Performance of LTE Downlink with Multiuser-MIMO Techniques

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ABSTRACT: *This paper evaluates the performance of Long Term Evolution (LTE) downlink with multiple inputs and multiple outputs (MIMO) techniques, where the use of multiple antennas at the transmitter and receivers. There are different combinations of array configuration and polarization, transmission and detection schemes that can be implemented to achieve different purposes in functional and performance terms. MIMO transmissions schemes include transmit diversity and spatial multiplexing and MIMO detection schemes such as zero forcing and soft spheres decoding (SSD). The performance metrics considered are throughput and bit error rate (BER) and these are used to evaluate the performance of LTE in flat fading and International Telecommunications Union B (ITU-B) Pedestrian channel with zero forcing and soft sphere decoding for Single Input Single Output (SISO), transmit diversity and spatial multiplexing. The simulations show that the performance of MIMO is better than SISO in both channel models particularly when SSD is employed. When high order modulation is utilized, performance in the flat-fading channel model is better than ITU pedestrian B channel at low SNR regions. Spatial multiplexing is ideal for achieving very high peak rates, while transmit diversity is a valuable scheme to minimize the rate of bit error occurrence thereby improving signal quality.*

Keywords: 3GPP LTE, M-QAM, ITU-B, MIMO, OFDM, SSD, UMTS, ZF

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1. Introduction

The demand for high speed and widespread network access in mobile communications increases everyday as the number of users increases and applications are constantly developed with greater demand for network resources. As a result of this trend, mobile communications has experienced significant developments within the last two decades which is the result of tremendous research that have been carried out. The 3GPP Long Term Evolution (LTE) is the system that marks the evolutionary move from third generation of mobile communication (UMTS) to fourth generation mobile technology. The first work on LTE began in release 7 of the 3GPP UMTS specifications involving the completion of its feasibility studies. This release also included further improvements on High Speed Packet Access (HSPA). Specification of LTE and SAE (System Architecture Evolution) constitutes the main work done in release 8 of the 3GPP UMTS specifications. As at the time of writing, work is currently in progress for the enhancement of LTE which is featured in release 10 of the 3GPP Universal Mobile Telecommunications System (UMTS) specifications and named LTE-Advanced (LTE-A). The design goals for LTE is to provide downlink peak rates of 100Mbps and uplink of 50Mbps, to exhibit spectral efficiency and flexibility by supporting scalable bandwidth which enhances the provision of more data and voice services over a given bandwidth. In addition, it should provide low latency, specifically, for the control plane: 50 – 100msec to establish the U-plane and for the User Plane: less than 10msec from the user equipment (UE) to server. In terms of mobility, LTE is designed to be optimized for low speeds of about 15km/hr, provide high performance at speeds up to 120km/hr and to maintain the link at speeds up to 350km/hr. With respect to coverage area it is expected that full performance will be achieved up to 5km [1-8].

2. System Model

In MIMO System with N_r receive antennas and N_t transmit antennas, the relation between the received and transmitted signals on OFDM subcarrier frequency k ($k \in 1... N$), at sample instant time n is given by

$$y_{k,n} = H_{k,n} x_{k,n} + n_{k,n} \tag{1}$$

Where $y_{k,n} \in C_{N_r \times 1}$ is the received output vector, $H_{k,n} \in C_{N_r \times N_t}$ represents the channel matrix on subcarrier k at instant time n, $x_{k,n} \in C_{N_t \times 1}$ is the transmit symbol vector and $n_{k,n}$ is a white, complex valued Gaussian noise vector with variance σ_n^2 and I is an $N_r \times N_r$ identity matrix.

Assuming perfect channel estimation, the channel matrix and noise variance are considered to be known at the receiver. A linear equalizer filter given by a matrix $F_{k,n} \in C_{N_r} \times N_r$ is applied on the received symbol vector $y_{k,n}$ to determine the post-equalization symbol vector $r_{k,n}$ as follows [9]

$$r_{k,n} = F_{k,n}\, y_{k,n} = F_{k,n}\, H_{k,n}\, x_{k,n} + F_{k,n}\, n_{k,n} \tag{2}$$

The Zero Forcing (ZF) or Minimum Mean Square Error (MMSE) design criterion is typically used for the linear receiver and the input signal vector is normalized to unit power [10]. In MIMO-OFDM systems, the key factor of link error prediction and performances is the signal to noise ratio (SNR) which represents the measurement for the channel quality information. In this study, the SNR is defined as follows [11]:

$$\gamma_{k,n} = \frac{\| H_{k,n} x_{k,n} \|^2}{N_t \sigma n^2} \tag{3}$$

Where $x_{k,n}$ is the transmitted symbol vector, $\|.\|_F^2$ is the squared Frobenius norm of a matrix.

3. LTE Transmission Modes

In LTE, usually they use multiple Antenna for downlink (at least from Category 3 UE and higher), meaning that eNode (Network) has use multiple Tx Antenna and UE use multiple Rx antenna. In LTE, they give a special name for each of the way of transmission and it is called Transmission Mode. For example, what we normally call 'SISO' (Single Transmission Antenna and Single reciever Antenna) is called TM1 (Transmission Mode 1). What we normally call 'Diversity' is called TM2. What we call 'MIMO' but no feedback from UE is called TM3. MIMO and UE feedback from UE (CQI, PMI, RI) is called TM4. A good summary of each Transmission Mode can be as following table 1.

Transmission mode 1 (TM-1) is one of the default transmission modes if a transmission mode is not specifically configured for a UE. In that case, if only one antenna port is used for PBCH transmission in the cell, then the UE defaults to TM-1. Based on this particular case, you could assume that this cell only has one transmit antenna (not a normal LTE deployment for cellular services). Single-antenna port, port 0 means that all DL transmissions to this UE are sent using only antenna port 0 even if the cell has more than one transmit antenna. This transmission scheme limits the DL performance for this UE. Without multiple antenna techniques, such as transmit diversity or MIMO, this device does not get the benefit of a robust signal at the cell edge or increased throughput using MIMO.

Transmission Mode	*Transmission schemes for PDSCH*
1	Single antenna port, port 0
2	Transmit diversity
3	Transmit diversity if associated rank indicator 1 otherwise large delay CDD
4	Closed Loop Spatial Multiplexing
5	Multiuser-MIMO
6	Closed Loop Spatial Multiplexing with a single transmission layer
7	If the number of PDSCH antenna port is one, single- antenna port, port 0: otherwise transmit diversity

3.1. MIMO Transmission Modes

MIMO improve the spatial and multiplexing gains by the use of diversity and spatial multiplexing [12]. The methods used to enhance the diversity and multiplexing gains is CLS .Closed Loop Spatial Multiplexing Independent data streams are transmitted from the N_t transmit antennas in CLSM

3.2.MIMO Receiver Algorithm

A brief description of the receivers is given below:

3.2.1 Zero-Forcing (ZF) Detection

Zero-Forcing (ZF) detection is the simplest and effective technique for retrieving multiple transmitted data streams at the receiver with very little complexity. The probability density function (PDF) for the signal-to noise-plus-interference ratio (SINR) at the output of a zero forcing (ZF) detector in a flat fading channel was derived in [3], [4]. The zero-forcing (ZF) technique is used to nullify the interference with the help of following weight matrix:

$$W_{ZF} = \left(H^H H\right)^{-1} H^H \tag{4}$$

Where $(.)^{-1}$ denotes the Hermitian transpose operation. In other words, it inverts the effect of channel as

$$\tilde{x}_{ZF} = W_{ZF}\, y = x + \tilde{z}_{ZF} \tag{5}$$

Where $\tilde{z}_{ZF} = w_{ZF} z = \left(H^H H\right)^{-1} H^H z$ .Note that the ZF error performance is directly proportional to the power of $\tilde{z}_{ZF}$. The post-detection can be calculated using SVD as

$$\left\|\tilde{z}_{ZF}\right\|_F^{\,2} = \left\|\left(H^H H\right)^{-1} H^H z\right\|^2 \tag{6}$$

$$= \left\|\left(V\Sigma^2 V^H\right)^{-1} V\Sigma U^H z\right\|^2$$

$$= \left\|V\Sigma^{-1} U^H z\right\|^2 \tag{7}$$

Since $\|Qx\|^2 = x^H Q^H Qx = x^H x = \|x\|^2$ for a unitary matrix Q, the expected value of the noise power is given as

$$E\left\{\left\|\tilde{z}_{ZF}\right\|_2^{\,2}\right\} = E\left\{\left\|\Sigma^{-1} U^H z\right\|_2^{\,2}\right\}$$

$$= E\left\{tr\left(\Sigma^{-1} U^H zz^H U\Sigma^{-1}\right)\right\} \tag{8}$$

$$= tr\left(\Sigma^{-1} U^{H} E\left\{zz^{H}\right\} U \Sigma^{-1}\right)$$

$$= tr\left(\sigma_z{}^2 \Sigma^{-1} U^H U \Sigma^{-1}\right)$$

$$= \sigma_z{}^2 tr\left(\sum{}^{-2}\right)$$

$$= \sum_{i=1}^{NT} \frac{\sigma_z{}^2}{\sigma_i{}^2} \qquad (9)$$

3.2.2 Soft Sphere Decoder

SSD gives the ML solution with soft outputs. These ML symbols are chosen from a reduced set of vectors within the radius of a given sphere rather than a complete vector length. The radius of the sphere is adjusted such that there exits only one ML symbol within the given radius. SSD provides sub optimal ML solution [11] with reduced complexity provided MMSE is used to estimate the channel. The Soft Sphere Decoder (SSD) solution is given by the following equation.

$$\arg\min_{x} \left\| y - Hx \right\| = \arg\min_{x} \left(x - \hat{x}\right)^{T} H^{T} H \left(x - \hat{x}\right) \qquad (10)$$

Where $(.)^{T}$ denotes the transpose of matrix.

3. Simulations Results and Discussions

Bandwidth	5MHz
Modulation	QPSK,16-QAM and 64-QAM
Cyclic prefix	Normal
IFFT size	512
Channel estimation	Perfect
Channel type	Flat-fading, ITU-Pedestrian B
Receiver decoder type	ZF ,SSD
Channel coding	Turbo
Number of iterations	1000
No. of Rx antenna	2
No. of Tx antenna	2
No. of users	1
Transmission modes	SISO/Transmit diversity/Open loop Spatial Multiplexing

Table 2. Simulation Parameters

In Figure 1, the performance metric under investigation is throughput. As hypothesized, the open loop spatial multiplexing clearly out performs transmits diversity and SISO in both channels with a peak data rate of 2.8Mbps from about 5dB SNR and above.

Apparently, the performance of SM in the ITU Pedestrian B channel proves to be better than in the flat-fading channel between 0 – 5dB SNR values.

The transmit diversity scheme outperforms SISO for the low SNR values specifically between 0 – 10dB, interestingly, there happens to be increase in SISO s throughput performance above that of transmit diversity after the 2dB mark in the ITU

Pedestrian B channel and at the10dB mark in the Flat-fading Channel, after which a peak rate of approximately 1.5Mbps is sustained as can be observed in fig.1. Following this simple analysis based on these channels, modulation and detection settings, it can be recommended that SISO be utilized for high SNR values, i.e. areas or regions near or around the base station, while transmit diversity can be utilized for low SNR values in areas farther away where the signal must have experienced significant fades and distortions due to obstructions or obstacles. These recommendations are based on the premise that transmit diversity is robust against multipath fading and its mode of operation is such that it sends the same signal from multiple antennas with some coding in order to exploit the gains from independent fading between the antennas, whereas spatial multiplexing operates by sending signals from two different antennas with different data streams, which increases the data rate by a factor of the minimum of the number of receiver or transmit antennas, i.e. min (N_t, N_r).

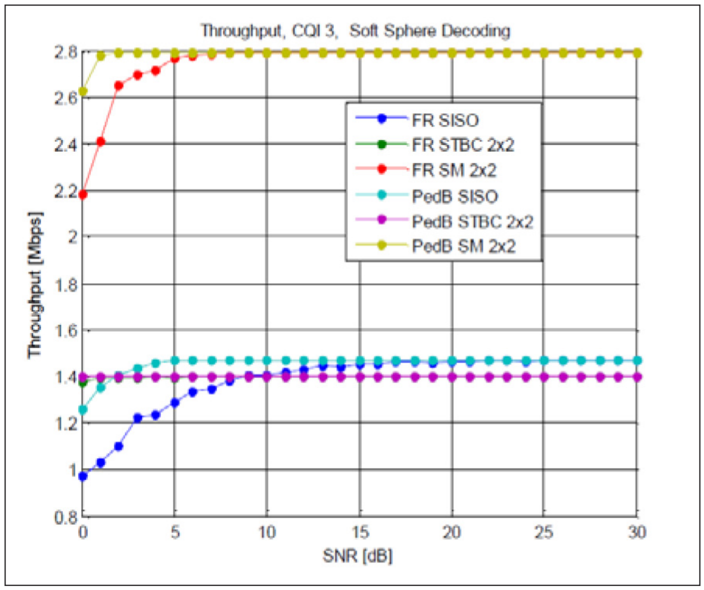

Figure 1. Throughput graph for SISO vs. 2 x 2 SM and 2 x 2 STBC (QPSK mod., Flat-fading vs. ITU Pedestrian B with SSD)

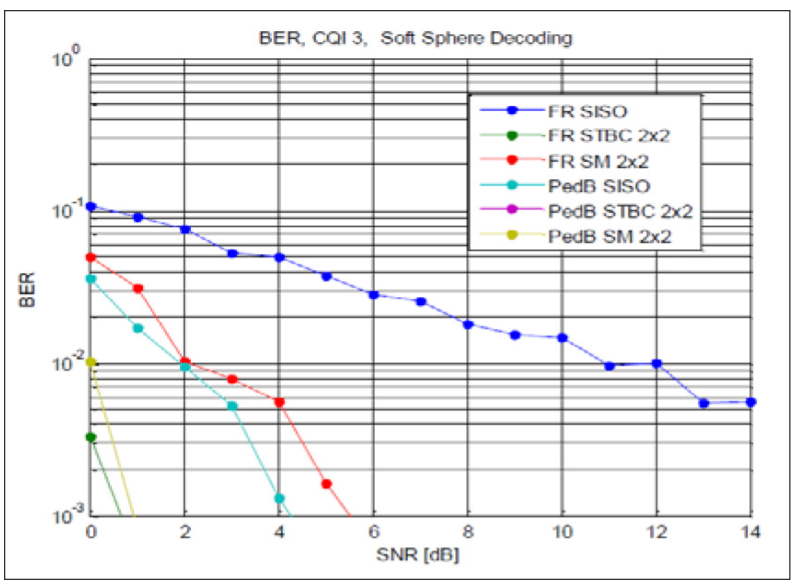

Figure 2. BER graphs for SISO vs. 2 x 2 SM and 2 x 2 STBC (QPSK mod., Flat-fading vs. ITU Pedestrian B with SSD)

In figure 2. the performance metric under consideration is the Bit Error Rate (BER) and from the figure it is observed that the transmit diversity scheme outperforms SISO and SM at low SNR values for both channel (Flat-fading and ITU Pedestrian B) scenarios. For instance, at 0dB the BER values are 2x10-3, 3.5x10-1, 10-1 for transmit diversity, spatial multiplexing and SISO

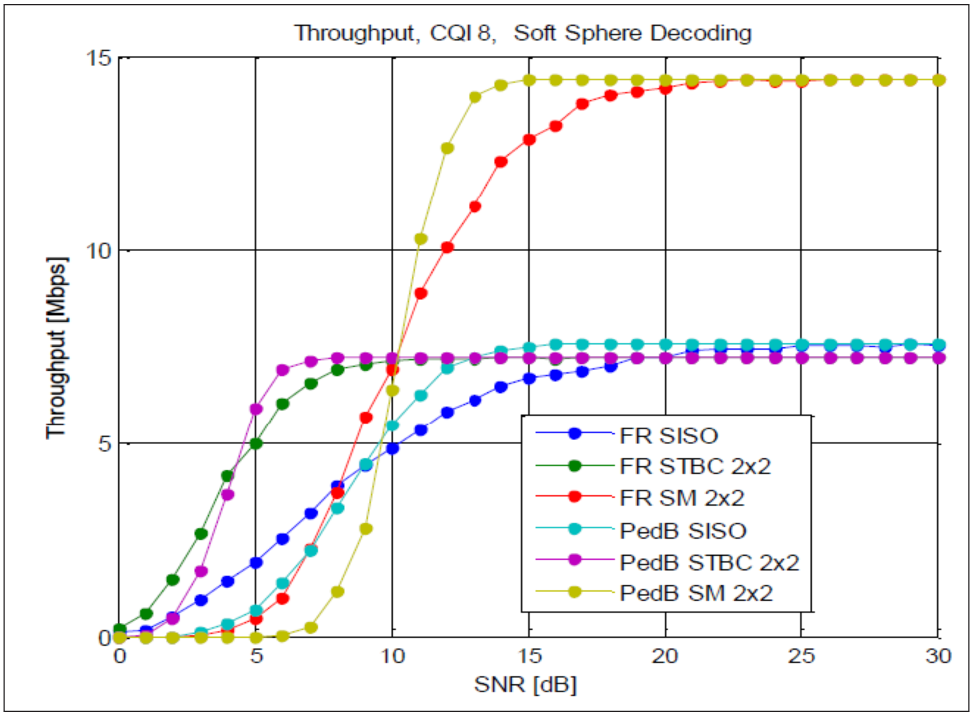

Figure 3. Throughput graphs for SISO vs. 2 x 2 SM and 2 x 2 STBC (16 QAM mod., Flat-fading vs. ITU Pedestrian B with SSD)

in the flat-fading channel scenario.

The open loop spatial multiplexing also exhibits a very good performance in the ITU Pedestrian B considering the fast rate of decay of its curve as compared to its performance in the flat-fading channel. Another alluring observation in this figure is the good performance of SISO in a ITU Pedestrian B channel unlike the poor performance obtained in a flat-fading channel meaning that SISO will experience low error rates, in high SNR areas, such as near the base station in a ITU Pedestrian B channel as observed in figure 2.

As an example, to attain a BER value of 10^{-2}, a SNR value of 2dB is required for spatial multiplexing while 11dB is required for SISO in the context of a flat-fading channel, resulting in a difference of 9dB which is significantly substantial. It is therefore suggested that transmit diversity be utilized whenever channel conditions deteriorates or in a scenario where the signal is bound to experience deep fading and distortion.

Figure 3. displays the throughput curves when 16QAM modulation is employed. As expected, the throughput performance exhibits marked improvement in all three techniques under consideration as compared with the QPSK case above. This is understandably so since the order of modulation has increased with each symbol now being represented by 4bits. Open loop spatial multiplexing peaks with an impressive value of about14Mbps although at a cost of high SNR values from approximately13dB in ITU Pedestrian B channel and between 20 – 25 dB in the flat-fading channel. Transmit diversity peaks at approximately 7Mbps and SISO peaks a little above that value, say 7.5Mbps within the same SNR range i.e. 20 – 25dB in the flat-fading channel. Transmit diversity delivers better performance than SM and SISO schemes between 0 – 10dB under both channel contexts after which SM exceeds it, but transmits diversity continues outperforming SISO up to an SNR value of 20dB when SISO achieves a slightly better performance and sustains it. It is noteworthy to observe that SISO actually exhibits better performance than open loop spatial multiplexing up to around the 8dB mark before open loop spatial multiplexing transcends considering the flat-fading channel instance.

A notable observation in this figure is that the performance of these antenna techniques for low SNR values between 0 – 5dB is better in the flat-fading channel than in ITU Pedestrian B channel but after the 5dB mark, throughput performance in the ITU Pedestrian B channel improves and transcends that achieved in the flat-fading channel but performance in both channels begins

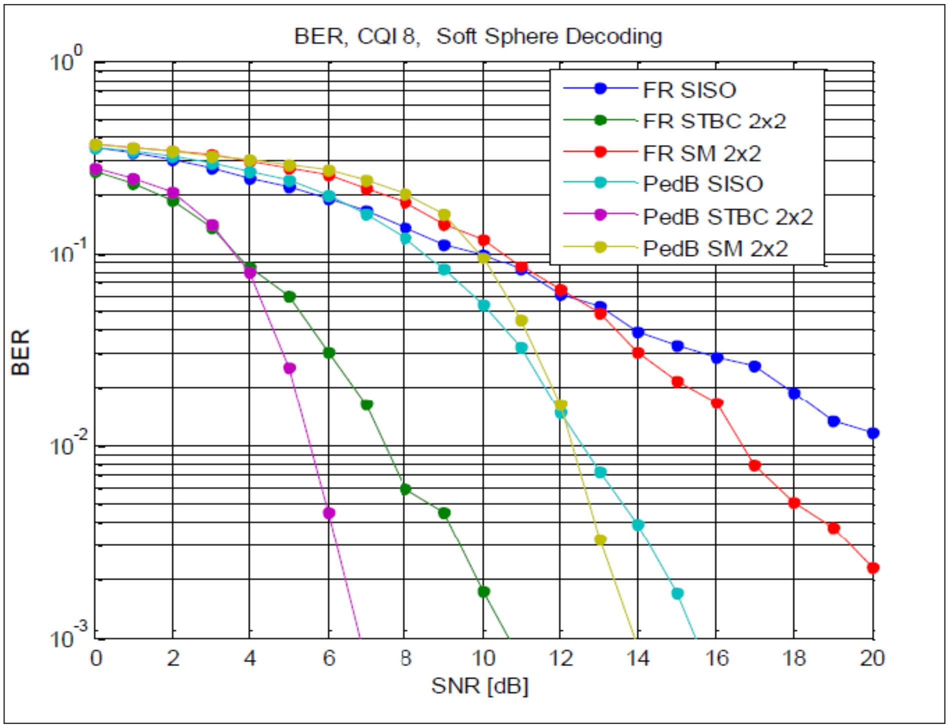

Figure 4. BER graphs for SISO vs. 2 x 2 SM and 2 x 2 STBC (16QAM, Flat-fading vs. ITU Pedestrian B with SSD)

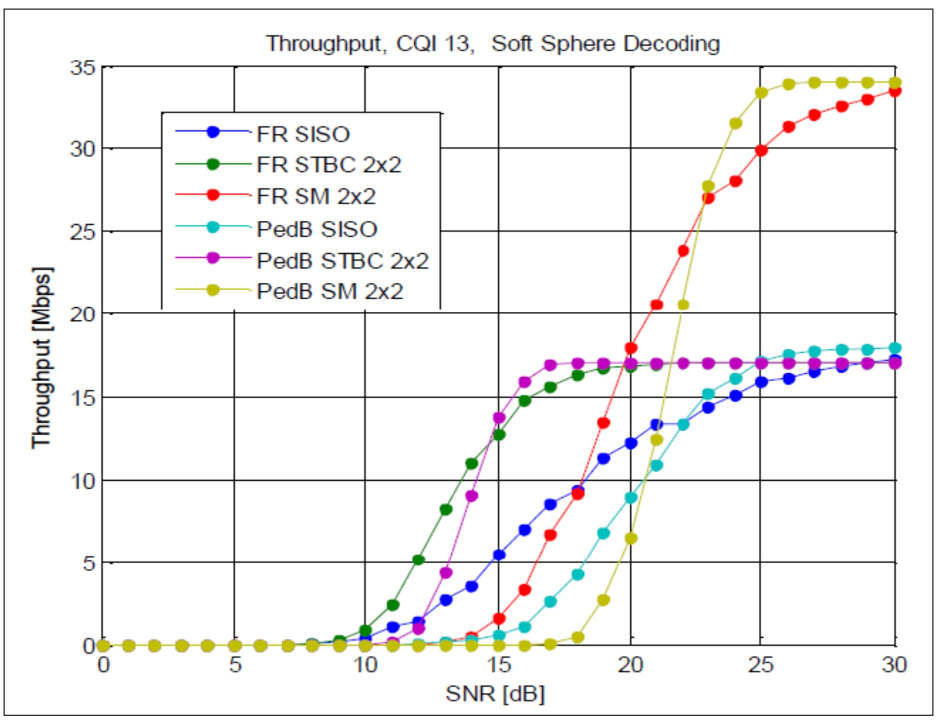

Figure 5. Throughput curves for SISO vs. 2 x 2 SM, and 2 x 2 STBC (64QAM, Flat-fading vs. ITU Pedestrian B with SSD)

to streamline from the 10dB point onward. This suggests that at low SNRs, throughput performance is slightly better in flat-fading channels.

As shown in figure 4 transmit diversity performs best for the lower SNR values and its curve has a fast decay or roll-off compared to the other two transmission modes. An appealing observation here is that performance in the ITU Pedestrian B channel is better than in the flat-fading channel; for instance, to attain a bit error rate value of 10- 2, approximately 5.5dB SNR is required when employing transmit diversity, 12.2dB for SM and 12.4dB for SISO in the ITU Pedestrian B channel as compared to 7dB, 17dB and 21dB for transmit diversity, SM and SISO respectively in a flat-fading channel which gives marginal SNR differences of 1.5dB, 4.8dB, and 8.6dB for each case respectively. One can also note that SISO has slightly better BER value than open loop spatial multiplexing up to an SNR value of 12dB after which open loop spatial multiplexing exhibits gradually better error rate

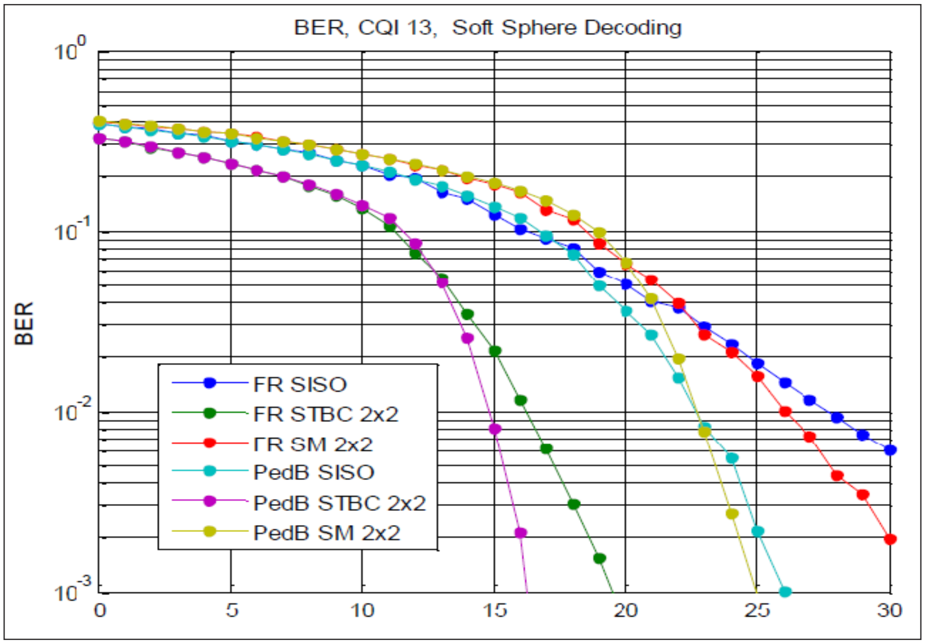

Figure.6. BER performance of SISO vs. 2 x 2 SM and 2 x 2 STBC (64QAM, Flat-fading vs. ITU Pedestrian B with SSD)

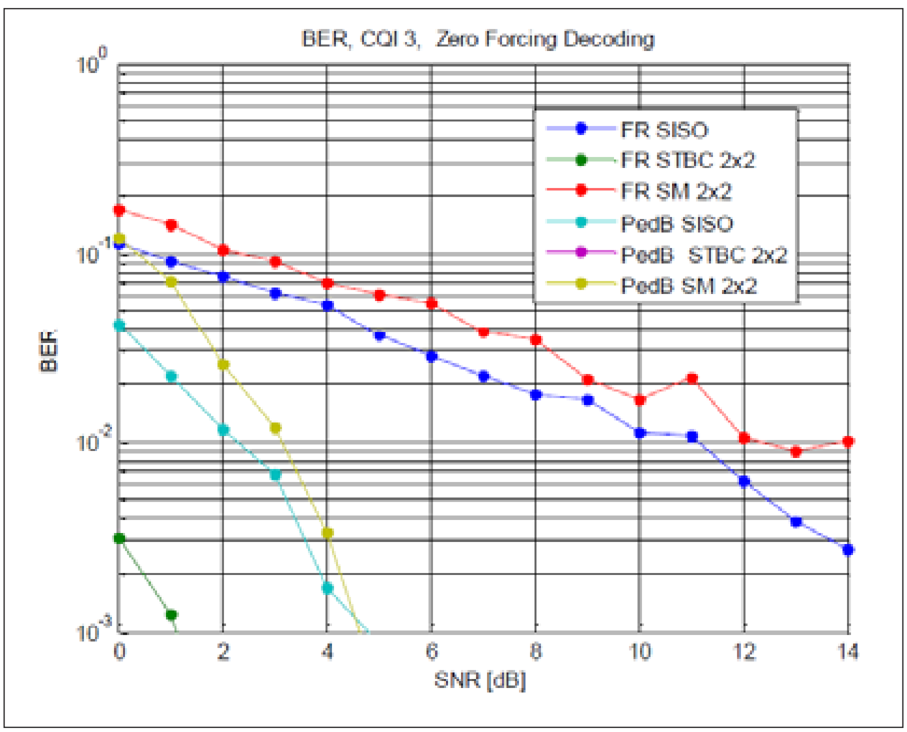

Figure 7. Throughput Performance of SISO vs. 2 x 2 SM, 2 x 2STBC (QPSK, Flat-fading vs. ITU Pedestrian B with ZF

performance as seen in the gradual widening of the margin between the two curves in the flat-fading channel. Finally, higher SNR values are required than in the preceding QPSK scenario and this can be attributed to the additional modulation bits incurred from the increase in order of modulation i.e. 4bits per symbol.

Figure 5. depicts the throughput of the different transmission modes. Here it clear that by increasing the order of modulation, all three transmission modes experience some sort of slow starting phase in the low SNR values (usually between (0 – 10dB) where the value of the throughput is essentially 0Mbps under both channel conditions(ITU Pedestrian B & Rayleigh). Above 10dB, a similar trend as obtained in 16QAM occurs. Since the order of modulation has increased (now 6 bits per symbols), all three modes have gained a throughput nearly double that which was obtained in 16QAM for the high SNR values. Open loop spatial multiplexing peaks at a whooping rate of 34Mbps, while SISO and transmit diversity are sustained about 17Mbps peak rates. Throughput of SM in the ITU Pedestrian B channel is slightly better than flat-fading between 23dB and SNR 25dB, but the same peak rate value is eventually sustained in both channel conditions. The crossing point for the transmit diversity and SISO also occurs around the same SNR values (10dB) from that of 16QAM to 30dB.

In figure 6, it is clearly obvious that when there is need of transmitting more bits, extra SNR is required. Here in 64QAM, in a similar way just as obtained in 16QAM, transmit diversity has the lowest BER for any given SNR point and its roll-off margin with SISO and open loop spatial multiplexing widens as the SNR value increases due to fast decay rate of the transmit diversity in the range of 10 -20 dB. Following in the same trend, open loop spatial multiplexing (SM) performs better than SISO at high SNR values up to the 23dB mark after which SM gradually starts to exhibit an increasingly better performance. These observations are for both channel conditions (ITU Pedestrian B and flat-fading).

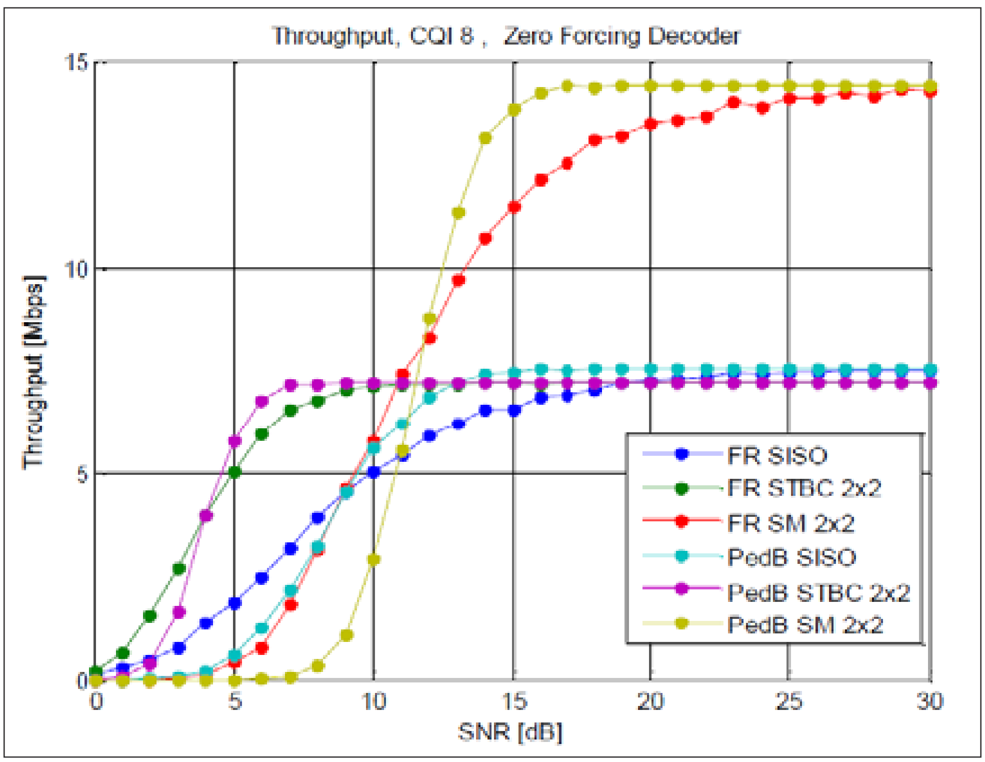

Figure 8. BER Performance of SISO vs. 2 x 2 SM, 2 x 2STBC (QPSK, Flat-fading vs. ITU pedestrian B with ZF detection)

In Figure 7, the instantaneous throughput value at 0dB for SM is observed to be much lower here as compared to the same scenario employing SSD (figure 5-1) though the same peak value of 2.8Mbps is eventually attained with better throughput performance observed in ITU Pedestrian B as against the flat-fading channel. The transmit diversity performance in flat-fading and ITU Pedestrian B channel has almost the same performance. From the analysis of the performance of SM, SSD can be recommended as suitable for utilization or adoption in low SNR areas over ZF. In fig. 8, transmit diversity gives the lowest BER performance. SM in flat-fading channel has a poor BER values though with better performance in the ITU Pedestrian B channel.

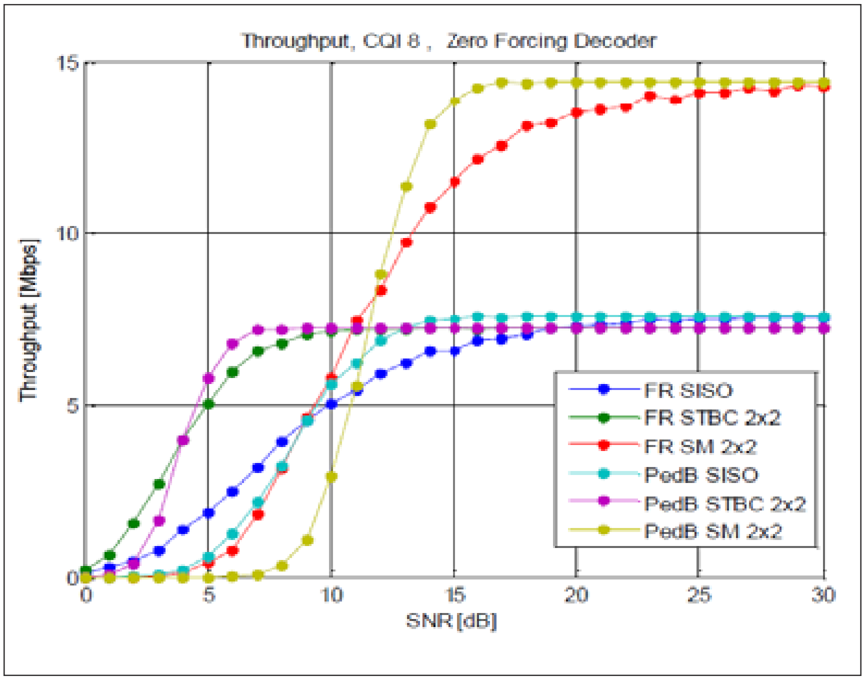

Figure .9. Throughput Performance of SISO vs. 2 x 2 SM, 2 x 2STBC (16QAM, Flat-fading vs. ITU pedestrian B with ZF detection)

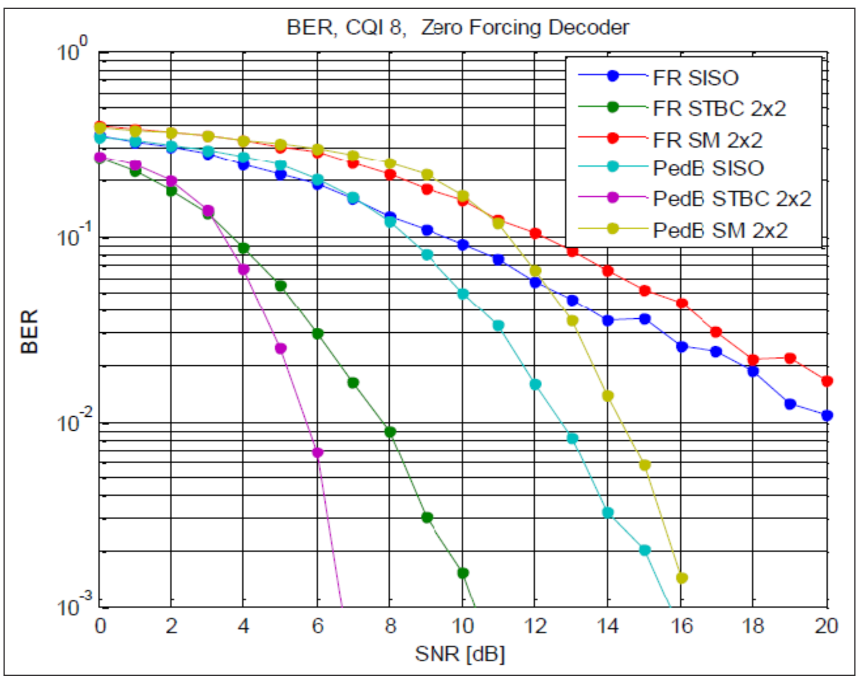

Figure 10. BER Performance of SISO vs. 2 x 2 SM, 2 x 2STBC (16QAM, Flat-fading vs. ITU Pedestrian B with ZF detection)

Based on this inference from the analysis, SM is highly recommended for use in the ITU Pedestrian B channel because it exhibits an impressive performance with respect to throughput and BER.

In figure .9, throughput performance in each of the schemes i.e. SISO, SM and transmit diversity is observed to be better at low SNRs in the flat-fading channel but at high SNRs throughput is better enhanced in the ITU Pedestrian B channel. The performance when Zero Forcing detection is utilized is also slightly reduced than that obtained when soft sphere decoding is employed as shown in fig.3. It is also interesting that SISO can perform roughly the same or even a little better than the transmit diversity MIMO technique with respect to throughput, but in terms of bit of error performance SISO is totally displaced by transmit diversity, this is clearly seen in the next figure, figure 10.

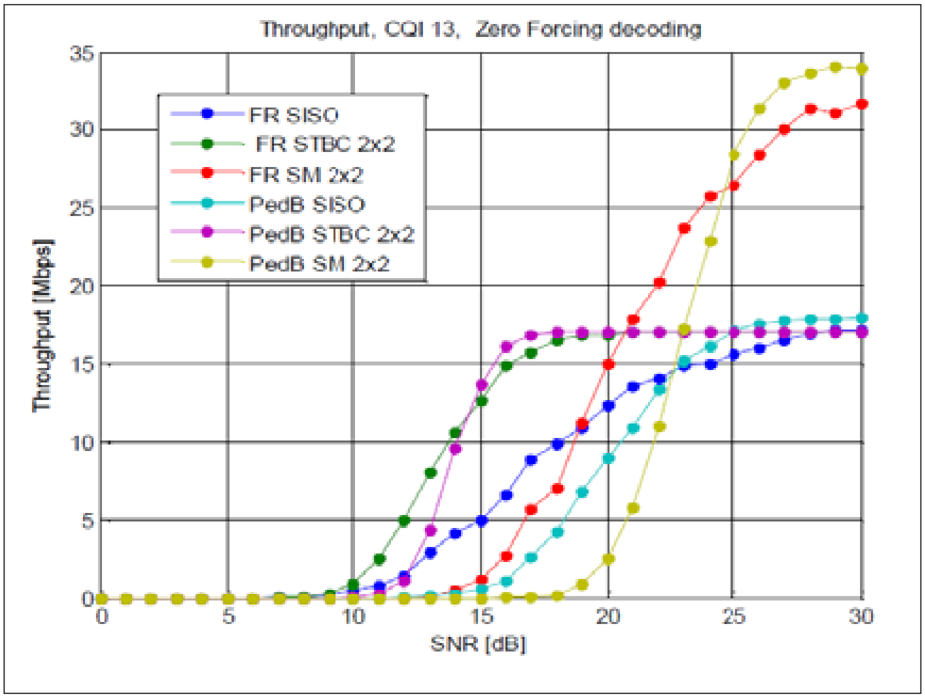

Figure 11. Throughput Performance of SISO vs. 2 x 2 SM, 2 x 2STBC (16QAM, Flat-fading vs. ITU pedestrian B with ZF detection)

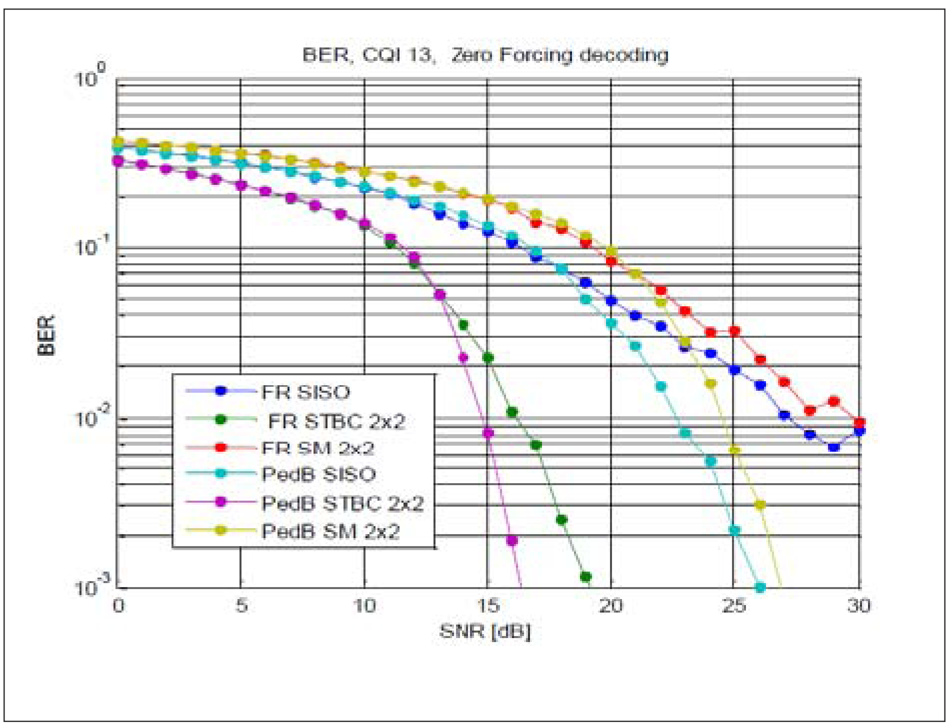

Figure 12. BER Performance of SISO vs. 2 x 2 SM, 2 x 2STBC (16QAM, Flat-fading vs. ITU pedestrian B with ZF detection)

Figure 10. displays the bit error rate curves, in line with the theory of MIMO antennas, transmit diversity exhibits very low bit error rates with the lowest error rates occurring in the ITU Pedestrian B channel. Spatial multiplexing (SM) in the flat-fading channel has the worst bit error rate, while its performance in a ITU Pedestrian B channel is fair. Considering this observation, spatial multiplexing can be utilized in the ITU Pedestrian B channel to achieve high throughput with minimal bit error rates.

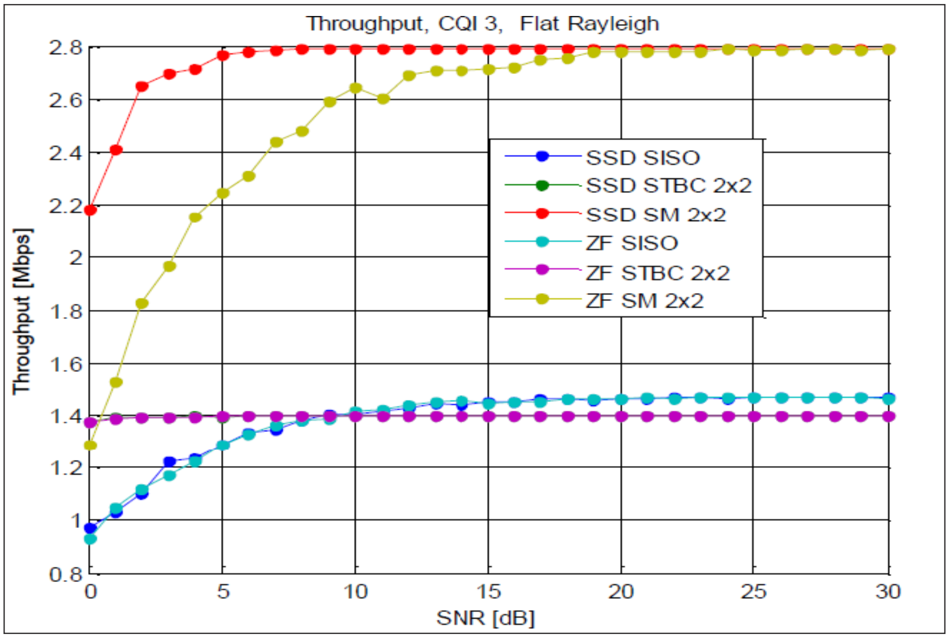

Figure 13. Throughput Performance of SISO vs. 2 x 2 SM, 2 x 2STBC (QPSK, ZF vs. SSD in Flat-fading channel)

Figure 11. shows the throughput results when utilizing zero forcing detection. A similar trend with the preceding figures can be observed; that is, throughput is slightly better in low SNR region in the flat-fading channel than in ITU Pedestrian B channel. In this figure, considering the throughput curves in flat-fading and ITU Pedestrian B channel for SM for example, it is clear that the throughput was higher in the flat-fading channel than ITU Pedestrian B channel until just about 25dB SNR where the performance in the ITU Pedestrian B improves and exceeds that obtained in the flat-fading channel.

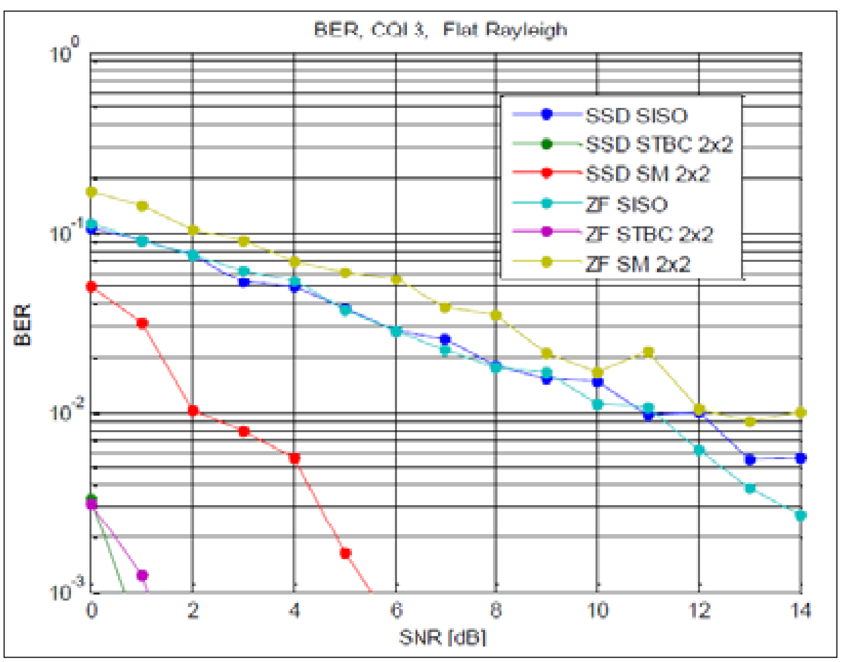

Figure 14. BER Performance of SISO vs. 2 x 2 SM, 2 x 2STBC (QPSK, ZF vs. SSD in Flat-fading channel)

In Figure 12. the order of modulation has increased to 64 QAM therefore more SNR is required to achieve low bit error rates as evidenced in fig.5-12. For instance, in the ITU Pedestrian B channel, in order to achieve a bit error rate of 10^{-3}, an approximate value of 17dB SNR is required when employing transmit diversity scheme.

Figure 11. shows the maximum attainable throughput is around 2.8Mb/s. SSD decoding outperforms the ZF decoder in the low SNR regions; this difference is particularly visible in spatial multiplexing which requires additional SNR values for same values

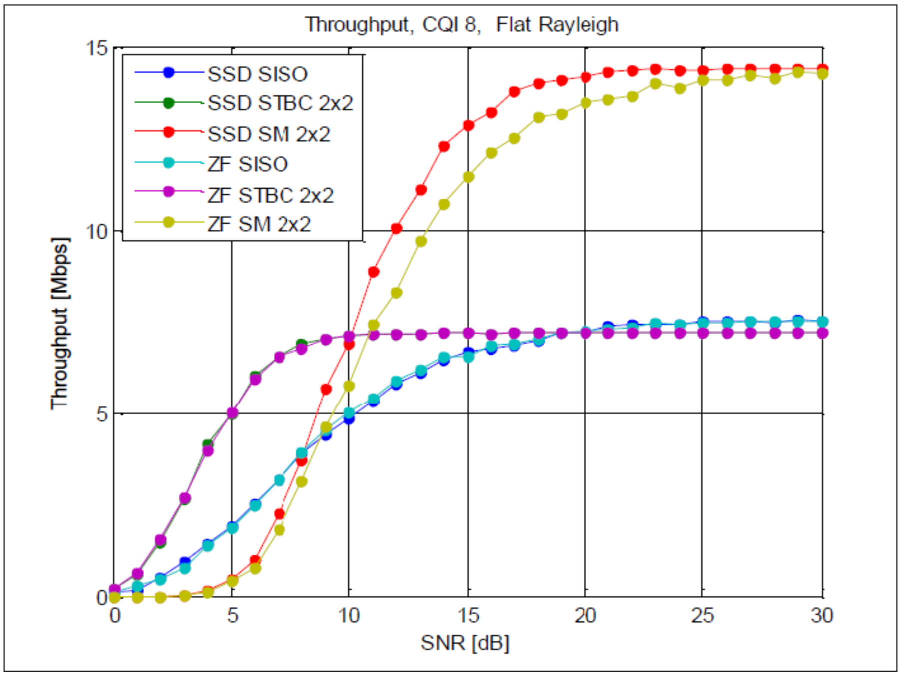

Figure 15. Throughput Performance of SISO vs. 2 x 2 SM, 2 x 2STBC (16 QAM, ZF vs. SSD in Flat-fading channel

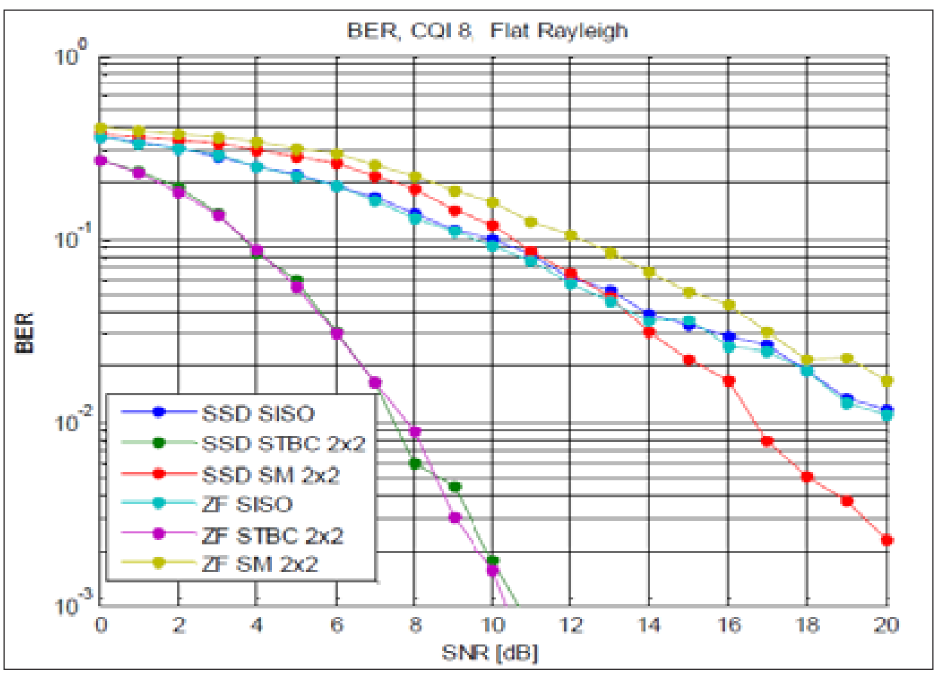

Figure 16. BER Performance of SISO vs. 2 x 2 SM, 2 x 2STBC (16 QAM, ZF vs. SSD in Flat-fading channel)

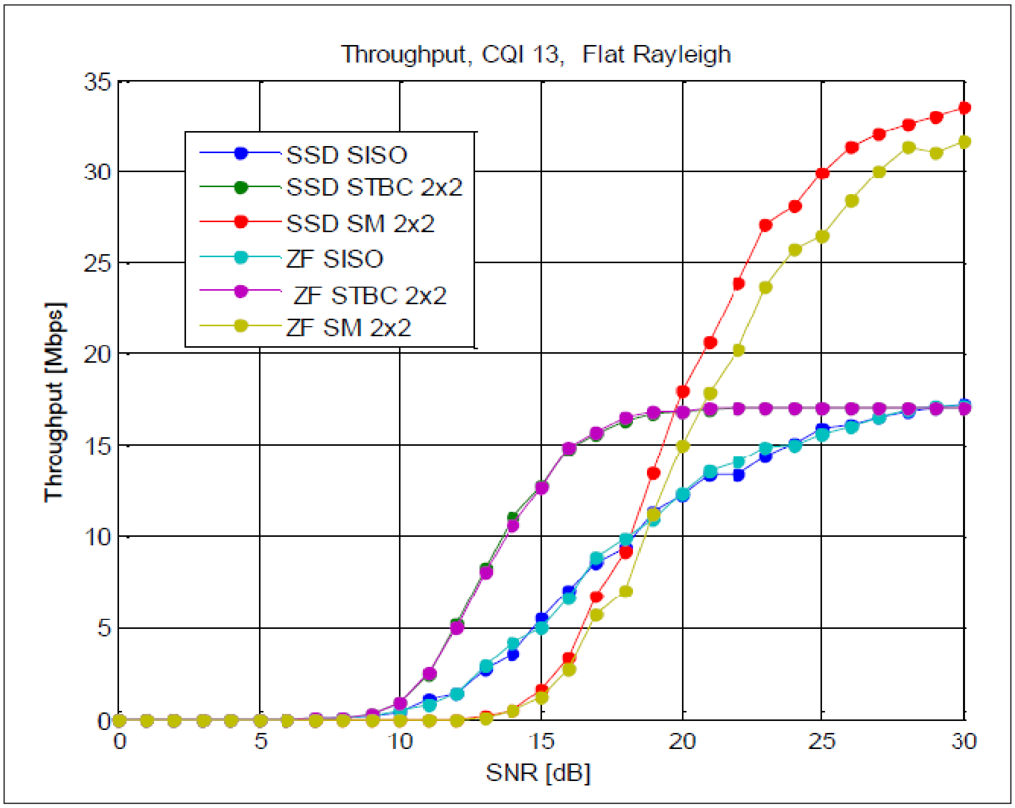

Figure 17. Throughput Performance of SISO vs. 2 x 2 SM, 2 x 2STBC (64 QAM, ZF vs. SSD in Flat-fading channel)

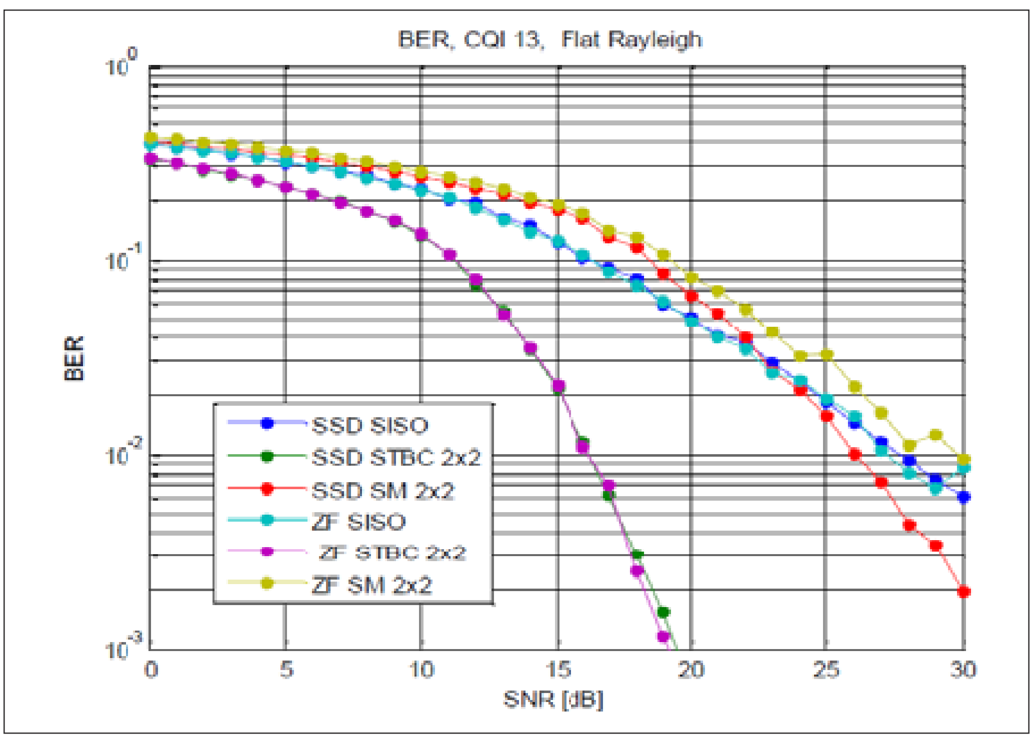

Figure 18. BER Performance of SISO vs. 2 x 2 SM, 2 x 2STBC (64 QAM, ZF vs. SSD in Flat-fading channel)

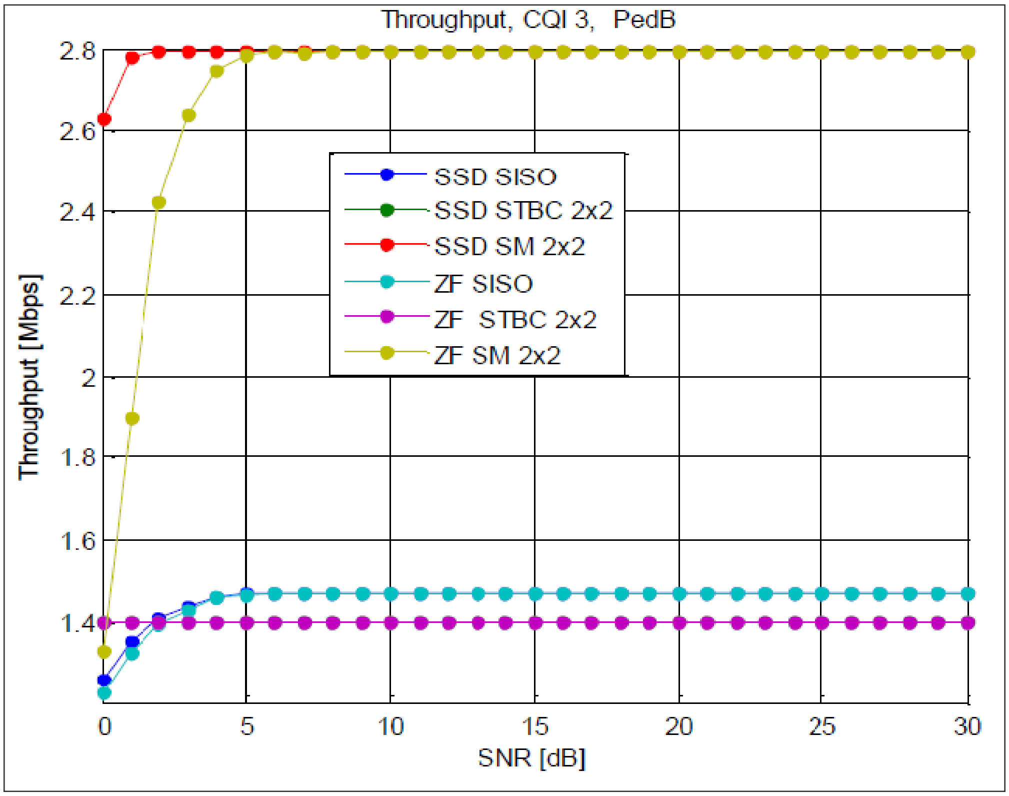

Figure 19. Throughput Performance of SISO vs. 2 x 2 SM, 2 x 2STBC (QPSK, ZF vs. SSD in ITU Pedestrian B channel)

of throughput up to 20 dB .Transmit diversity has the same performance irrespective of the detection methods. The curves reveal that transmit diversity attains low bit error rate with SSD followed by ZF. The SSD spatial multiplexing follows the transmit diversity in low SNR region.

Figure 14. it is observed that with SSD detection the bit error rates are lower than with ZF detection, a vivid example that shows this is when we compare the SM curve with SSD (red curve) and with ZF (yellow), there clearly exist a very wide margin in between them. In contrast, the BER curves of SISO with ZF and SSD seems interwoven making it difficult to accurately and precisely determine the one with better BER performance.

In Figure 15. Throughput achieved with SSD is roughly the same as in ZF for SISO and transmit diversity but there is some increase in throughput with SSD than ZF when utilizing spatial multiplexing (SM).

In Figure 16. transmit diversity has the best BER performance and there is roughly similar performance between SSD and ZF detection (purple and green curves), SISO performance with detection schemes (ZF and SSD) have similar BER with minimal differences. SM with ZF detection had the worst BER performance.

The performance displayed in fig.17 is displayed follows a similar trend like that obtained in 16 QAM except that it can be observed that throughput values have increased since the order of modulation has increased peaking at approximately at 34Mbps with SM employing SSD detection. Performance of SSD and ZF are very similar for SISO and transmit diversity.

Here, the BER performance with 64 QAM are displayed, additional SNR is required for better performance. Transmit diversity with SSD and ZF detection exhibit similar performance, and a similar trend is noticed with SISO as well.

5. Conclusion

In this paper, an effective study, analysis and evaluation of the LTE downlink performance with different MIMO techniques in comparison with the traditional SISO system has been carried out. The performance is evaluated with respect to two definitive metrics namely throughput and BER, considering the use of different decoders at the receiver (soft sphere and zero forcing decoders) in two different channel models, namely flat fading and ITU pedestrian B channel. In both receivers, for higher order of modulation (16QAM and 64QAM), the flat-fading channel performs better for the low SNR regions (up to 4, 9, 12 dB) for transmit diversity, SISO and spatial multiplexing respectively. However, for low order of modulation, QPSK in this instance, performance in the ITU pedestrian B channel is better at the low SNR region. In rich multipath environments like ITU pedestrian B channel, performance for users far away from the base station is low due to losses caused by the presence of many scatterers, but for the flat-fading channel, performance is better in these low SNR areas particularly when SSD is used, however, additional SNR is required in the case of zero forcing decoder. Analysis of the results obtained reveal that the performance of MIMO is better than SISO in both channel models particularly when SSD is employed. When high order modulation is utilized, performance in the flat-fading channel model is better than ITU pedestrian B channel at low SNR regions. Spatial multiplexing is ideal for achieving very high peak rates, while transmit diversity is a valuable scheme to minimize the rate of bit error occurrence thereby improving signal quality.

References

[1] Zyren, J. (2007). Overview of the 3GPP long term evolution physical layer, freescale.com, July, 2007. [Online]. Available: http://www.freescale.com/files/wireless_comm/doc/white_paper/3GPPEVOLUTIONWP.pdf. [Accessed: May.05, 2010]

[2] IXIA Technologies. (2010). SCFDMA single carrier FDMA in LTE, ixiacom.com, November 2009. [Online]. Available: http://www.ixiacom.com/pdfs/library/white_papers/SC-FDMA-INDD.pdf [Accessed: June 15,2010]

[3] Nokia Siemens Networks. (2008). Charting the course for mobile broadband heading towards high-performance all- IP with LTE/SAE, nokiasiemensnetworks.com, 8, 2008 [Online] Available: http://w3.nokiasiemensnetworks.com/NR/rdonlyres/392CF9E3-5C1E-417F-B177- 8BFB396BD921/0/broadband_lte_sae_update.pdf. [Accessed: 10 September 2010]

[4] Sesia, S., Toufik, I., Baker, M. (2009). *LTE – The UMTS Long Term Evolution: From Theory to Practice*. First Edition West Sussex: John Wiley & Sons.

[5] Suo, S., Yang, Y., Tang, Y., Wang, Y. (2009). Evaluation of MIMO structure and channel model in LTE system, In: Fourth *International Conference on Communications and Networking*, CHINACOM.

[6] Agilent Technologies. (2010). MIMO channel modeling and emulation test challenges, January.

[7] Rumney, M., Pahls, M. J., Leung, M., Lorch, P., eds. (2010). LTE and the evolution to 4G wireless: Design and measurement challenges, U.S.A: *Agilent Technologies Publication*.

[8] 3GPP TR 25.913 v7.3.0. Technical specification group RAN; requirements for E-UTRA and E-UTRAN, release 7.

[9] Schwarz, S., Mehlfuhrer, C., Rupp, M. (2010). Calculation of the spatial pre processing and link adaption feedback for 3GPP UMTS/LTE *Wireless Advanced (WiAD),2010 6th Conference on*. 1 –6.

[10] TSE, D., Viswanath, P. (2008). Fundamentals of Wireless Communications, Cambridge University Press

[11] Mehlf˘Uhrer, C., Wrulich, M., Ikuno, J. C., Bosanska, D., Rupp, M. (2009). Simulating the long term evolution physical layer. *Proc. of the 17th European Signal Processing Conference (EUSIPCO 2009)*. Glasgow, Scotland

[12] Gore, D., Heath, R. W., Paulraj. A. (2002). On the performance of the zero forcing receiver in presence of transmit correlation, *In*: *Proceedings IEEE Int. Symp. Inform. Theory*, 159.

[13] Li, P., Paul, D., Narasimhan, R., Cioffi, J. (2006). On the distribution of sinr of the mmse mimo receiver and performance analysis, *IEEE Trans. Inform. Theory*, 52 (1), 271–286, January.

[14] Honig, M. L. (2009). Advances in Multiuser Detection, M. L. Honig, Ed.,John Wiley & Sons, INC., Publications.

[15] Krishna, P., Kishan Rao, K., Anil Kumr, T. (2015). Multiuser MIMO Transmission Modes for Transmit Diversity and Spatial Multiplexing in Long Term Evalutions, *ARPN Journal of Engineering and Applied Sciences*, 10 (5), March.