MIMO-Future Wireless Communication

Pravin W. Raut, S.L. Badjate

Abstract*-*The exceptional growth of the telecommunication industry in recent years fueled by the widespread popularity of mobile phones and wireless computer networking. The demand of wireless communication is constantly growing and need the tether less connectivity. The major limitations to this growth is the disadvantages of traditional wireless communication System due to the limitations of available frequency resources, Bandwidth, channel capacity, complexity, reliability, transmission data rate and physical areas.

This paper addresses the overview of new technology Multi-Input-Multi-Output (MIMO)-the Future Wireless system will be much more efficient to meet the heavy demand of Wireless communication in available limited frequency resources.

MIMO channel is frequency selective (multipath) and is known to boost channel capacity for high-data rate transmissions, low power implementation, sophisticated signal processing algorithm. The FPGA based coding techniques will reduce the size, complexity and increase the reliability of connectivity.

Keywords – MIMO, FPGA, Transmitter, Receiver, OFDM. Antenna, Channel estimation.

I. INTRODUCTION

The wireless system designers are faced numerous challenges to fulfill the demand of the wireless communication for higher data rates, better quality service, fewer dropped calls , higher network capacity including limited availability of radio frequency spectrum and transmission problems caused by various factors like fading and multipath distortion. These needs requires new techniques that improve spectral efficiency and operational reliability. Multi-Input-Multi-Output (MIMO) technology promises a cost effective way to provide these capabilities.

MIMO uses multiple antennas at both the transmitter and receiver to improve the communication performance. It is one of the several forms of smart antenna technology. MIMO technology has attracted attention in wireless communications, because it offers significant increases in data throughput and link range without additional bandwidth or transmit power. It achieves this by higher spectral efficiency (more bits per second per hertz of bandwidth) and link reliability or diversity (reduced fading). Because of these properties, MIMO is a current

theme of international wireless research.

The increasing demand for capacity in wireless systems has motivated considerable research aimed at achieving higher throughput on a given bandwidth. One important recent discovery shows that in a multipath environment, the use of space-time coding with multiple antennas on both ends of the link can increase the capacity of the wireless channel.

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MIMO algorithms sends data over multiple paths, thereby increasing the amount of information the system carries and the data is received by multiple antennas and recombined properly by other algorithms to recover the data at the receiver. MIMO is an underlying technique for carrying data. It operates at the physical layer, below the protocols used to carry the data, so its channels can work with virtually any wireless transmission protocol. For example, MIMO can be used with the popular IEEE 802.11 (Wi-Fi) technology. For these reasons, MIMO eventually will become the standard for carrying almost all wireless traffic. MIMO the only economical way to increase bandwidth, range and will become a core technology in wireless systems. Assessing the performance of these algorithms requires detailed understanding of multiple-input multiple-output (MIMO) channels as well as models that capture their complex spatial behavior.

II. COMMUNICATION MODEL

There are four types of Communication models or multiple antenna systems – SISO, SIMO, MISO and MIMO.

SISO:

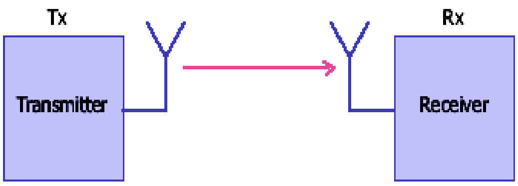

Fig.1- Single Input Single Output (SISO)

The existing technology is Single Input Single Output (SISO). This has one antenna at both the transmitter and the receiver employs no diversity technique. Both the transmitter and the receiver have one RF chain (that's coder and modulator). SISO is relatively simple and cheap to implement and it has been used age long since the birth of radio technology. It is used in radio and TV broadcast and our personal wireless technologies (e.g. Wi-Fi and Bluetooth).

SIMO :

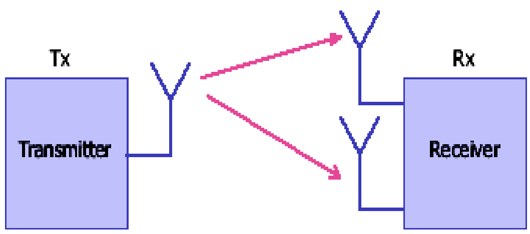

Fig.2- Single Input Multi Output

One antenna at the transmitter, two antennas at the receiver employs a receive diversity technique. To improve performance, a multiple antenna technique has been developed.

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A system which uses a single antenna at the transmitter and multiple antennas at the receiver is named as Single Input Multiple Output (SIMO).

The receiver can either choose the best antenna to receive a stronger signal or combine signals from all antennas in such a way that maximizes SNR (Signal to Noise Ratio). The first technique is known as switched diversity or selection diversity. The latter is known as maximal ratio combining (MRC).

MISO :

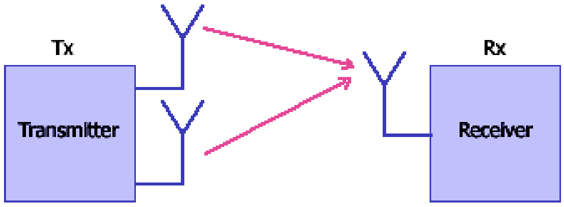

Fig.3- Multi Input Single Output (MISO)

Two antennas at the transmitter, one antenna at the receiver employs a transmit diversity technique. A system which uses multiple antennas at the transmitter and a single antenna at the receiver is named Multiple Input Single Output (MISO). A technique known as Alamouti STC (Space Time Coding) is employed at the transmitter with two antennas. STC allows the transmitter to transmit signals (information) both in time and space, meaning the information is transmitted by two antennas at two different times consecutively. Multiple antennas (each with an RF chain) of either SIMO or MISO are usually placed at a base station (BS). This way,the cost of providing either a receive diversity (in SIMO) or transmit diversity (in MISO) can be shared by all subscriber stations (SSs) served by the BS.

MIMO :

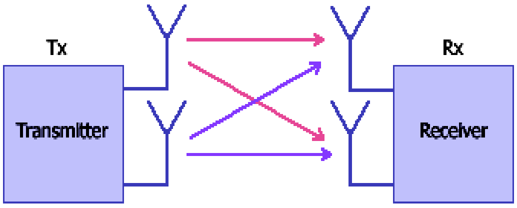

Fig.4- Multi Input Multi Output (MIMO)- size2x2

To multiply throughput of a radio link, multiple antennas (and multiple RF chains accordingly) are put at both the transmitter and the receiver. This system is referred to as Multiple Input Multiple Output (MIMO). A MIMO system with similar count of antennas at both the transmitter and the receiver in a point-to-point (PTP) link is able to multiply the system throughput linearly with every additional antenna. For example, a 2x2 MIMO will double the throughput. Two antennas at both the transmitter and the receiver side uses transmit and receive diversity.

III. HISTORY OF MIMO

Before 1990s, antenna arrays were used to provide diversity and/or direct the signal reception to mitigate co-channel interference. This motivated the development of techniques: **Beamforming (**Focus electromagnetic energy in desired directions) and **Spatial diversity (**Combination of signals in an antenna array equipped with low correlation elements).

MIMO was originally conceived in the early 1970s by Bell Labs engineers trying to address the bandwidth limitations that signal interference caused in large, high-capacity cables. At the time, however, the processing power necessary to handle MIMO signals was too expensive to be practical. The earliest ideas in this field go back to work by A.R. Kaye and D.A. George (1970), Branderburg and Wyner (1974) and W. van Etten (1975, 1976). Jack Winters and Jack Salz at Bell Laboratories published several papers on beamforming related applications in 1984 and 1986.

In 1993, Arogyaswami Paulraj and Thomas Kailath proposed the concept of spatial multiplexing (SM) using MIMO to emphasized applications to wireless broadcast systems.In 1996, Greg Raleigh and Gerard J. Foschini refined new approaches to MIMO technology, considering a configuration where multiple transmit antennas are co-located at one transmitter to improve the link throughput effectively.

Bell Labs was the first to demonstrate a laboratory prototype of spatial multiplexing in 1998, where spatial multiplexing is a principal technology to improve the performance of MIMO communication systems.

One year later, in 1999, Gigabit Wireless Inc. and Stanford University successfully held the first outdoor prototype demonstration. And Iospan Wireless Inc. (formerly Gigabit Wireless Inc., acquired by Intel) produced the first commercial product in 2002. As one of the first, a 4x4 MIMO academic test-bed started operation at University of Alberta in 2003.

Advances to and cost reductions in signal-processing technology, coupled with increased demands to overcome the limits of existing mobile communications approaches, have since led researchers to reconsider MIMO for wireless systems.

IV. WIRELESS STANDARDS

In 2001, lospan wireless Inc. developed first commercial system that used MIMO with orthogonal frequency division multiple access technology (MIMO-OFDMA) based on both diversity coding and spatial multiplexing. The first wireless LAN standard based on MIMO-OFDM an IEEE 802.11n is developed by Airgo Networks In 2005 to give a significant performance increase in both range and rate relative to conventional wireless LAN. Performance results show that net user throughputs over 100 Mbps are achievable, which is about four times larger than the maximum achievable throughput using IEEE 802.11a/g. For the same throughput, MIMO-OFDM achieves a range that is about 3 times larger than non-MIMO systems. This significant improvement in range-rate performance makes MIMO-OFDM the ideal solution not only for wireless LAN, but also for home entertainment networks and all upcoming 4G networks systems.

V. WIRELESS GENERATIONS

1G - This was introduced in early 1980s which used for Analog Communication techniques like analog Cell Phones operating on 150 MHZ Frequency.

2G - This was introduced in late 1980s which used for Digital Communication techniques with TDM, FDM or CDMA. This was used for the transmission of Voice signal Operating on GSM 900 MHZ with GPRS 56Kbps to 114 kbps. After this 2.5G is also introduced which is a stepping stone between 2G and 3G cellular wireless technologies

3G-This introduced just recently. The UMIT - Universal Mobile Telecommunications System is one of the third-generation (3G) cell phone technologies, which is also being developed into a 4G technology. This used digital communication techniques like CDMA. Also used for the transmission of Voice signal as well as multimedia services. It is Operating on 1.8 – 2.5 GHZ with the Data Rate up to 2Mbps (384 kbps WAN)

4G- Traditional definition : Fourth-Generation Communications System (also known as Beyond 3G) is a term used to describe the next step in wireless communications. The 4G system will be able to provide a comprehensive IP solution where voice, data and streamed multimedia can be given to users on an "Anytime, Anywhere" basis, and at higher data rates than previous generations.

VI. MIMO SYSTEM

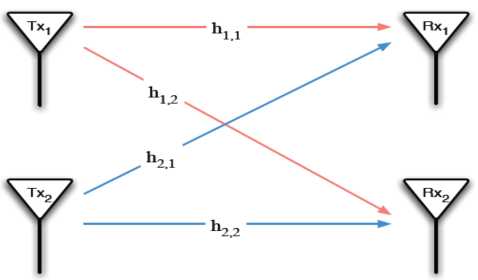

Fig.5- Communication Channel in 2x2 MIMO Systems

One possible way to improve the reliability of wireless communications is to employ diversity. Diversity is the technique of transmitting the same information across multiple channels to achieve higher reliability.

Even if one particular channel is unusable the information may still be recovered from the redundant transmission over the other channels. Therefore the overall reliability of the communications system is improved, at the cost of transmitting redundant information.

MIMO systems are able to achieve impressive improvements in reliability and capacity by exploiting the diversity offered by the multiple channels between the transmit and receive antennas. In the 2×2 system in Figure 7 there is the potential for both transmit and receive diversity. Receive diversity is when the same information is received by different antennas. For instance the information sent from Tx1 is transmitted across channels h1,1 and h1,2, and received by both Rx1 and Rx2.

Transmit diversity is when the same information is sent from multiple transmit antennas. One possible way to achieve this is to code across multiple symbols periods. For instance, at time t antenna Tx1 could transmit the symbol s then at time t+1 antenna Tx2 would transmit the same symbol s. The Alamouti scheme uses a method similar to this to obtain transmit diversity.

A: FUNCTIONS OF MIMO

MIMO can be sub-divided into three main categories, Precoding, Spatial multiplexing (SM), and Diversity coding.

Precoding- is multi-layer beam forming in a narrow sense or all spatial processing at the transmitter in a wide-sense. In (single-layer) beam forming, the same signal is emitted from each of the transmit antennas with appropriate phase (and sometimes gain) weighting such that the signal power is maximized at the receiver input. The benefits of beam forming are to increase the signal gain from constructive combining and to reduce the multipath fading effect. In the absence of scattering, beam forming results in a well defined directional pattern, but in typical cellular conventional beams are not a good analogy. When the receiver has multiple antennas, the transmit beam forming cannot simultaneously maximize the signal level at all of the receive antenna and precoding is used. Note that precoding requires knowledge of the channel state information (CSI) at the transmitter.

Spatial Multiplexing (SM) - requires MIMO antenna configuration. In spatial multiplexing, a high rate signal is split into multiple lower rate streams and each stream is transmitted from a different transmit antenna in the same frequency channel. If these signals arrive at the receiver antenna array with sufficiently different spatial signatures, the receiver can separate these streams, creating parallel channels for free. Spatial multiplexing is a very powerful technique for increasing channel capacity at higher **Signal to Noise Ratio (SNR)**. The maximum number of spatial streams is limited by the lesser in the number of antennas at the transmitter or receiver. Spatial multiplexing can be used with or without transmit channel knowledge.

Fig.6- Spatial Multiplexing

Diversity Coding-techniques are used when there is no channel knowledge at the transmitter. In diversity methods a single stream (unlike multiple streams in spatial multiplexing) is transmitted, but the signal is coded using techniques called space-time coding. The signal is emitted from each of the transmit antennas using certain principles of full or near orthogonal coding. Diversity exploits the independent fading in the multiple antenna links to enhance signal diversity. Because there is no channel knowledge, there is no beam forming or array gain from diversity coding. Spatial multiplexing can also be combined with precoding when the channel is known at the transmitter or combined with diversity coding when decoding reliability is in trade-off.

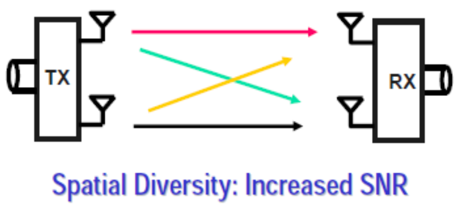

Fig.7- Spatial Diversity

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B: CHANNEL CAPACITY OF WIRELESS COMMUNICATION SYSTEMS

According to Shannon theory, the capacity of a channel for error free transmission of information is given by : C = B log2 (1 + SNR)

where B is transmission bandwidth, and SNR is the signal to noise ratio of the channel.

This equation gives the absolute maximum capacity of the channel (in bits/second). The channel capacity can be increased by increasing the bandwidth used in transmission, or to increase in SNR.

Multi-Antenna systems use a rather novel approach to increase the overall capacity of a wireless communications system by using more channels. Each of the individual transmission channels is still limited according to above Equation. However the overall capacity of the system is now the sum of the capacities of the individual channels.

C: MODELING THE WIRELESS COMMUNICATION CHANNEL

Under assumptions that the channel is “flat fading” channel, the complicated transmission environment can be mathematically represented by using complex numbers to represent the magnitude and phase change of the transmission channel. The in-phase component is the real part of the complex representation, and the quadrature component is the imaginary part.

For a SISO system this model can reduce the entire transmission environment to a single complex number. The system can then be represented using Equation (1),

$$y = h x + e \quad \text{--------------------(1)}$$

where **h** is the complex number representing the channel, **x** is the input signal, **e** is a complex number modeling the thermal noise at the receiver.

Similarly MIMO systems can be modeled with Equation (2). The variables have the same meaning as for the SISO case, however instead of the scalar complex numbers in Equation (1), the variables are matrices of complex numbers.

$$Y = HX + E \quad \text{--------------------(2)}$$

D: MIMO ADVANTAGES

The increased bandwidth lets wireless networks serve more users at a given data rate than they could without MIMO. MIMO’s higher speeds are critical for letting wireless networks handle data-intensive multimedia files. The increased bandwidth also lets wireless networks serve more users at a given data rate than they could without MIMO. And the increased range of MIMO LANs’ base stations would let large businesses serve their entire organization with fewer stations, thereby saving them money. Because the technology reduces the effects of interference and can focus on better-quality signals, MIMO networks use less radio-transmission power than other wireless networks, so there is less battery drain on portable systems and less chance of interference with or from other systems.

In addition, because MIMO sends transmissions along multiple paths, most of the signals can avoid objects and other sources of interference that cause fading and interruptions. And senders can adjust the power and phase given to antennas to steer signals toward the paths with the best transmission quality. More precise steering could minimize the interference a sender causes or receives. MIMO’s signaling properties could also help create more robust wireless security. It would be difficult for hackers to set up their receivers to properly receive all of the signals that have been broken up and sent via multiple antennas along different paths.

E: IMPLEMENTATING MIMO

MIMO is implemented via chips. MIMO has several important implementation issues. For example, users can achieve modest performance gains by implementing MIMO only at the transmitter, but enabling both transmitters and receivers to take advantage of the technology yields much greater Improvements.

In addition to typical wireless-processing cores, the chips contain ports for multiple antennas and matrix-manipulation processing elements optimized to process MIMO signals. Developers can implement MIMO in base stations or LAN cards. For a big organization, integrating MIMO into a base station is much less expensive than upgrading hundreds of LAN cards. Most of the LAN will integrate MIMO into almost all types of radio-based wireless equipment. The chips are implemented using FPGA, DSP coding techniques.

F: NEW IMPLEMENTATION APPROACHES

The Researchers are now focusing on two popular coding schemes for using MIMO to carry traffic: orthogonal frequency- division multiplexing (OFDM) and code-division multiple access (CDMA).

OFDM increases bandwidth and data capacity by splitting broad channels into multiple narrowband channels—each using a different frequency— that can then carry different parts of a message simultaneously. To maximize capacity, the channels are spaced closely together but avoid interference because neighboring channels are orthogonal to one another and thus have no overlap.

CDMA is a type of multiplexing that lets multiple signals occupy a single transmission channel, optimizing the use of available bandwidth. The system varies a transmitted signal’s frequency according to a defined pattern, known as a code, so that only a receiver whose frequency response is programmed with the same code can successfully intercept it. Thus, signals intended for multiple recipients can be coded differently and carried at the same time on the same channel.

G. MIMO-OFDM

When generated OFDM signal is transmitted through a number of antennas in order to achieve diversity or cap any gain (higher transmission rate) then it is known as MIMO-OFDM. Like any other communication systems MIMO-OFDM system also has transmitter and receiver, but it has multiple antennas -both at transmit and receive end.

MIMO system can be implemented in various ways. If we need to take the diversity as an advantage to combat fading then we need to send the same signals through various MIMO antennas and at the receiving end all the signals received by MIMO antennas will receive the same signals traveled through various path. In this case the entire received signal must pass through un-correlated channels. If we are inserted to use MIMO for capacity increase then we can send different set of data (not the same set of data like diversity MIMO) via a number of antennas and the same number of antennas will receive the signals in the receiving end. For MIMO to be efficient antenna spacing need to be done very carefully- at least half the wave length of the transmitting signal.

VII. TECHNICAL CHALLENGES

Despite its promise, MIMO still faces several challenges. Designing MIMO systems, which send signals over multiple transmission paths, is a challenge, particularly because most wireless engineers have worked only on systems designed to use one transmission path, according to Raleigh.

Progress in MIMO research poses strong scientific challenges in the areas of modeling (of mobile space-time wireless channels), information theory (coding, channel capacity and other bounds on information transfer rates), signal processing (signaling and modulation design, receiver algorithms), and finally the design of the wireless fixed or mobile networks that will incorporate those MIMO links in order to maximize their gain. More specifically, joint design of sensible multiple access solutions (CDMA, OFDMA, TDMA and variants) as well as medium access (MAC) protocol for wireless MIMO is challenging.

Also, MIMO has worked well in a laboratory environment between two fixed nodes. However, there are questions about how well it will work in a real-world environment between mobile nodes. Many of the algorithms and the performance gains assume that you know the nature of the transmission. First-generation MIMO vendors are reducing this problem by using small antenna arrays.

VIII. CONCLUSION

The MIMO design using FPGA Based with suitable Signal Processing Algorithms will improve Channel capacity, Bandwidth, High data rate transmission, Power requirement, Bit Error Rate, Size, Complexity and Reliability of connectivity in available limited frequency resources

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