Space Time Block Codes for MIMO systems

Er.Wamik Majeed[1] Er.Seema Singh[2]
[1]P.G. Student [2]Assistant Professor
[1,2]Department of Electronics & Communication Engineering
[1,2]ICL IET KUK

Abstract— Multi Input Multi Output (MIMO) system multiple antennas are put to use at the transmitter section and the receiver section. By a single radio channel, MIMO transmits and receives two or more data streams. Then the system can discharge two or more times the data rate per channel without any additional transmit power or bandwidth. The put together of multiple antennas at the transmitter mixed with the help of advanced algorithms which are based on digital signal processing and the receiver yields expressive advantage in terms of diversity and capacity. spatial multiplexing and Space-time block coding and are MIMO based techniques that provide link quality and high magnitude in the system. SM and STBC can be combined to give a transmission scheme that will give a maximum average data rate over the MIMO channel and minimize the order of diversity for each stream. The basic parameters that describe the quality of wireless link include Speed, Range and Reliability. There is always a trade-off to achieve all three qualities. But an attractive candidate in this regard is MIMO system which can increase all of the above, examine and note the similarities or differences of, to single antenna system. MIMO exploits multipath rather than moderate it. Space Time Block Code (STBC) is a special form of MIMO and originally employed for 2 transmit and 1 receive antenna by Alamouti under flat fading circumstances.

Key words: Multi Input Multi Output, Diversity, Space-time block coding, spatial multiplexing, Alamouti Plan, Flat Fading, Matlab Simulink

I. INTRODUCTION

The aims of wireless communications are confined bandwidth, lower power consumption, superior data rates, and error free data links. Wireless networks are mainly focuses on the adjustment of high data bit rate and voice quality services. At the same time, they should be spreaded in any environment and must be bandwidth effective. Further, they should provide mobility, portability, minimum interfering from other users, privacy and security. Most important demand to meet all these expectations is posed by time varying multipath fading [1]. Due to the above mentioned expectations it is necessary to understand the behavior of wireless channel. In wireless channels, there are various different paths through which a signal propagate between two or more versions of the transmitted signal which arrive at the receiver at slightly different time's causes fading. The eventuated signal generally varies broadly in phase and amplitude. Time varying multipath fading can be slow or fast. The fading channel suffers from sudden decline in power, due to the destructive addition of multipath. This may lead to mysterious fades and reliable regaining of the signal at the receiver becomes boundless difficult. In other words it leads to outage, if the ratio of signal power to noise power (SNR) at the receiver falls below a certain threshold. Power control is the most effective technique to moderate fading. The requirement of the transmitter dynamic range and information of the channel which results in degradation and complexity made this approach out of favor, to the common masses. To moderate the effects of multipath fading, the diversity technique is used. Different replicas of transmitted signal to receiver are provided by the diversity. If these replicas provided from diversity fade independently, then the possibility of all experiencing deep fading simultaneously is very low. Space (spatial), time (temporal), frequency, using different directional antennas (angular) and using different polarizations to transmit the same signal (polarization) diversity can be implemented through diversity. In various situations, however, the channel is both significantly time varying and frequency selective i.e. the wireless channel can be assumed to be frequency flat and quasi static. Multiple antennas can be installed by the system engineers at both transmitter and receiver to attain spatial diversity. To moderate the effects of fading, Relay networks which are having ability of providing spatial diversity are used, thereby providing robustness gain. On a small size terminal, it is practically not feasible to place multiple antennas. Relay nodes as virtual antennas can therefore be used by a single antenna receiver. The power of wireless channel also grows multiple with the number of transmit and receive antennas and offers multiplexing gain by providing spatial diversity in MIMO systems. In a two-way cooperative MIMO system, either a user can act as relay and can transmit other users' data when idle, or in another case relays can be passive i.e. they do not transmit their own data but rather choose to cooperatively listen. Distributed, virtual or networked MIMO, which is also referred as Cooperative MIMO uses cooperating nodes with multiple antennas to emulate a virtual antenna array. A small set of relay nodes are active at any given time, in a large set of single antenna relay nodes. Such type of MIMO systems are studied in and find applications in ad- hoc and sensor networks employing decode and forward relaying. A new class of Distributed space time block codes (DSTBC) is recommended which enable effective node cooperation in networks with large number of relay nodes. Due to the distributed and ad-hoc nature of cooperative links as compared to codes designed for co-located MIMO systems, such code design in practice is often very complex to realize. In modern communications digital communication using MIMO, also called as "volume-to-volume" wireless link and has emerged as one of the most significant technical breakthrough. With a chance of resolving the bottleneck of traffic capacity in future Internet-intensive wireless networks the technology, digital communication using MIMO figures prominently on the list of recent technical advances. More surprising is that just a few years after its invention, the technology seems on the edge, to penetrate large-scale standards-driven commercial wireless products and networks such as broadband wireless access systems, third-generation (3G) networks and beyond, wireless local area networks (WLAN).

MIMO systems can be defined as, given an arbitrary wireless communication system, we will consider a link in which both the transmitting ends as well as the receiving ends of communication network is equipped with multiple antenna elements. The idea behind MIMO is that the signals on the transmit (TX) antennas at one end of a communication network and the receive (RX) antennas at the other end of a communication network are “combined” in such a way that the quality (bit-error rate or BER) or the data rate (bits/sec) of the communication for each MIMO user will be improved. Such an advantage can be used to operator’s revenues significantly and to increase both the network’s quality of service.

A central part idea in MIMO systems are space–time signal processing in which time (the usual dimension of digital communication data) is complemented with the spatial dimension inherent in the use of multiple spatially dispersed antennas. As such expansion of the so-called smart antennas can be viewed by MIMO systems, a popular technology using antenna arrays for improving wireless broadcast. Each antenna element on a MIMO system operates on the matching frequency and therefore does not have need of additional bandwidth. Also, for comparison, the total power during all antenna elements is less than or equal to that of a single antenna system i.e.

$$\sum_{k}^{N} = 1 \quad p_k \leq 1 \quad \ldots (1)$$

Where, pk is the power allocated through the k^{th} antenna element, and P is the power if the system had a single antenna element, and N is the total number of antenna elements A MIMO system consumes no extra power due to its multiple antenna elements ensured from equation no. (1) Single selection opportunistic relaying with amplify-and-forward (AaF) and decode-and-forward (DaF) strategies, is obtainable in [2]. Here distributed relay selection algorithms are used for outage probability and is analyzed under an cumulative power constraint and is used for outage optimal opportunistic relaying but, such schemes often require large collaboration overhead. The necessity of global channel state information (CSI) is one of the key problems in cooperative system. When CSI is known, pair of neighboring nodes can cooperatively beam form towards final destination to increase performance of multi antenna scheme and boost capacity. Optimal channel estimation and training design for two way AAF relay networks and Novel channel estimation for two hop MIMO relay systems using parallel factor analysis is proposed and discussed. The proposed algorithm provides destination node full information of all channel matrices and at the same time requires lesser number of training blocks, yields less estimation error, and is related to both one way and two way MIMO relay systems with single and multiple relay nodes. Other recent works on channel estimation problem for multi relay MIMO systems using tensor approach can be found. Comparison of different channel estimation schemes for MIMO two way relaying system is done. A rate effective two phase training protocol for cascaded channel estimation, essential for maximum likelihood (ML) detection has been recently proposed. But, it requires a complex maximum likelihood detector.

MIMO can have special presentation depending on its applications. MIMO can be engaged for diversity gain by transmitting indistinguishable information on separate antennas or can be engaged for capacity gain by transmitting information in parallel stream at the related size.

II. A GENERAL SUMMARY

A. Space Time Block Codes and Trellis Codes

To achieve maximum diversity is the goal of the space time coding, which is the product of transmitting antennas and receiving antennas in an MIMO system. When the channel is unknown, space time block codes (STBC) can provide coding gain, maximum diversity, high throughput and lower encoding and decoding complexity. The decoding complexity of STBC should be low as the mobile transmitter and receiver has a limited available battery power. Space time trellis coding (STTC) combines signal processing at the receiver with coding techniques used for multiple transmit antennas. Alamouti suggested a rate one orthogonal space time block coding (OSTBC) scheme for two transmit and one receive antennas. The codes provided simple decoding using only linear processing and full diversity. But, there is a loss in performance as compared to STTC. Alamouti scheme is still more interesting due to its simplicity in implementation, with some performance consequence.

Although, OSTBC can provide full diversity at low computational cost, but it suffers loss in capacity for multiple receive antennas system and moreover, when code rate is less than one. Complex orthogonal designs that provide full diversity and full rate are impossible to be designed for more than two transmit antennas. To design full rate codes for complex constellations, quasi orthogonal space time block codes (QOSTBC) were proposed. Here, the separate decoding property is relaxed. It is possible to construct one-full rate diversity QOSTBC by using rotated versions of the symbols. Such codes are called as rotated QOSTBCs. STBCs provide full diversity and low decoding complexity. But STBC do not provide large coding gains. On the other hand STTCs are designed to provide high coding gain and full diversity at the expense of higher decoding complexity. Higher coding gains can also be achieved if STBC is concatenated with outer trellis code, designed for AWGN channel. Such codes are said as super orthogonal space time trellis codes (SOSTTC). SOSTTC considers STBC as modulation schemes for multiple transmit antennas. The outer trellis code for slow fading channel are usually based on the set partitioning concepts of Ungerboeck codes for the additive white Gaussian noise (AWGN) channel. The codes discussed till, use special channel estimation techniques for detection. The pilot signals are sanded by the transmitter during training phase and receiver uses them to estimate the channel. In all these, quasi static fading is assumed. But, the problem becomes worse for fast fading channels.

Space-Time Block Coding (STBC) is based on the format presented by Alamouti. This format provides transmit and receive diversity to MIMO scheme (Fig.1). This figure shows Maximal Ratio Receive Combining (MRRC) scheme. The format uses two transmit antennas network and one receive antenna network and may be defined by the following three functions:

1) Encoding and deciding transmission sequence information Symbols at the transmitter.
2) Signals combining with noise at the receiver.
3) Maximum likelihood detection.

In Alamouti STBC, two different symbols are simultaneously transmitted from the two antennas network during any symbol period.

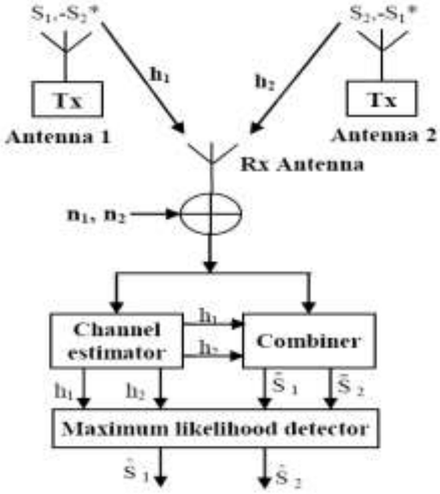

Fig. 1: Almouti's Scheme

During first time period, the first symbol in the sequence, S_1, is transmitted from the upper antenna system 1 while the second symbol, S_2, is simultaneously transmitted from the lower antenna system 2. During the next symbol time the signal – S_2* is transmitted from the upper antenna system and the signal S_1* is transmitted from lower antenna system. This sequence is shown in Table.1.

	Tx_1	**Tx_2**
Time t	S_1	S_2
Time t+T	$-S_2^*$	S_1^*

Table.1 The encoding and transmission sequence for Alamouti STBC scheme

$$\begin{array}{cc} & \xrightarrow{Space} \\ Time \ \downarrow & \begin{bmatrix} S1 & S2 \\ -s2* & S1* \end{bmatrix} \end{array}$$

Transmission Matrix

The received signals can be expressed as,

$$r_0 = r(t) = h_1s_1 + h_2s_2 + n_1 \qquad (2)$$

$$r_1 = r(t + T) = - h_1s_2^* + h_2s_1^* + n_2 \qquad (3)$$

Where, r_0 and r_1 are the received signals at time t and t + T and n_1 and n_2 are complex random variables representing receiver noise and interference in the communication system. The combiner signals S_1 and S_2 are then sent to the maximum likelihood detector.

$$S_1=h_1^*r_0 + h_2r_1 \qquad (4)$$

$$S_2=h_2^*r_0 – h_1r_1^* \qquad (5)$$

The actual transmitted symbols, S_1 and S_2 are recovered at the receiver system which requires knowledge of the channel coefficients, h_1 & h_2. These channel coefficients are often estimated at the receiver system.

B. *Differential Space Time Modulation*

Coding and space time modulation take advantage of the presence of multiple transmit antennas to precede the performance on multipath radio channels. Most work on space time coding has assumed that perfect channel estimates are available at the receiver. In some situations, it may be costly or difficult to estimate the channel precisely, in which case it is natural to consider the design of modulation techniques that do not have need of channel estimates at the transmitter or receiver system. We put forward a general approach to differential modulation for multiple transmit antennas systems based on group codes. This approach can be applied to any number of transmit antennas system and receive antennas system and any signal constellation.

We derived low complexity differential receivers, modulator design criteria, and error bounds which we use to construct optimal differential modulation schemes for two transmit antennas systems. These schemes can be demodulated with or without using channel estimates. This gives permission to the receiver to exploit channel estimates when they are available. When estimates are not available the performance degrades by approximately 3 dB.

Differential modulation schemes for MIMO channels are employed by Differential space time modulation that neither requires channel knowledge nor pilot symbols, for recognition of symbols. However, if there is a career offset due to the divergence between transmit clock and receive clock or relative motion of the receiver and transmitter system, the channel does not prolong fixed over two consecutive time periods. In such cases, the performance of differential detection design degrades considerably. To overcome this problem, Bhatnagar et al. proposed a double differential modulation scheme for cooperative wireless communication over fast fading Nakagami-m channels.

C. *Spatial Multiplexing*

Concept of spatial multiplexing (SM) is unlike from that of space-time block coding technique. The SM provides high throughput as compared to STBC at higher SNR. The SM method uses multiple antennas at the transmitter station and receiver station to make available a linearly increasing capacity gain with increased number of antennas system. In this antennas system, a high rate bit stream is decomposed into N independent bit sequences which are then transmitted using a variety of antennas systems. While using the same frequency spectrum these signals get mixed in the channel. At the receiver station individual bit streams are divided, projected and combined together to yield the distinctive signal. Thus MIMO transmits N streams bits through a single channel, thereby can distribute N or more times the data rate per channel without additional bandwidth or transmit power. Spatial Multiplexing (SM) is used to achieve highest possible throughput. Foschini introduced multilayered space-time architecture. Since then, different space time architectures have been proposed such as the Bell Labs Layered Space Time architectures (BLAST). In the SM scheme, the input is demultiplexed into N separate streams and each stream is transmitted from an independent antenna. As a result, the throughput increases N-fold as N symbols per channel are transmitted from N transmit antennas systems. But, the diversity gain suffers and hence, SM is better suited for high data rate systems operating at relatively high SNRs. On other hand, STBC is more suitable for transmitting data at low rates and low SNRs. Sphere Decoding (SD) instead of ML decoding, is used in SM. In ML detection, a search for closest integer lattice point to the given vector is performed. So, ML detection reduces to solving an integer least squares problem. ML detection gets computationally intractable when some applications like SM, there complexity in decoding grows exponentially. SD limits the number of possible codeword's by considering only those codeword's (lattice points) that are within a sphere centered at received signal vector. Inside the sphere the nearby lattice point would also be the closest lattice point for the whole lattice. The problem of finding the nearby lattice point to the point of interest is discussed in [5]-[7]. Another approach to design receivers system with low decoding complexity than ML decoding is to make use of equalization techniques to separate different symbols. Combination or hybrid of SM and STBC is generally used to achieve higher throughput and maximum possible diversity. Also MIMO can enhance the data rate by transmitting several information streams in parallel at matching transmit power. This is known as spatial multiplexing which is otherwise known as multiplexing parallel information streams in space. In SM spectrum utilization remains similar. So data rate is very high. MIMO effectively takes advantage of multipath for multiplying transfer rates.

D. MIMO-OFDM

Multiple-input multiple-output with orthogonal frequency division multiplexing (MIMO-OFDM) system has been receiving great concentration, as one of the solutions for achieving high speed, efficient, and high quality service for the 4G wireless networks. OFDM is a multicarrier transmission layout that has turn out to be the technology of choice for next generation wire line digital communication systems and wireless systems because of its high speed data rates, high spectral efficiency, high quality service and robustness against narrow band interference and frequency selective fading. OFDM thwarts Inter Symbol Interference (ISI) by inserting a Guard Interval (GI) using a Cyclic Prefix (CP) and moderates the frequency selectivity of the Multipath (MP) channel with a trouble-free equalizer system. OFDM is widely adopted in a variety of communication systems such as Digital Video Broadcasting (DVB), Digital Audio Broadcasting (DAB), and even in the beyond 3G Wide Area Networks (WAN). On the other hand, the MIMO configuration promises to increase capacity and performance proportionally with the number of antennas. OFDM can be combined with the MIMO architecture to increase diversity gain and to enhance system capacity on the wireless channel. For frequency selective fading channels MIMO-Orthogonal Frequency Division Multiplexed (MIMO-OFDM) systems [3], [4] are designed. An additional degree of diversity called frequency diversity i.e. the code could operate over space, time and frequency is provided by frequency selective channel. Thus, maximum diversity can be achieved by transmitting symbols through different frequencies and different antennas. MIMO-OFDM systems still does not provide maximum possible diversity gain because correlation and frequency diversity among subcarriers are unseen in such systems. Space time coded OFDM (STC-OFDM) system is another approach for transmission over MIMO channels using OFDM. A STC-OFDM also known as space frequency code replaces time with OFDM frequencies in the structure of space time codes.

III. MODERN EXHIBITIONS

STBC designs based on quadratic field extensions for two transmitting antennas system are reported in [8]. The average codeword error rate of the proposed optimal quadratic STBC is lower than the golden STBCs and optimal cyclotomic. Full diversity non coherent Alamouti based Toeplitz STBCs are proposed in [9]. The proposed codes use the Alamouti coding scheme and the Toeplitz matrix structure to construct a non unitary non coherent STBC. These codes outperform differential codes. Natarajan et al. proposed full diversity multi group decodable STBCs with rate greater than one. For group greater than or equal to 3, these are the first instances of multi group decodable codes having rate greater than one reported in the literature. S.Zhao et al. proposed a concatenated scheme with Polar codes and STBC named Polar-STBC format. The proposed design inherits the advantages of Polar codes that can achieve low encoding and decoding complexity at the same time, high capacity and sufficient diversity gain is also achieved due to concatenation with STBCs. STBCs that provides full rate and achieve high spectral efficiency, transmit linear combinations of information symbols through every transmit antenna. Inappropriate choice of co effectives for linear combination may lead to increased processing bits and peak to average power ratio (PAPR) values. Integer Space Time Codes utilizes integer co effectives in the code structure to reduce the number of processing bits and PAPR values.

STBCs find applications in MIMO radar systems also, as they permit the use of non-orthogonal waveforms while providing waveform diversity with full signal separation. But, use of STBCs necessitates the theory of a motionless objective. A modified adaptive block coding scheme alleviates the issue of target Doppler shifts. The proposed scheme attempts to reduce the ambiguity in detection at lower antenna transmit power too. Recently a scheme proposed by Le et al. namely spatially modulated OSTBC (SM-OSTBC) scheme that is based on the concept of spatial constellation codeword's (SC). The proposed scheme generates transmit codeword matrices by multiplying SC matrices with OSTBC codeword matrices. The proposed SM-OSTBC scheme is able to attain low decoding complexity and second order transmits diversity by satisfying the non vanishing determinant property and high spectral efficiency. STBCs for MIMO channels have been constructed by Salomon et al. by concatenating orthogonal designs with diversity transforms (DT). DT spreads the channel alphabets without sacrificing bandwidth, Euclidean distance or information rate. The distribution of the obtained code alphabet becomes Gaussian like leading to high diversity gain. This has high transmission rate and low implementation complexity. Recently, an effective MIMO scheme with signal space diversity for future mobile communications is proposed in [10]. It uses space time component interleave and rotated modulation and attempts to jointly optimize channel coding and modulation. At the same time, it maximizes achievable rate for MIMO systems and improves energy efficiency and link reliability.

IV. CONCLUSION

Use of STBCs for the MIMO systems have generated lot of awareness for improved performance and increasing spectral efficiency in wireless communication systems. Although, a lot of effort has been made in the area of STBC-MIMO systems and the literature is now extensively offered but orthogonal designs suggested by Alamouti, Tarokh et al. remain always popular and are still appropriate in the present context, as orthogonal designs show the way to simple, optimal receiver structure due to the opportunity of decoupled detection along orthogonal dimensions of space and time. STBC with lower modulation order always gave low bit error-rate when compared with STBC that employ higher order modulation methods. STBC with digital modulation can be employed in multi antenna system to boost the reliability and throughput. This is the fundamental model for MIMO Research.

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