Performance Evaluation of MIMO Symbol Detection Techniques in LTE Downlink Extended Pedestrian Environment for Spatial Multiplexing

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ABSTRACT
In wireless Multiple Input Multiple Output (MIMO) channels, the accurate detection of the transmitted information becomes complex with the order of MIMO. The complexity issues become even more pronounced with the order of modulation viz. 16-QAM, 64-QAM and 256-QAM. This paper evaluates the performance of Long Term Evolution (LTE) downlink in the extended pedestrian environment for various MIMO symbol detection techniques. Channel Detector algorithms such, Minimum Mean Square Error (MMSE), Zero Forcing (ZF) and Sphere Decoding have been evaluated for various modulation schemes. The investigation being undertaken is in terms of Physical layer BER with specific application to Spatial Multiplexing**.**

Keywords
LTE, Multiple input Multiple output, ZF , MMSE .

1. INTRODUCTION
The contemporary wireless standards such as Long term Evolution (LTE), LTE-Advanced etc. adopt MIMO-OFDM in order to operate the system at ultra-high speed with reasonable bit error rates [1]. The use of 2x2 MIMO and 4x4 MIMO with 64-QAM and 256-QAM is inevitable in future wireless technologies. However, while attaining optimum performance of the system, the conventional algorithms for detection renders to a computationally complex receiver. So it is necessary that an efficient and low complexity MIMO symbol detection technique be used at the receiver side to improve the performance of the LTE downlink system. So far, several algorithms offering various tradeoffs between performance and computational complexity have been developed [2,3]. This paper presents a review of conventional MIMO symbol detection algorithms and implement some of them to analyze the performance of LTE downlink extended pedestrian environment with spatial multiplexing. This paper also suggests the approach to develop a near optimal, low complexity algorithms for near future wireless standards like 4G/5G.

MIMO is one of the crucial enabling technologies in the LTE system to achieve the required peak data rate and the increase of the channel capacity. It involves the use of multiple antennas at the transmitter, receiver or both. There are different combinations of transmission and detection schemes that can be implemented to achieve different purposes in functional and performance terms. Future wireless systems will employ multiple antennas at both transmitter and receiver to improve quality, capacity, and reliability [3].

2. MIMO SYMBOL DETECTION SCHEMES
A MIMO system with't' transmit antenna and 'r' receiving antenna is represented as [4]

$$y = Hs + n \qquad (1)$$

Where s is [t x 1] transmitted symbol vector y is [r x 1] received symbol vector H is [r x t] channel matrix and n is [r x 1] noise vector introduced by channel.

Detection methods are classified on the basis of their performance as optimal, suboptimal and near optimal Algorithms, where the names define their performance characteristics.

ML detection is optimal in terms of performance but uses exhaustive search, so the complexity is very high [5]. Suboptimal algorithms are usually very low on complexity but at the same time, their performance is not reliable for bad channels. E.g. Zero Forcing, Minimum Mean Square Error (MMSE) Method, Successive Interference Cancellation (SIC) [6]. Near optimal algorithms claim to have performance very close to optimal algorithms but with considerably less complexity, e.g. Sphere decoding, K-best detection [7,8,9].

2.1 Conventional MIMO Symbol Detection Algorithms

2.1.1 Maximum Likelihood (ML) detection
ML detection aims at minimizing the noise. The ML detection is carried out by exhaustively searching for all the candidate vectors and selecting the maximum likely one with the smallest error probability [10]. Complexity increases exponentially with the number of transmitted antennas because it searches for every possible candidate. For example, when a transmitter is equipped with 2 antennas and 16-QAM is employed for signaling, we have 162 = 256 possible candidates for detection.

2.1.2 *Zero Forcing (ZF) detection*
ZF detection aims at removing the noise by simple multiplying the received symbol with Pseudo Inverse of the channel matrix 'H'. Theoretically this means that the interference caused by the channel H is completely removed i.e. "forced to zero". However, in general the transformed noise by Zero forcing method is larger than actual noise i.e. noise enhancement [6].

The complexity of Zero forcing detector is linear, but its performance can be unreliable in many cases.

2.1.3 Minimum mean Square Error (MMSE) detection

To reduce the impact from the background noise, the MMSE detector employs an equalizer which aims at minimizing the noise. The equalization matrix for MMSE minimizes the mean square error by reciprocating the effect of noise variance on the received symbol. Again the complexity is linear but ZF or MMSE detection can only perform satisfactory for low noise channels.[6].

2.1.4 The sphere decoding algorithm

Sphere Decoding Algorithm for ML detection allows the efficient determination of all data vectors s є S for which Hs lies within a hypersphere with given radius 'r' about the received vector y [6], i.e.

$$|| y — Hs ||2 < r2$$

If there are any s inside this hypersphere, the ML solution must be one of them because the ML solution is closest to y. To find the solution, it then suffices to calculate and minimize ||y—Hs||2 for the data vectors produced by the sphere decoding, which implies a substantial reduction of complexity. Nevertheless, sphere decoding also has a drawback of dynamic complexity which causes difficulties in the hardware implementation. Furthermore, the expected order of complexity of the sphere decoder is proved to be exponential [11].

3. LTE PHY DOWNLINK MODEL

Fig. 1 shows the system model for LTE downlink with extended pedestrian channel. The block diagram can be divided into two functional units, the transmitter and the receiver. At the transmitting end, Information bits are layer mapped for 2 antennas and precoder adds the precoding bits to the information symbols as per the LTE standards. These information symbols were then modulated by QPSK, 16 QAM or 64 QAM and transmitted via extended pedestrian channel. At the receiver side, the corresponding symbols are demodulated and then detected using ZF, MMSE or sphere decoding technique. The decoder then decodes the detected symbol to produce the output bits.

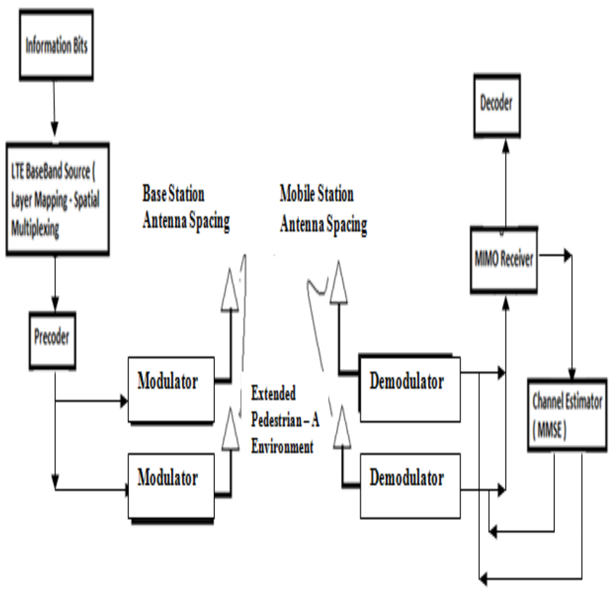

Fig. 1: System model of LTE Downlink

4. RESULTS & DISCUSSIONS

LTE physical downlink system with 2 x 2 MIMO configuration is simulated for extended pedestrian environment. MIMO symbol detection techniques viz. ZF, MMSE and SD were employed for QPSK, 16 QAM and 64 QAM modulation schemes. BER vs. SNR curves were plotted to analyze the performance. MATLAB Simulink is used for simulation purpose.

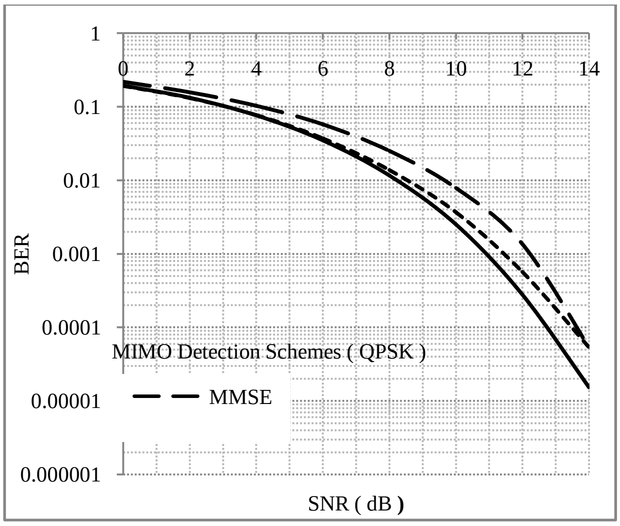

Fig. 2: BER vs. SNR plot for QPSK modulation scheme

Fig. 2 shows BER vs. SNR plot for 2x2 MIMO with QPSK modulation scheme. It reveals that the performance of sphere decoding is best among the three while MMSE performs the worst. ZF performs equivalent to sphere decoding up to 4dB SNR. The plot infers that 1% BER is obtained by MMSE detection above SNR of 9 dB, while for ZF it is obtained at SNR of 8.5 dB. Sphere decoding achieves 1% BER at SNR of 8 dB.

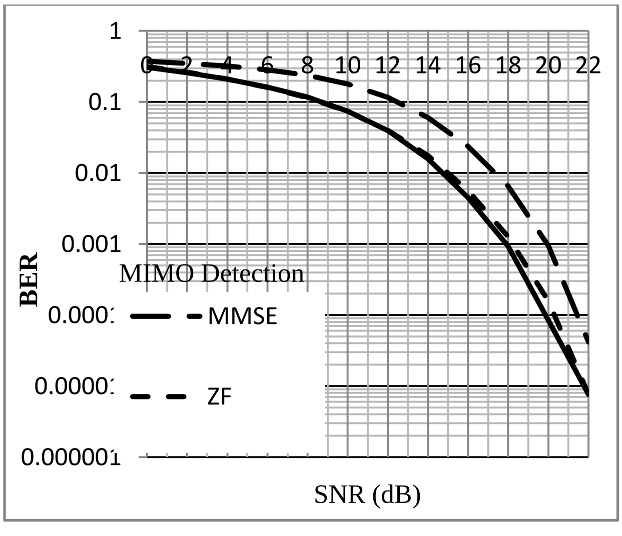

Fig. 3: BER vs. SNR plot for 16QAM modulation scheme

The curve in Fig. 3 reveals that performance of MMSE detection is inferior among all three detection schemes. The ZF detection technique performs almost equivalent to the sphere decoding for entire SNR range. For MMSE, 1% BER is obtained above 17 dB while for ZF and sphere decoding; it is achieved at nearly 15 dB. The plot also reveals that performance of SD marginally exceeds the performance of ZF for SNR range of 13dB to 21dB.

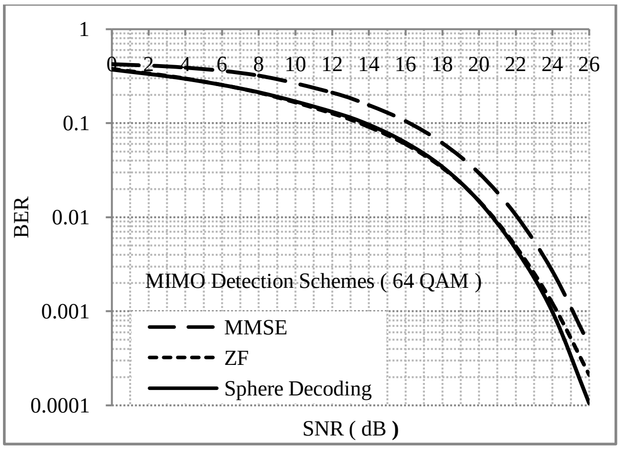

Fig. 4: BER vs. SNR plot for 64 QAM modulation scheme

Fig. 4 shows BER vs. SNR plot for 2x2 MIMO with 64 QAM modulation scheme. The plot shows that in this case also, ZF outperforms the performance of MMSE detection. BER of 1 % is achieved at 22dB SNR for MMSE detection, while for ZF and MMSE it is achieved at 20dB SNR. ZF detection technique performs almost equivalent to the sphere decoding for SNR upto 21 dB. After that sphere decoding starts to outperform ZF.

5. FUTURE APPROACH : HYBRID DETECTION ALGORITHM

In case of future wireless communication networks using 64-QAM and 256-QAM, novel hybrid detection approaches need to be developed, particularly for MIMO based systems. While using a hybrid method, one should consider the complexity of individual algorithms in the worst case scenario. The usual approach of developing a hybrid algorithm is to combine a sub optimal algorithm with a near optimal algorithm. While following this method. There are numerous possibilities of developing new hybrid algorithms. One possible method is to detect signals in good condition i.e. high SNR symbols with the sub optimal algorithms and detect the remaning symbols with the near optimal algorithm. This approach will result in dynamic complexity depending upon the condition of transmission channel. If the channel is less noisy, most of the symbols can be detected with the sub optimal algorithm which offer linear complexity[4], but if the channel is highly noisy, most of the symbols will fall in low SNR region. These symbols will be detected by the near optimal algorithm, which has exponential complexity[8]. Another method is to detect all the symbols with the suboptimal algorithm, and then select a set of possible candidates for correct symbols and detect them using the near optimal algorithm. However complexity must be considered here because this method will have the complexity involved in sub optimal detection process along with the complexity of a reduced search space near optimal detection. In worst cases, when the search space reduction is minimal due to high channel noise, the overall complexity may increase even higher than the complexity of near optimal algorithm.

Another approach is to use two or more sub optimal algorithms to achieve high performance and keep the complexity low. However these algorithms must be aided with some enhancement techniques like lattice reduction [12], to achieve near optimal performance. The performance achieved by using this approach is not very high, but it is feasible to apply in cases where low complexity with moderately high performance is key requirement. The Hybrid approach suggested in [13] is a combination of list detection and Monte Carlo technique. This algorithm adds Gaussian noise symbols to the received vector to incline the overall nature of the noise towards Gaussian characteristics. Conventional ZF/MMSE is then used to cancel the channel matrix and quantize the data. From the detected data, a set of possibly correct candidates of symbols are chosen. ML detection is performed on these candidates to detect the correct symbol. While the performance is near ML, The complexity is less than ML and varies with SNR. For high SNR values, lower complexity is expected since the zone of the constellation affected by the Gaussian noise is smaller. The Hybrid Algorithm in [14] is useful when designing a receiver for a specific standard. This algorithm aims at achieving just the acceptable error rates (JAER) for any particular standard. The algorithm applies a MIMO detection method on the go according to the estimated channel conditions and the acceptable error rates. Firstly, a detector-switching unit predicts the error-rate performance of different MIMO detection methods according to the estimated channel matrix and power of noise plus interference. Then the lowest-complexity detection method meeting the JAER criterion is determined. The detector switching unit informs the Channel Adaptive MIMO detector the adopted detection method for each stream using a flag vector. Switching strategy attacks the stream with the maximum error rate and switches that stream to a more powerful detector. Algorithm in [15] is a hybrid algorithm based on sphere decoding and ZF detection. In this algorithm, the output of ZF detector is used as a reference signal to determine the reliability of a transmitted signal. a permutation matrix is defined on the basis of increasing order of reliability, and is used to permute the channel matrix H and ZF output signals. Sphere detection is then started from the most reliable element which is based on the information from reference signal. By finding the candidate transmitted vectors early and replacing the search radius by their distance from the received vector, there will be less points inside the sphere. This results in reducing the complexity of the algorithm.

6. CONCLUSION

Performance of LTE downlink using 2 x 2 MIMO antenna system is evaluated for extended pedestrian scenario WITH spatial multiplexing. The BER vs. SNR performance for various symbol detection algorithms is analyzed for QPSK, 16QAM and 64 QAM modulation schemes. As can be seen form the graphs, the performance of ZF supersedes the performance of MMSE detection scheme for low SNR and performs almost equivalent to MMSE at higher SNR. Also, the performance of ZF is nearly equivalent to the sphere decoding throughout the SNR range. Results suggest that, instead of choosing SD for higher performance, ZF detection can be used for LTE downlink channel with extended pedestrian scenario to achieve almost same performance with comparatively very low complexity.

7. ACKNOWLEDGMENT

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