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Reduced Complexity by Incorporating Sphere Decoder with MIMO STBC HARQ Systems

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ABSTRACT

The objective of incorporating Sphere Decoder is to reduce the computational complexity of Maximum Likelihood Detector which improves SNR, reduces BER and less time consumption.

In the proposed system, we present a radius selection algorithm which improves the performance of Sphere Decoder to reduce complexity in decoding part of Multiple Input Multiple Output (MIMO) system based on Space Time Block Codes (STBCs) and Hybrid Automatic Repeat Request (HARQ) systems. Detectors like Maximum Likelihood detector (ML), V-BLAST and Zero Forcing Detectors (ZF) are used to detect the errors at the receiver side. Quadrature Phase Shift Keying (QPSK) modulation technique, Rayleigh fading channel, MIMO-HARQ and STBC process are used for this implementation.

The Sphere Decoder's internal parameters like radius(r), Euclidian distance (d), centre point level (c), level of sphere partition (k) are modified to achieve high throughput communication at the receiver side. The main idea of this work is searching over the noiseless possible received signal that lies within a hypersphere of radius (r) around the actual received signal. The Sphere Decoder decodes the data by dividing the data to different levels of hypersphere and then it decodes only the near lattice points simultaneously which reduces the consumption of time. The average delay and average data rate with SNR are compared for both STBC and HARQ systems. Thus the simulation results show that the new approach achieves higher reduction in the exponential complexity of the received signals and use of ML detector is better than ZF and V-BLAST detectors with Sphere Decoder.

Keywords: Multiple Input Multiple Output (MIMO), Hybrid Automatic Repeat request (HARQ), Space Time Block Codes (STBCs), Sphere Decoder (SD).

1. INTRODUCTION

The use of multiple antennas at both the transmitter and the receiver provides high capacity gains without increasing the bandwidth or transmitted power [2]. Thus, multiple input multiple output (MIMO) systems have attracted much attention and serious research interests [2]. Improving the performance is the main challenge of receiver design. Therefore, a number of decoding algorithms with different complexity performance tradeoffs can be used[2]. The optimum detection method is the Maximum Likelihood (ML) detection[1] [3]. However in MIMO systems, ML algorithm has an exponential complexity with the constellation size and the number of antennas [4]. Therefore, Sphere Decoding (SD) was proposed as an alternative for ML that provides optimal performance with reduced computational complexity[1] [5],[6]. This is the fast detection approach for received signals. It reduces the complexity for received signals and less time consuming.

2. DESCRIPTION

2.1. *Quadrature Phase Shift Keying (QPSK) Modulation:* This digital modulation technique is a form of phase shift keying in which two bits are modulated at once by selecting the four carrier phase shifts (0,90,180

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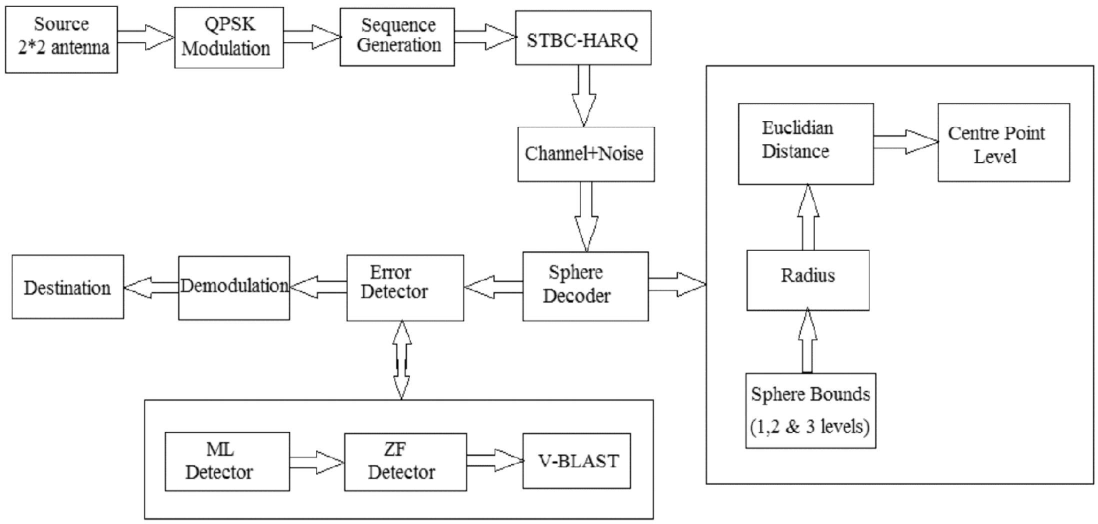

Figure 1: Block diagram including Sphere decoder

or 270 degrees). It allows the signal to carry double the information than ordinary PSK using the same bandwidth at the same Bit Error Rate.

2.2. Sequence Generator: It is a digital logic circuit whose purpose is to produce a sequence of outputs.

2.3. Space-time block coding: This technique is used in wireless communication to transmit multiple copies of data using multiple transmitting & receiving antennas without any bandwidth expansion to improve the data transfer reliability. The transmitted signals may be affected with some atmospheric disturbances. Although there is redundancy in the data some copies may arrive less affected at the receiver. The space time block coding combines all the copies of the received signal to extract as much information as possible from each of them and it is easy to implement. [1]

In Figure 1, Space Time Block Coding is done in the transmitter side. Two signals y_1 and y_2 are transmitted simultaneously from the antennas T_{y1} and T_{y2} in the time slot T_1, and the signals $-y_2$ and y_1 at the time slot T_2. The complex fading envelope is assumed to be constant across the corresponding two consecutive time slots. Independent noisy samples are added in each time slot.

At the receiver side the actual transmitted signals are obtained from the received signal z_1 and z_2 . These two signals are passed to the combiner, simple signal processing is done in the combiner to separate the signals aided by the channel estimator which will provide perfect estimation of the channel.

2.4. Hybrid Automatic Repeat request (HARQ): In standard Automatic Repeat request (ARQ), redundant bits are added to transmitted data using cyclic redundancy check (CRC). If the receiver does not receive the message properly then it will request a new message from the sender. This feedback message is known as the acknowledgement (ACK) (may be positive or negative). The retransmissions take place until the data bits reach the destination properly without any error. The performance of the data flow would be much better if there were no retransmissions so HARQ technique is used. [1]

The HARQ is the use of ARQ along with error correction technique called 'Soft Combining.' In the Soft Combining technique, the data that is not decoded properly is not discarded but it is stored in a buffer and will be combined with next retransmission. To control errors in data transmission Forward Error Correction (FEC) is used over noisy or unreliable communication channels. This technique creates a Forward Error Correction (FEC) code which is used in HARQ to encode the original data. Two cases are possible in sending the parity bits. When the receiver detects an error in the message, then negative acknowledgment has been sent to the sender which then sends the parity bits or initially the message is combined with the parity bits.

2.5. Sphere Decoder: The main idea of sphere decoder is to reduce the computational complexity of the ML Detector by searching over only the noiseless received signals within a hyper sphere of radius R around the received signal. Euclidean distance is the ordinary distance between two points in Euclidean space (3D plane). The radius R should be chosen properly. If the radius too small then it results in an empty sphere and then starting the search again. Simultaneously if the radius is too large then it increases the number of lattice points which are to be searched.[1]

2.5.1.Approach:Mathematical Approach: Minimization of a cost function f(x1,……..,xk) with respect to its K arguments taking value in a discrete set of cardinality L.

Digital communication approach: To recover the information in a multi user system, the digital communication approach is used by minimizing the distance between the received symbol and the possible transmitted symbols.

2.5.2. Principle: The distance is seen as a sum of non-negative functions with an increasing number of arguments

$$d=f(x1,\ldots,xk)=h(xk)+h(xk,xk-1)+\ldots+h(xk,\ldots,x1)$$

Graphically the process is a K-level tree graph with one upper most node(level K) and L^{k-1} leaves (level 1). Each branch corresponds to an intermediate distance.

2.5.3. Algorithm: There are two stages

1. Initialization:
2. Pruning

1. Initialization
   - At level K – smallest intermediate value leads to L next nodes at level (K-1).
   - At level (K-1) – smallest value among the L nodes and so on until the level 1.
   - Sum of the K values give the starting radius $u_{0.}$
2. Pruning
   - It is the exploration of the other branches.
   - Each branch which will certainly give a higher u_o is pruning out.
   - If a leaf is reached with a smaller sum than u_o, u_o is updated with that new value. This process continues until all branches have been pruned out.

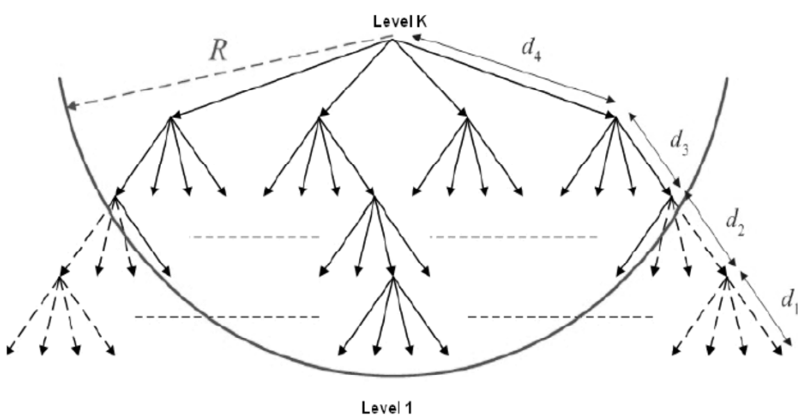

Figure 2: Data bits subsets in a hypersphere

R – Radius of hypersphere

d1, d2, d3, d4 – Euclidian distance

K – Level of sphere partition

Figure 2 explains the Initialization and Purning data bits subset in a hypersphere. The Radius selection algorithm will extend the performance of sphere decoder.

Zero Forcing (ZF) detector uses inverse filter to amplify noise which results in noise enhancement. This leads to poor bit error rate performance.

So ZF detector is replaced by V-BLAST (Vertical Bell Laboratories Layered Space Time) detector in which the strongest signals are decoded first and then they are subtracted from the received signals. This process continues until all the received signals are decoded. But Error propagation is a problem in this detector because if the incorrect decisions are taken then that actually increases the interference.

So V-BLAST is again replaced by Maximum Likelihood (ML) detector which determines the minimum Euclidean distance of Sphere decoder (SD). The Sphere Decoder searches over only the noiseless received signals & closest lattice points and then sent to the ML detector which reduces the computational complexity of the received signals. Otherwise the ML detector has to test all the possible received signals. As the number of antennas and constellation order increases it becomes quite difficult for this detector to extract the signals. [3]

3. SIMULATION

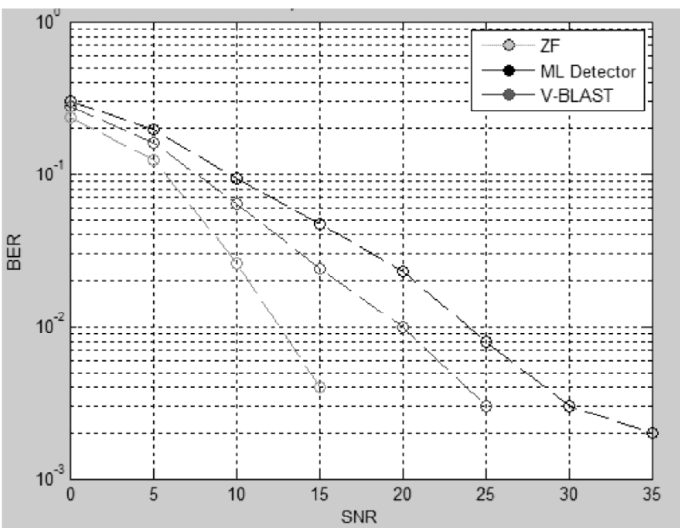

Figure 2: Comparison of SNR versus BER for three detectors (ML, ZF, V-BLAST)

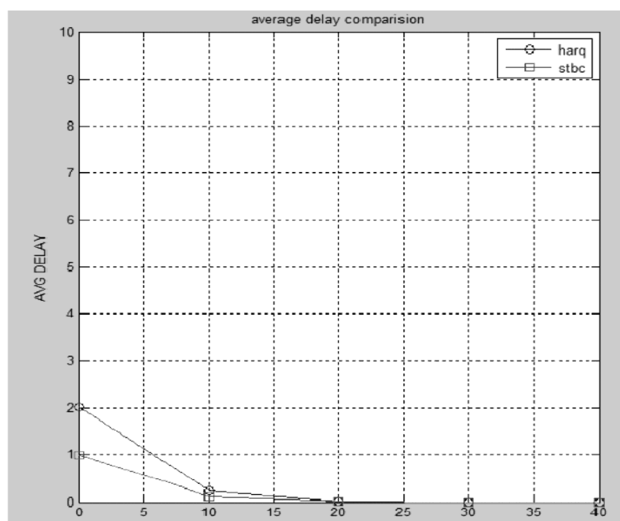

Figure 3: SNR versus average delay comparison for STBC and HARQ Systems

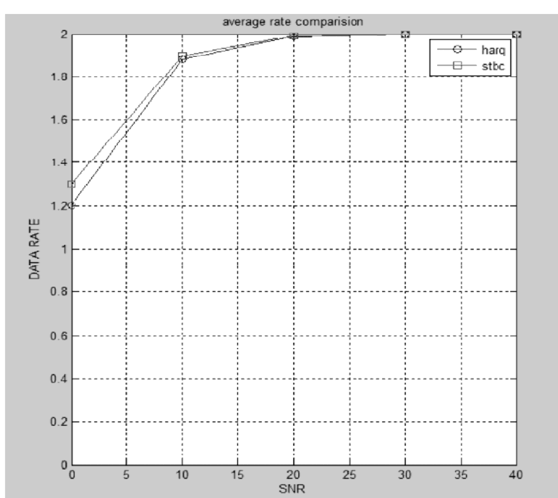

Figure 4: SNR versus average data rate comparison for STBC and HARQ Systems

In Figure 2, the SNR versus BER of the decoded information is showed by the comparative study of 3 schemes. The first scheme ML detector is used in receiver side to calculate BER. The second scheme is V-BLAST which utilizes a combination of old and new detection techniques to separate the signals in an efficient way and achieves large spectral efficiencies in the process. The third scheme is zero forcing equalization to form a linear equalization algorithm used in communication system which applies the inverse of the frequency response of the channel.

In Figure 3, the SNR is compared with average delay of STBC and HARQ Systems in which the STBC is comparatively good than HARQ for the reduction of delay.

In Figure 4, the SNR is compared with average data rate of STBC and HARQ Systems in which both HARQ and STBC achieves same SNR but the data rate is slightly higher for STBC when compared to HARQ.

4. CONCLUSION

This paper provides summary of low complexity implementation of a Sphere Decoder covering the receiver design in the MIMO STBC HARQ Systems. In general context, the conventional decoders take more time to decode the information. In the Sphere Decoder this problem has been solved by splitting the information into levels using radius selection algorithm in which the information is decoded simultaneously in different levels.

The performance of Sphere Decoder is better in terms of SNR, BER with ML detector. Finally, the upcoming trials and performance measurements by varying the internal parameters of the Sphere Decoder will be key to evaluate precisely the benefits of it in the future wireless Systems.

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