et al (2006). This implies that in CDMA, a number of transmitters are allowed to transmit simultaneously on the same channel, resulting in sharing of bandwidth by many users. This is called multiple accesses. CDMA system of communication operates just fine under ideal conditions of orthogonal and synchronised codes of all users. It, however, suffers under real time non-ideal conditions which are presence during most of the practical implementation and subsequently while the system being in
operation. Due to non-ideal orthogonality and difficulty in maintaining synchronization at receiver, each user of the system gets interference from many other users attempting multiple accesses. Channel delays and frequency offset also add the interference amount. The amount of interference may vary from an insignificant level at times to very serious levels affecting the quality of the received communications adversely in Ojanpera & Prasad (1998). The interference due to multiple accesses is called MAI. It causes undesirable effects and may be grossly intolerable in asynchronous communications which normally prevails in reverse link. The mobile node located close to the base station can cause lot of interference to the mobile nodes located at a distance resulting in path loss. A large number of mobile nodes may get blocked if the power level of near mobile nodes is not managed properly. This problem is well known as near-far effect. A well designed power controlling strategy is required to equalize power level of the received signal at various mobile nodes in Hassan Moradi et al (2006). The CDMA communication system capacity is primarily limited by the amount of the MAI presence in Guo et al (2004). The CDMA, however, has higher capacity in comparison to other systems, since it reuses frequency and has variable rates of transmission. Its practical and real time implementation capacity achieved is much lower than the maximum theoretical achievable capacity in Andrews & Meng (2004). Communication industry still lags in employing more efficient multiuser detection receivers to increase the capacity. Multiuser detection receivers are normally more complex and lack robustness. To overcome these issues, a good amount of research has been reported by various literatures on interference cancellation and adaptive filtering techniques. The first method for interference cancellation reported in literature is based on the use of smart antenna system which is built with capability of digital signal processing. Basically, many artificial intelligence based algorithms are used to convert traditional antenna into smart antenna system, such as array antenna, beam forming antenna etc. The smart antenna system directs and controls radiation
power towards only desired users and thus minimizes undesirable interference to other users. This paper has only scope of improved technique for successive interference cancellation based on smart algorithm with a goal of overall increasing the efficiency of CDMA communication system.

Fundamentally there can be two standard groups of techniques, called serial and parallel techniques, which are used quite often for reducing interference levels in CDMA. The serial scheme reduces interference in successive steps. It is considered as a better option for reducing interference due to its compatibility with existing industrial systems, good capability of accommodating error correcting codes and its robustness with asynchronous communication types in Andrews & Meng (2004). The successive interference cancellation (SIC) technique is very powerful method to reduce interference to such an extent that spectral efficiency of a channel can reach to Shannon capacity under ideal conditions in Viterbi (1990). There are few drawbacks in SIC that needs attention to address research in this regard. It needs that signal strength of each user be estimated. If the estimation of signal is not accurate, subsequent users will be decoded wrongly. SIC takes more time compared to parallel scheme. User power control strategy and power management is very rigorous and must be precisely done. Multipath propagation poses another big challenge to SIC as all such components must be cancelled out in Andrews & Meng (2003). An improved technique for dealing with MAI uses Gaussian mixture model and maximum likelihood algorithm based receiver at an optimum computational cost in Erseghe & Tomasin (2009). Gaussian mixture model provides systematic analysis very accurately and yet free from complexities in Mitra & Lampe (2008). Gaussian mixture model is considered as more suitable for ultra wide band interference reduction. The model has been used recently for many applications including frequency offset estimation and MAI in time-hopping ultra wide band communications in Tomaso Erseghe & Antonio Maria Cipriano (2011).
Successive cancellation scheme uses technique of cancelling interference by successively subtracting the interference from the received signals. The signal with highest power $P$ may be detected and is removed from the received signal $s(t)$ so that a relatively weaker signal can be detected more accurately in Mosa Ali Abu-Rghelff (2007).

M-ary Frequency Shift Keying (M-FSK), can reduce bandwidth efficiency as the number of the transmitted symbols, $M$, increases. But, on the other hand, if the transmitted signals, $M$, are all mutually orthogonal, the power efficiency of M-FSK increases as there is hardly any buffered signal in queue. M-FSK has also no adverse effects on performance even if amplified by nonlinear amplifiers. The orthogonal property of M-FSK is used by OFDM to provide power efficient transmission for communication schemes like CDMA in Rappaport (2010). OFDM is a multicarrier modulation scheme in which a base station divides high bit rate data chunk into many low bit rate data chunks or streams and then modulates each of these streams on separate subcarriers. The subcarriers are chosen in such a way that they are orthogonal to each other. OFDM modulation is used for high speed data rate transmissions for all sight microwave channels. It has high bandwidth efficiency and combats better with multipath fading problem. Bandwidth efficiency is based on the fact that OFDM communication system effectively utilizes available spectra by allowing subcarriers of minimum power in Stirling-Gallacher & Povey (1997). In the presence of multipath conditions, OFDM has quite a low bit error rate in Stefan Kaiser & Lutz Papke (1996). The two types of interferences, inter symbol and inter carrier are kept under control by inserting a guard interval between adjacent symbols. The guard ring should be greater than multipath spread in Stefan Kaiser & Lutz Papke (1996). The problem of deep fade can be kept under control by using OFDM along with Direct Sequence CDMA (DS-CDMA) to provide multiple accesses for users transmitting on the same subcarriers having orthogonal
spreading codes. There are quite a number of factors that are critical for the OFDM transmitter design. These may be guard ring, subcarrier spacing, symbol duration and type of subcarrier. One has to consider parameter choices based on available bandwidth and bit rate requirements.

One of the most critical components for the design of OFDM-DS-CDMA transmitter system is channel coding. The channel coding is performed for the easy detections and subsequently correction of errors which may have corrupted data communication during transmission over a given channel. The channel codes are also used for protecting data while transmitting between processing point in the computational system and storage devices. There are basically two methods for channel coding, block coding and convolutional coding. The latter is mainly used in many applications due to its advantages of real time and online error correcting capability which achieves reliable data transfer. These codes are performed by hardware design using \( m \) shift registers. Each of the shift register has capacity to store one bit digital information. Binary data bits enter from one end of the shift register and output sequence is generated by using special class of generator polynomials in Band & Cruickshank (1996). The output sequence has \( n \) bits which consist of \( k \) input bits and additional bits generated by generator polynomial. The output sequence also depends on past input bits apart from the current input bit. If the input bits also form a direct part of output sequence then the codes are called recursive or systematic codes. There are many types of popular convolutional codes in use but one particular class of convolutional codes called punctured convolutional codes is a very important class in Uchoa-Filho et al (2006). The general notation of a given convolutional codes may be represented by \((n, k, m)\) where symbols are as defined earlier. The term \( k/n \) is called code rate. The code is a measure of code efficiency in Katsiotis et al 2010. We have simulated results for the range of values of \( n \) from 3 to 8, \( k \) from 2 to 7 and \( m \) from 3 to 8. The
The constraint length of the convolutional codes is given by \( L = k (m-1) \). The complexity of a Viterbi decoder increases with the increasing code rate in Katsiotis et al 2009. Puncturing normally uses standard code rate of \( 1/2 \) to expand it for higher code rates for encoding and decoding. The trellis complexity for convolutional codes is higher than that of punctured convolutional codes in Uchoa Filho et al (2005). This makes an easier choice for punctured convolutional codes for reasons of reduced complexity in Bhaskar & Joiner (2005). There is one shortcoming on punctured convolutional codes that those suffer from distance spectra. The punctured convolutional codes may have trellis representations which have much less complexity than the conventional trellis. This indicates that conventional trellis may not have minimal trellis representation in McEliece & Wei Lin (1996).

The 4G mobile system is developing quickly and will give a superior data rates. It is supported on integration of presented wireless communication systems among improved frequency range and reduces cell radius of base station in Kundu et al (2008). The direct sequence code division multiple accesses (DS-CDMA) based mobile communication system has been optimized for different performance parameters. The optimization performances incorporate with software as well as hardware implementations. Quite often intelligent circuits are developed to maximize the efficiency of antenna systems. Intelligent and smart antenna systems were employed with adaptive properties. This results in higher directional gain and efficiency in Kundu et al (2008). The 4G communication will require superior and deliberate design to achieve its goals. The miniaturized patch antenna can give desired bandwidth and power ratings in Fakoukakis et al (2006). Analysis is done to considered users at different power levels at various direction of arrival of the signal. DS-CDMA system was implemented using adaptive linear (ADALINE) neural networks to get better efficiency in Amsavalli & Kashwan (2012). Here, the research work was concentrated on
reducing BER and improving MAI cancelation. The throughput has been enhanced through several approaches by forming smart beam designs for mobile application at higher speed in Mouhamadou et al (2006) & Sanyal et al (2006). Directional array gain was enhanced through signal processing system by means of supplementary benefit of concentrated interference in the identical direction in Sanyal et al (2006). This can eventually be accomplished as a better system capacity and elevated throughput. The different research results indicate that DS-CDMA communication system has undergone newer developments due to incorporation of intelligent system into it. Numerous algorithms have been utilized to create an additional robust and flexible system in Koo et al (2007). The coding techniques and error control design have also been implemented on mobile communication to improve system performance in Kashwan & Amsavalli Arumugam (2012). Algorithms have merits and demerit for special situations and applications. This may be attributed to the restrictions of system dependence and occurrence limitations. The operating circumstances and ambience also play very important role on design to produce final results. The hardware implementation of design may include other rewards compared to what algorithm and software based systems have. If smart methods are included all along by hardware design, the system becomes highly precise and gives improved efficiency. Adaptive techniques are far better to several other techniques for different variable conditions in Elias Yaacoub et al (2009). The different variable conditions are hard to forecast and can have high uncertainty. This may have an effect on the efficiency of the system. The SNR with improved throughput and less interference is reported by Elias Yaacoub et al (2009). Minimal trellis module depends on convolutional codes that has improved efficiency in the OFDM-CDMA based mobile radio communications. The authors used BER as a major factor to determine the system performance in Kashwan et al (2011) and reported a 10% decrease in BER in Kashwan and Amsavalli Arumugam (2012). The position and nature of feeding techniques also plays role in
general on overall efficiency of the mobile communication system in Kashwan et al (2011). The most of the research results have demonstrated enhanced system capacity. A novel technique of hardware based design implemented on FPGA for CDMA mobile communications system has higher speed with low complexity involved. It also improved channel utilization in Amsavalli & Kashwan (2012).

We have chosen a Filtered-XLMS (F-XLMS) algorithm, where X represents reference signal, for antenna array. F-XLMS is very effective for controlling dynamic signals and circuit outputs, especially filter circuits. It used fundamental principle of LMS with an introduction of a dynamic unit between filtered output and reference signal in Tang & Lee (2012). The purpose of this modification is to update adaptive coefficients in such a way that reference signal is adaptively changed to improve the filter response in presence of dynamic noise in Tahir Akhtar & Wataru Mitsuhashi (2009). FXLMS is very stable for a phase shift in range of $\pm \frac{\pi}{2}$. The other major advantage of using F-XLMS is that it can be applied for multiple input multiple output (MIMO) systems. Originally, XLMS was very slow in convergence properties but with many improved structures, such as transform-domain based LMS, were proposed to overcome the slow convergence speed in Kuo & Morgan (1999).

2.6 SUMMARY

This chapter has described the fundamental idea for the complete design methodology of experimental work and result analyses. The design and testing of smart patch antenna and its applications are explained briefly.

The brief explanations of the forthcoming chapters of research work and a comprehensive details about the FPGA based transceiver for DS-CDMA mobile communication, Successive Interference Cancellation, channel
coding, design of smart patch antenna along with reduction in Bit Error Rate are presented. The interference suppression is also discussed in detail to understand the fundamental issues of DS-CDMA communication systems for mobile applications.