A Novel Combination of the V-BLAST Algorithm with Kalman Filter for Single User MIMO LTE Downlink

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***Abstract*—Long Term Evolution (LTE) utilizes various kinds of technologies at downlink such as Orthogonal Frequency Division Multiple Access (OFDMA) and a Multiple Input Multiple Output (MIMO) technique, which is either used to reduce Bit Error Rate (BER) as spatial diversity or to increase the capacity as spatial multiplexing. It's commonly known that the maximization of spatial diversity gain leads to degrade the spatial multiplexing gain or vice versa. In order to enhance both spatial multiplexing and diversity gains in rich scattering environments, a new combination of Vertical-Bell Laboratories Layered Space-Time (V-BLAST) and Kalman filter has been introduced simultaneously. Such scheme is tested for different channel types such as Rayleigh and Rician channels with realistic radio environments such as Additive White Gaussian Noise (AWGN), User Defined, Rural Area, Typical Area, Bad Urban, and Hilly Terrain. The simulation results show the maximum capacity achieves in AWGN environment over Rayleigh channel with 2x2-MIMO. Whereas, in case 4x4-MIMO, the highest capacity is obtained in Rural area environment over Rayleigh channel. The proposed system improves both the reliability and capacity in rich scattering environments such as Bad urban environment and Hilly terrain environment compared with conventional system.**

***Keywords*—LTE, OFDM, MIMO, Linear Detectors, V-BLAST and Kalman Filter**

I. INTRODUCTION

The present and future cellular system face severe challenges with an exponential growth of mobiles that use the multimedia applications such as video streaming. The LTE system has focused on the MIMO system to enhance either the capacity or the reliability of the wireless communication channel (Agiwal et al., 2016). The MIMO and OFDM systems are efficient techniques to improve a spectral efficiency in the LTE downlink (Yu et al., 2015). The OFDM and multiple antenna techniques have been considered as a best solution for increasing the capacity gain and the robustness of the LTE system. However, there are various methods for data detection and correction such as linear equalizers: Zero-Forcing (ZF) and Minimum Mean Squared Error (MMSE) or nonlinear detector such as the V-BLAST algorithm (Bai et al.,2009; Chong et al., 2014). There is a trade-off between the gain of spatial multiplexing and spatial diversity in the MIMO system (Chong et al., 2014).

The main contribution of this paper to overcome the key challenge of the MIMO system in LTE by introducing a new combination of the V-BLAST algorithm and Kalman filter receiver in the Release 8 LTE MIMO downlink to obtain higher capacity and diversity without increasing the channel bandwidth or the transmission power. The suggested model is tested of LTE V-BLAST 2x2/4x4-MIMO with Kalman filter and compared with LTE SISO system. This paper examines the V-BLAST technique and Kalman filter in LTE system with different channels and various environments. The proposed paradigm exhibits a better performance in terms of throughput and BER. In addition, this model tries to be simplified for user devices.

The rest of this paper is structured as follows. Section II reviews the related works. Section III presents the general block diagram of spatial multiplexing MIMO model with the V-BLAST technique. Section IV discusses the common types of linear detectors such as zero-forcing and minimum mean square error. Section V introduces the V-BLAST technique. Section VI discusses the working algorithm of the V-BLAST technique. Section VII introduces the designed system of LTE V-BLAST MIMO for the downlink. Section VIII presents the simulation parameters of the suggested model. Section IX presents the simulation results. Finally, section X summarizes the paper.

II. RELATED WORK

Many projects have tried to address the LTE capacity problem for downlink. As stated in (Berardinelli et al., 2010), the Singular Value Decomposition (SVD) method has been analyzed for spatial multiplexing MIMO of the LTE Release 8 downlink, but it did not attain MIMO capacity because of the loss of such technique in the quantization process of V matrix at the receiver for the feedback message. As a result, the SVD approach could not obtain the required level of spectral efficiency. Since BSs must process and exchange

Channel State Information (CSI) for pre-coding utilization, this leads to a loss of some capacity (bandwidth). Practically, the SVD technique does not exploit all advantages of closed loop MIMO transmission in the LTE system such as power balance across antennas. However, the SVD option is just used in LTE uplink.

Other projects have attempted to solve the LTE capacity and reliability. Authors used the V-BLAST/STBC combination to improve both capacity and BER of the system at the same time. This proposed model suffered from a high complexity. However, a new suggested algorithm was introduced to reduce the computational complexity based on the low complexity of the QR decomposition (Chong et al., 2014).

The proposed paradigm of V-BLAST-based Sphere Decoding was used by (Mohamed and Sayed El-Rabaie, 2015) to enhance both the reliability and capacity of the LTE-Advanced system. The authors work to divide the receiving detection into small blocks with varied complexity and performance to attain an optimal solution of error propagation problem in the V-BLAST algorithm.

As reported in (Zhang et al., 2016), non-orthogonal multiplexing technique of layer-division-multiplexing (LDM) with multiple antenna technology and multiple layers was used to realize higher multiplexing gain and an efficient implementation than TDM/FDM techniques. The LDM system achieves the offered gain of the superposition code with Small extra signal processing complexity and memory have been added for customer devices with such technique. Alternatively, the V-BLAST algorithm with multiple antenna technique offers a higher multiplexing gain and low complexity for customer devices.

III. PRINCIPLE OF MIMO SYSTEM

This section depicts Spatial Multiplexing-MIMO (SM-MIMO) system with two transmitted and received antennas and V-BLAST architecture. Spatial multiplexing gain of the V-BLAST technique is achieved with uncoded transmission across the MIMO flat fading channel as shown in Fig. 1. From Fig. 1, there are Line of Sight (LoS) components such as h11 and h22 that are the desired ones and Non-Line of Sight (NLoS) components such as h21 and h12 which are the interfering ones.

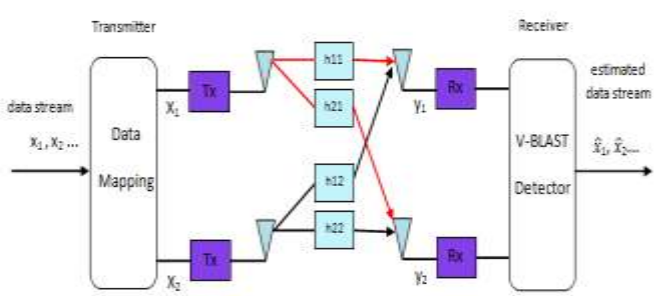

Fig. 1. The System Model of 2x2 SM-MIMO based on the V-BLAST algorithm

Where x is a transmitted signal and $\hat{x}$ is an estimated transmitted signal. However, the receiver is required to separate these components to avoid inter-symbol interference (ISI).

$$\mathbf{y} = \mathbf{Hx} + \mathbf{n} \tag{1a}$$

$$\begin{bmatrix} y_1 \\ y_2 \end{bmatrix} = \begin{bmatrix} h_{11} & h_{12} \\ h_{21} & h_{22} \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \end{bmatrix} + \begin{bmatrix} n_1 \\ n_2 \end{bmatrix} \tag{1b}$$

$$\boldsymbol{y} = \mathbf{h}_1 x_1 + \mathbf{h}_2 x_2 + \mathbf{n} \tag{1c}$$

Where **y** is the received vector, **h** is the column vector of channel matrix **H**, x is the transmitted symbols and **n** is the AWGN vector with σ_n^2 variance (Mohamed and Sayed El-Rabaie, 2015).

IV. LINEAR DETECTORS

A Linear detection is utilized when CSI is only known at the receiver. The linear detector works to suppress interference signals from different antennas except the desired ones. This can be done by inverting the channel matrix. The received signal is multiplied by weight matrix W to extract the transmitted signal.

$$\hat{\mathbf{x}} = \mathbf{W} * \mathbf{y} \tag{2}$$

Where **W** is a weight matrix or channel inversion, $\hat{\mathbf{x}}$ is an estimated transmitted signal. The common linear detectors are ZF and MMSE (Cho et al., 2010).

A. Zero Forcing Detectors

This is an easiest receiver detector that works to inverse the channel matrix and is applied to the received signal. The channel response can be cancelled by using an inverse filter. The resulting signal has zero ISI between symbols. A zero-forcing equalizer does not treat a noise effect. A 'Moore-Penrose generalized inverse', 'pseudo-inverse' of the channel matrix can fulfill the same function as a zero-forcing outcome (Jafarkhani, 2005). In order to explain the main concept of this equalizer and how it is applied to the received signal, define:

$$\mathbf{W}_{ZF} = \mathbf{H}^{\dagger} \tag{3}$$

Where $\mathrm{H}^{\dagger}$ is pseudo-inverse of the channel matrix.

$$\mathbf{W}_{ZF} = (\mathbf{H}^{H}\mathbf{H})^{-1}\mathbf{H}^{H} \tag{4}$$

Where$(.)^{\mathrm{H}}$= Hermitian operator (conjugate and transpose) (Cho et al., 2010).

B. Minimum Mean Squared Error Detectors

It is utilized for noisy channels, whereas zero-forcing is employed for noiseless channels. MMSE has a better performance because this type deals with the signal interference and noise ratio (SINR). The weight matrix of MMSE is shown in (5):

$$\mathbf{W}_{MMSE} = (\mathbf{H}^{H}\mathbf{H} + \sigma_n^2\mathbf{I})^{-1}\mathbf{H}^{H} \tag{5}$$

Where σ_n^2 is a noise variance, we denote an identity matrix with (Nr, Nr) dimension, and Nr is the number of received antennas (Cho et al., 2010).

V. PRINCIPLE OF V-BLAST

The V-BLAST receiving algorithm works with MIMO technology to combat the interference vector by vector. Therefore, V-BLAST is not just used for Single User-MIMO (SU-MIMO), but it can also be employed for Multi-User MIMO (MU-MIMO) (Paulraj, 2003). It can also be defined as the "ordered successive interference cancelation (OSIC)" technique in the receiving side. V-BLAST can be used for the nonlinear receiver for fast fading channel. It comprises of a set of linear detectors, which have advantages of less complexity for hardware design, which in turn enhances the performance. However, V-BLAST is combined from a group of linear detectors that operate in parallel to decode the input signal as visualized in Fig. 2. Each linear detector decodes one symbol, which is subtracted from the received signal in each phase. As a result, the interference level will be reduced for the next stage. V-BLAST can either use ZF or MMSE, and it is merely required that the CSI to be available at the receiver (Cho et al., 2010).

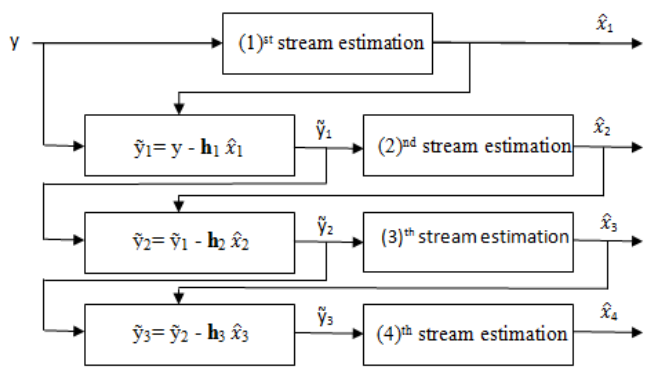

Fig. 2. V-BLAST for four spatial streams (Nt= Nr=4) (Cho et al., 2010)

$$\tilde{y}_1 = \boldsymbol{y} - \mathbf{h}_1 x_1 \quad (6a)$$

$$= \mathbf{h}_1(x_1 - \hat{x}_1) + \mathbf{h}_2 x_2 + \cdots + \mathbf{h}_{Nt} x_{Nt} + \mathbf{n} \quad (6b)$$

From (6b), If $x_1 = \hat{x}_1$, the interference is removed in stage of estimating x_2, otherwise, the error propagation will take place which influences whole V-BLAST performance. The major weakness of V-BLAST is an error propagation that is related to the interference for former detected symbols. The algorithm decodes the symbols from strongest symbol to weakest one. In order to find the first best symbol, the others are considered as noise, and then its effect has been cancelled. The second symbol is processed from a new group of equations and so on. This algorithm includes three processes such as ordering, interference nulling and interference cancellation (subtracting). As it is demonstrated in (Cho et al., 2010), there are four different approaches of an ordering stage.

A. Approach 1: Ordering based on SINR

Higher SINR symbol is detected first. It can be assumed that the MMSE detector uses for the receiver with SINR ordering given as:

$$\mathbf{SINR}_i = \frac{\mathrm{E_x}|\mathbf{w}_{i,MMSE}\mathbf{h}_i|^2}{\mathrm{E_x}\sum_{l\neq i}|\mathbf{w}_{i,MMSE}\mathbf{h}_i| + \sigma_n^2\|\mathbf{w}_{i,MMSE}\|^2} \quad (7)$$

Where $i = 1,2,\ldots,N_t$, Ex is symbol energy, $\mathbf{w}_{i,MMSE}$ is i^{th} row of weight matrix, l is l^{th} symbol that was subtracted from the received signal, and $\mathbf{h}_i$ is i^{th} column vector of $\mathbf{H}$ matrix.

B. Approach 2: Ordering based on SNR

This can be used with ZF detector.

$$\mathrm{SNR_i} = \frac{\mathrm{E_x}}{\sigma_n^2\|\mathbf{w}_i\|^2}, \quad \mathrm{i} = 1,2,\ldots,\mathrm{N_t} \quad (8)$$

It is same as the first one but this considers SNR rather than SINR.

C. Approach 3: Ordering based on column norm

This method has less computationally expensive than the previous ones. It can calculate the vector norm for the channel matrix. If we consider the received signal like this

$$\boldsymbol{y} = \mathbf{Hx} + \mathbf{n} = \mathbf{h}_1(x_1 - \hat{x}_1) + \mathbf{h}_2 x_2 + \cdots + \mathbf{h}_{Nt} x_{Nt} + \mathbf{n} \quad (9)$$

It can observe the strongest transmitted symbol from i^{th} column vector of channel matrix based on the vector norm $\|\mathbf{h}_i\|$ of the channel matrix and orders them.

D. Approach 4: Ordering based on the received signal

In former approaches, the noise characteristics and channel gain are used to detect ordering. However, this technique decides the ordering based on the received signal to attain better performance. It merely works by ordering once whereas the channel matrix is the same. The main difference between the V-BLAST and previous equalization is the interference cancellation and ordering processes. If we take out these stages, it can detect symbols by using ZF or MMSE for interference nulling that works to suppress the interference with a nulling operation by finding a null subspace that is an orthogonal vector onto the received signal vector (Jafarkhani, 2005; Shreedhar et al., 2012).

VI. OPERATING ALGORITHM OF V-BLAST WITH ZF

V-BLAST can be implemented in an iterative way to enhance the performance. Decoding strongest symbol and subtracting its effect from the received signal has many benefits to reduce the interference level. The V-BLAST algorithm with ZF works as follows:

1. Initialize.
2. Generate the weight matrix by taking the pseudo-inverse of $\mathbf{H}$ ($\mathbf{G}_1 = \mathbf{W}_{\mathrm{ZF,k}}^{i} = \mathrm{H}_{\mathrm{k}}^{i\,\dagger} = (\mathbf{H}_{\mathbf{k}}^{i\,H}\mathbf{H}_{\mathbf{k}}^{i})^{-1}\mathbf{H}_{\mathbf{k}}^{i\,H}$).
3. *j*=1.
4. Ordering symbols based on approach 3 of ordering

TABLE I
CHANNEL PARAMETER CONFIGURATION MULTIPATH ENVIRONMENT (GHYADH, 2012)

Environment													
User-defined	Delay (∇) (0.1*1e-7)	0											
	Gain (PdB)	0											
Rural area	Delay (∇) (0.1*1e-7)	0	1	2	3	4	5						
	Gain (PdB)	0	-4	-8	-12	-16	-20						
Typical urban	Delay (∇) (0.1*1e-7)	0	2	4	6	8	12	14	18	24	30	32	50
	Gain (PdB)	-4	-3	0	-2	-3	-5	-7	-5	-6	-9	-11	-10
Bad urban	Delay (∇) (0.1*1e-7)	0	2	4	8	16	22	32	50	60	72	82	100
	Gain (PdB)	-7	-3	-1	0	-2	-6	-7	-1	-2	-7	-10	-15
Hilly terrain	Delay (∇) (0.1*1e-7)	0	2	4	6	8	20	24	150	152	158	172	200
	Gain (PdB)	-10	-8	-6	-4	0	0	-4	-8	-9	-10	-12	-14

approaches $(g_j = argmin\left\|(G_j)_n\right\|^2, \quad n \notin \{k_1 \dots k_{j-1}\})$.

Where $\left(G_j\right)_n$ is n^{th} row of $\mathbf{G}_1$ and $k_1 \dots k_{j-1}$ transmitted symbols.

5. Find the estimated symbol by nulling operation $(X_{g_j} = \left(G_j\right)_{k_j} * \boldsymbol{y}_j)$.
6. Slicing X_{g_j} to obtain $\hat{x}_{g_j}$ $(\hat{x}_{g_j} = Q(X_{k_j})$, where $Q(.)$ is a quantizing process to slice a nearest constellation point.
7. Perform cancellation of previous detected signal from the received vector ($\boldsymbol{y}_{i+1} = \boldsymbol{y}_i - (\mathbf{H}_k^i)_{k_j}\hat{x}_{k_j}$).
8. Produce a new pseudo-inverse for subsequent iteration $\mathbf{G}_{j+1} = \mathrm{W}_{\mathrm{ZF,k_j}}^i$.
9. j=j+1.

VII. THE LTE V-BLAST MIMO WITH KALMAN FILTER SCHEME

A simplified proposed model of V-BLAST and Kalman filter is introduced in the LTE Release 8 downlink in order to improve both the capacity and reliability of the LTE downlink system. All computer model realizations follow the 3GPP standard. The downlink transceiver chain is depicted in Fig. 3.

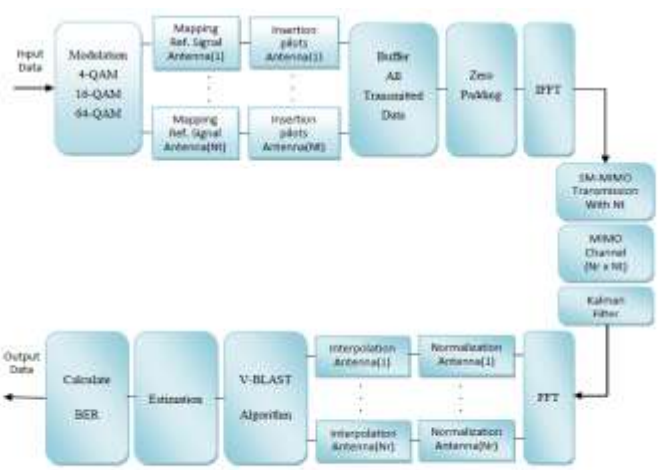

Fig. 3. LTE V-BLAST MIMO for the downlink transceiver

The first step of producing code is to generate 2 or 4 random data streams according to 2x2-MIMO or 4x4-MIMO respectively. Then, the data stream is modulated by QAM scheme such as 4-QAM, 16-QAM and 64-QAM. The higher modulation order can achieve effective use of bandwidth and obtain higher throughput. The second step is required to map the reference signals of distinct phases for antennas in certain positions. The reference signals are used to calculate the channel frequency response at the receiver. QPSK modulation is employed to modulate the pilot signal. Insertion of reference signals places the pilots into these positions. The transmitted data from all antennas are buffered. Next, the zero-padding process is necessary because of the IFFT size is greater than the number of subcarriers that is dependent on the system bandwidth. The subsequent step is to insert all data into IFFT block to create OFDMA symbols, which are directly pushed to *Nt* transmitted antennas to transmit over $N_t \times N_r$ MIMO channel. The next step is the operation of the channel model, various channel environments are employed such as AWGN or direct path, User-defined, Rural area, Typical urban, Bad urban, and Hilly terrain. These environments have different path gains and path delays as shown in Table I above.

The multipath affects the MIMO capacity and BER. The MIMO channel paradigm is operated on two radio channel types such as Rayleigh and Rician. The k-factor is equal to zero in case Rayleigh channel; and K-factor is 1000 in case Rician channel. Also, the MIMO channel included such parameters as the number of transmit and receive antennas, path gains (PdB), delay profile (∇), and Doppler shift (f_d).

$$f_d = \frac{F_c \times v}{c} \qquad (10)$$

Where F_C is carrier frequency in Hz, v is the velocity of the mobile equipment in Km/h and c is the speed of light through the space in m/s.

The correlation between antenna ports for both transmitter and receiver is not considered in this work to obtain high performance MIMO channel with flat fading scenario, and the distance between antennas should be large.

The receiving signal is processed through Kalman filter to estimate the present values of stochastic signal in the discrete time based on the history and the present value of another stochastic signal that is correlated with it. Kalman filter precisely works on the signals, which are produced via finite-dimensional linear dynamic system, and is excited via

AWGN. However, Kalman filter is inserted orthogonal projection as a fundamental gadget in the optimal estimation for the practical problems. Therefore, the Kalman filter is an optimal filter with lower computational requirement (Basar, 2009). Then, the receiving signal is applied to FFT block to demodulate the OFDMA symbols and the zero padding is removed from the received data. Subsequently, the obtained symbols have the same size as the number of subcarriers that is dependent on the system bandwidth. The next process is a pilot normalization because all reference signals have same amplitude but different phases. This process makes all reference signals have same amplitude and phase equal to 1 and zero degrees respectively. As a result, the channel frequency response is obtained from the normalization of reference signal. The subsequent step is the linear interpolation of pilots to estimate the frequency response of data subcarriers, which includes the calculation of imaginary pilots within resource blocks. The linear interpolations are performed vertically and horizontally for all pilot positions of antennas to evaluate the channel coefficients between two adjacent pilots. As a result, the channel matrix of H is calculated as shown in (11).

TABLE II
RELEASE 8 LTE DOWNLINK PHYSICAL LAYER PARAMETERS.

Parameter	Value
Frequency range	UMTS FDD and TDD
Bandwidth	1.4 MHz
No. of resource blocks	6
No. of subcarriers	72
Frequency division (Δf)	15KHz
FFT size	128
Cyclic prefix	Normal
Modulation scheme	4-QAM/16-QAM/64-QAM
Channel model	Rayleigh/Rician
Environment	AWGN/User-defined/Rural area /Typical urban/Bad urban and Hilly terrain
Antenna technology	MIMO
MIMO	2x2/4x4
Detection algorithm	ZF-V-BLAST/ ZF
Transmission mode	Opened Loop Spatial Multiplexing (OLSM)
Tx correlation	0
Rx correlation	0
UE speed	3Km/h
No. of UE	1
No. of BS	1
K-factor	1000
Duplexing	FDD
Multiple access scheme	OFDM
SNR (dB)	Varied
No. of frame has been transmitted	4

$$\mathbf{H} = \begin{bmatrix} h_{1,1} & \cdots & h_{1,Nt} \\ \vdots & \ddots & \vdots \\ h_{Nr,1} & \cdots & h_{Nr,Nt} \end{bmatrix} \quad (11)$$

The following step extracts the corrected data from the received signal. The V-BLAST algorithm is applied in our model to attain the spatial multiplexing. The V-BLAST algorithm is accomplished in three stages, namely: ordering, interference nulling and interference cancellation. In this simulation, the V-BLAST algorithm uses the ZF detector to find interference nulling and an approach 3 is employed as the ordering stage that is based on the vector norm to obtain highest transmitted symbols. Then, the corrected symbols are demodulated to bits representation according to the QAM order. Finally, the bit error rate is calculated for the simulation model.

VIII. SIMULATION PARAMETERS

The proposed paradigms of LTE V-BLAST MIMO and LTE SISO have been performance evaluated under Release 8 LTE specifications. The key parameters of the simulation are listed in Table II.

IX. SIMULATION RESULTS

In this section, the proposed model of LTE V-BLAST MIMO with Kalman filter is simulated with different channel types, environments and modulation orders. The comparison of proposed model for LTE MIMO receiver with the LTE SISO system in terms of the capacity and BER are presented. Also, the proposed model of LTE MIMO with Kalman filter has been tested with the V-BLAST algorithm and ZF linear detector. All results have been obtained by changing of these parameters such as SNR, QAM order, channel type and environment.

A. BER comparison of different environments and QAM orders for LTE V-BLAST 2x2-MIMO with Kalman filter

In this subsection, we will show the simulation results of the system performance for the proposed receiving model for LTE 2x2-MIMO across different modulation orders and environments over Rayleigh channel.

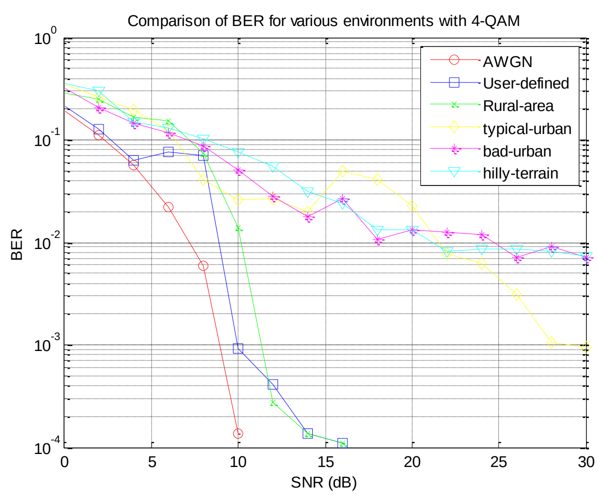

Fig. 4. BER comparison of various environments with 4-QAM for LTE V-BLAST 2x2-MIMO with Kalman filter over Rayleigh channel

Fig. 4 shows that the 4-QAM order has lowest BER values during all points over AWGN, it has just a direct path or a LoS component. The reason for this is that the AWGN has no multipath propagation, i.e., it has no ISI effect. Due to the

User-defined environment has a LoS component and one echo or reflection, it becomes in the second place after AWGN in terms of BER calculation. The Hilly terrain and Bad urban have almost same values of BER. Typical urban and Rural area environments are approximately same for all SNR values which are lower than 8 dB, after that point the Rural area has very much lower BER ratio than Typical urban. Fig 5 and 6 visualizes 16-QAM and 64-QAM orders respectively.

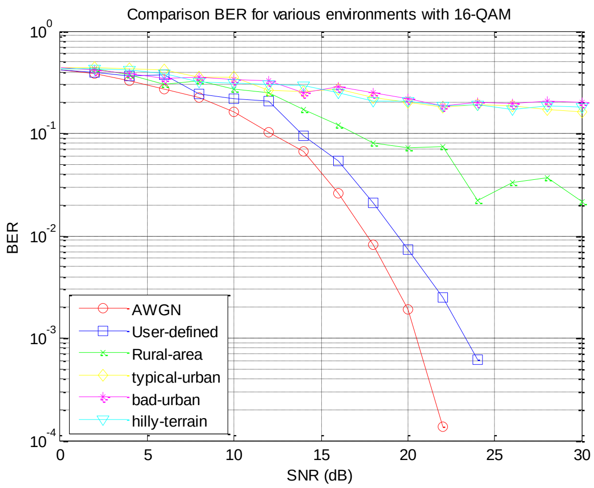

Fig. 5. BER comparison of various environments with 16-QAM for LTE V-BLAST 2x2-MIMO with Kalman filter over Rayleigh channel

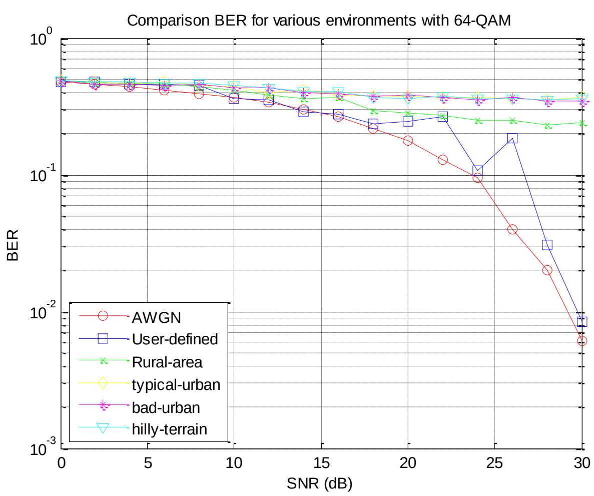

Fig. 6. BER comparison of various environments with 64-QAM for LTE V-BLAST 2x2-MIMO with Kalman filter over Rayleigh channel

A higher modulation order means more bits per symbol per second to be transmitted to achieve higher spectral efficiency. It is clearly seen that more bit errors to be occurred with higher modulation order.

B. BER comparison between LTE SISO and LTE V-BLAST 2x2-MIMO with Kalman filter

In this subsection, both systems have 16-QAM and tests for various environments over Rayleigh channel. However, as depicted in Fig. 7 a Fig. 8, the LTE SISO system has a better performance than the LTE V-BLAST 2x2-MIMO with Kalman filter system. Fig. 7 shows that same the BER value of LTE SISO can be obtained by increasing 1dB power for LTE MIMO. From Fig. 9, our proposed receiving model has started to be best than LTE SISO with higher SNR.

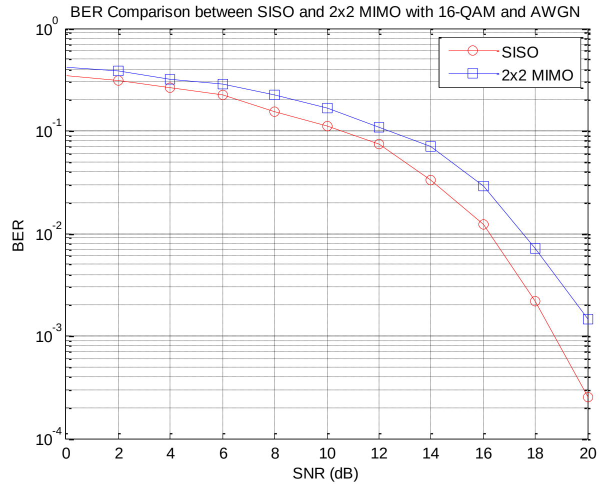

Fig. 7. LTE V-BLAST 2x2-MIMO with Kalman filter vs. LTE SISO with 16-QAM and AWGN environment over Rayleigh channel

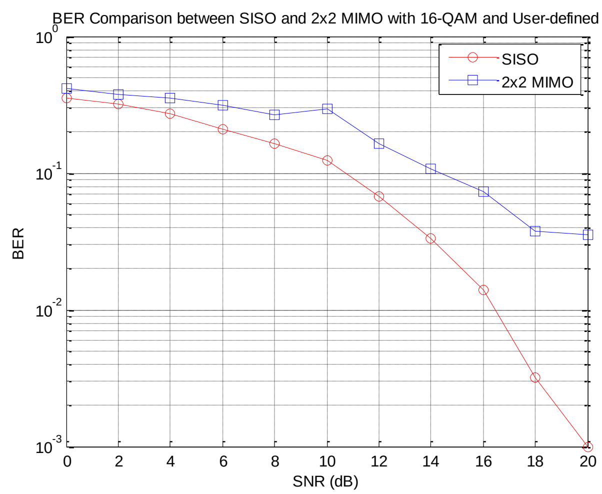

Fig. 8. LTE V-BLAST 2x2-MIMO with Kalman filter vs. LTE SISO with 16-QAM and User-defined environment over Rayleigh channel

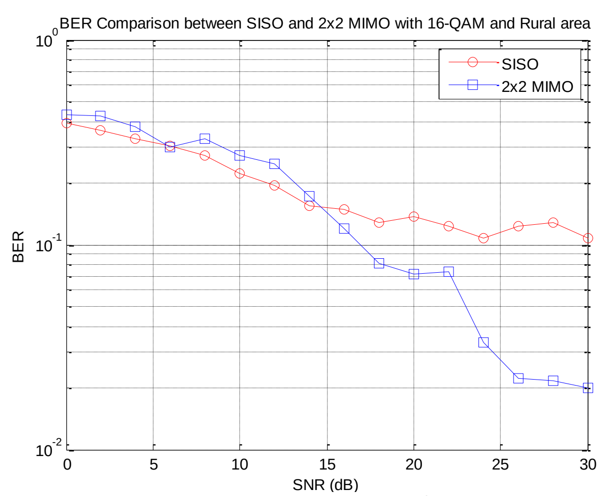

Fig. 9. LTE V-BLAST 2x2-MIMO with Kalman filter vs. LTE SISO with 16-QAM and Rural area environment over Rayleigh channel

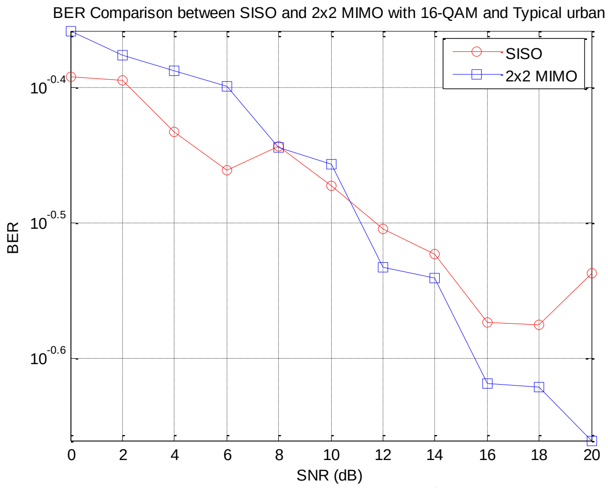

Fig. 10. LTE V-BLAST 2x2-MIMO with Kalman filter vs. LTE SISO with 16-QAM and Typical urban environment over Rayleigh channel

Fig. 10 shows that the proposed receiving model for LTE MIMO has lower BER calculation than LTE SISO with SNR values that are higher than 11dB.

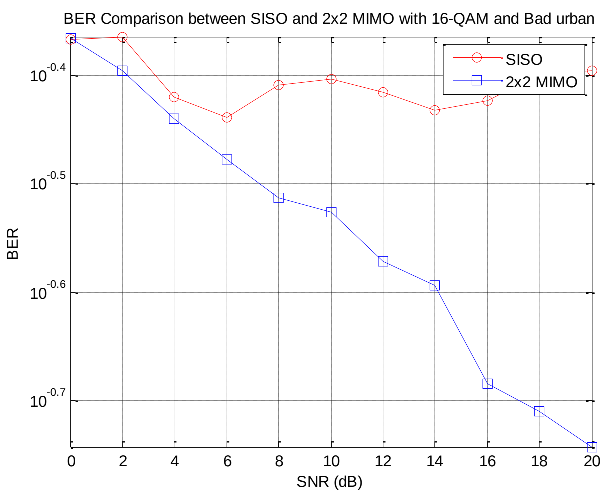

Fig. 11. LTE V-BLAST 2x2-MIMO with Kalman filter vs. LTE SISO with 16-QAM and Bad urban environment over Rayleigh channel

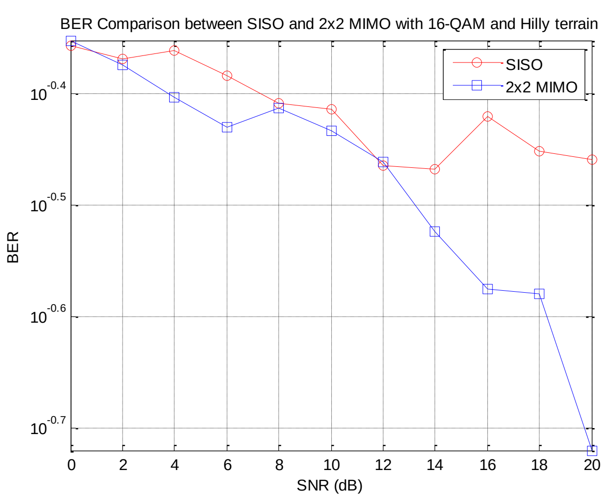

Fig. 12. LTE V-BLAST 2x2-MIMO with Kalman filter vs. LTE SISO with 16-QAM and Hilly terrain environment over Rayleigh channel

From Fig. 11 and Fig. 12, LTE V-BLAST 2x2-MIMO with Kalman filter has a better performance than LTE SISO for all SNR values. It can be concluded that LTE V-BLAST 2x2-MIMO with Kalman filter has a better performance than LTE SISO in higher multipath propagation environments. Thus, our proposed model is a robust receiving model with a good reliability for practical applications in dense urban cities.

C. BER comparison between different channel models

In this subsection, the proposed receiving model of LTE V-BLAST 2x2-MIMO with Kalman filter has been evaluated for both Rayleigh and Rician channels over Hilly terrain environment. The modulation order is set to 4-QAM. The Rayleigh channel has a zero value of k-factor, which can be defined as the power ratio of the direct path to the power ratio of scattered paths (reflected paths). The Rayleigh has no LoS component. However, the Rayleigh channel has a lower BER than Rician channel as shown in the Fig. 13. The proposed model will be more convenient for real environment of mobile communication with no LoS component.

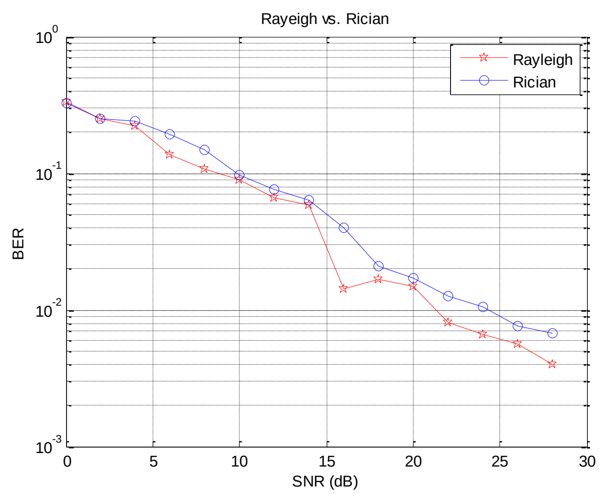

Fig. 13. BER comparison between Rayleigh and Rician channels for LTE V-BLAST 2x2-MIMO with Kalman filter over Hilly terrain environment

D. BER Comparison of ZF and V-BLAST detectors

In this subsection, our proposed receiving model of LTE 2x2-MIMO with Kalman filter has been tested with both the V-BLAST algorithm and ZF linear detector. The simulation is carried out with 16-QAM and various environments over Rayleigh channel.

It is clearly visualized that the V-BLAST algorithm has a less BER than ZF over all environments, the difference becomes more noticeable in multipath environments such as User-defined, Rural area, Typical urban, Bad urban, and Hilly terrain. However, V-BLAST is more reliable than ZF because of V-BLAST has three stages ordering, interference nulling and interference cancellation compared with ZF which has just interference nulling. These two new stages in V-BLAST produce benefits and better performance in terms of BER.

Therefore, the combination of V-BLAST with Kalman achieves higher performance than traditional linear detector. This combination of LTE MIMO receiver can also improve the capacity of the system as shown in the subsequent section.

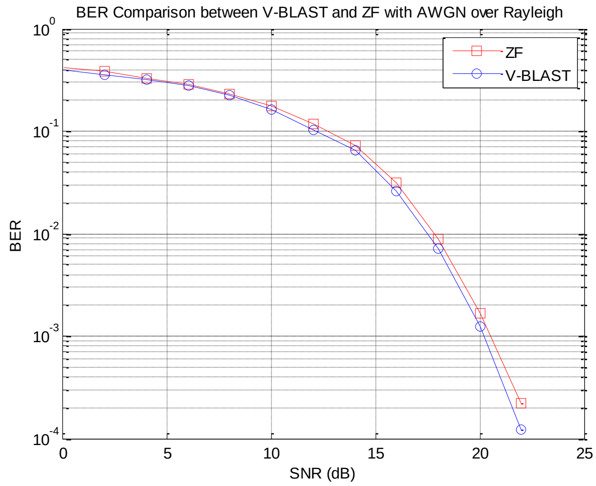

Fig. 14. BER comparison of LTE 2x2-MIMO with Kalman filter between the V-BLAST algorithm and ZF linear detector over AWGN environment and Rayleigh channel

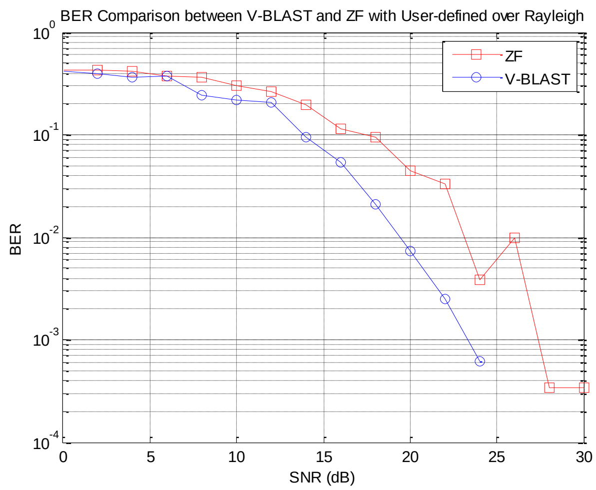

Fig. 15. BER comparison of LTE 2x2-MIMO with Kalman filter between the V-BLAST algorithm and ZF linear detector over User-defined environment and Rayleigh channel

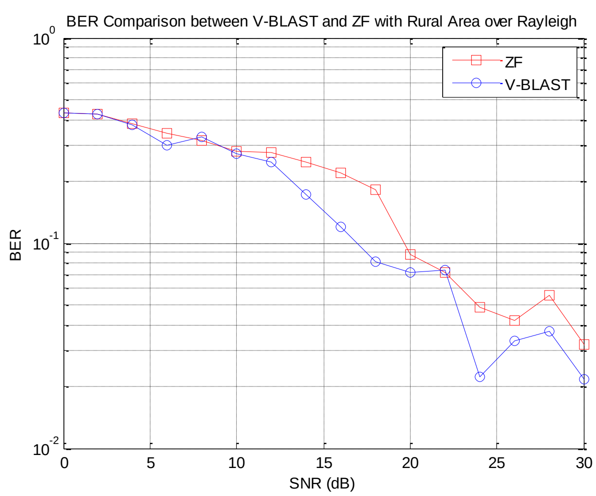

Fig. 16. BER comparison of LTE 2x2-MIMO with Kalman filter between the V-BLAST algorithm and ZF linear detector over Rural area environment and Rayleigh channel

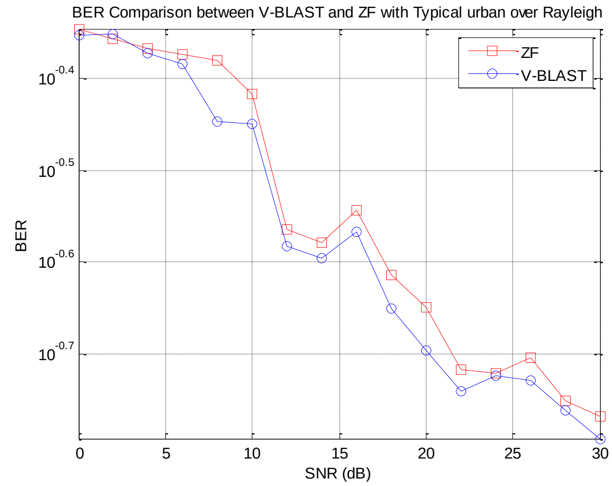

Fig. 17. BER comparison of LTE 2x2-MIMO with Kalman filter between the V-BLAST algorithm and ZF linear detector over Typical urban environment and Rayleigh channel

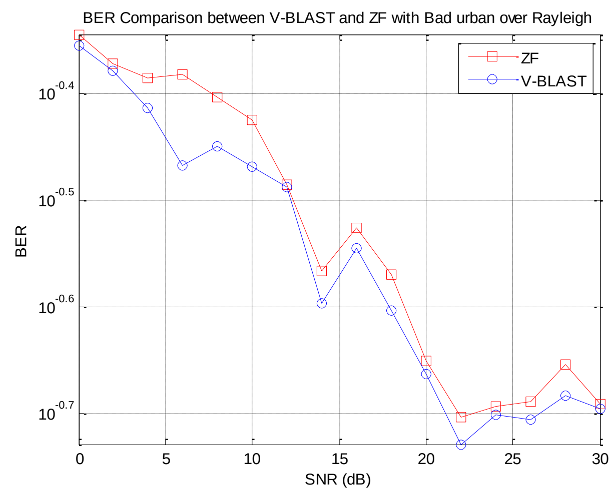

Fig. 18. BER comparison of LTE 2x2-MIMO with Kalman filter between the V-BLAST algorithm and ZF linear detector over Bad urban environment and Rayleigh channel

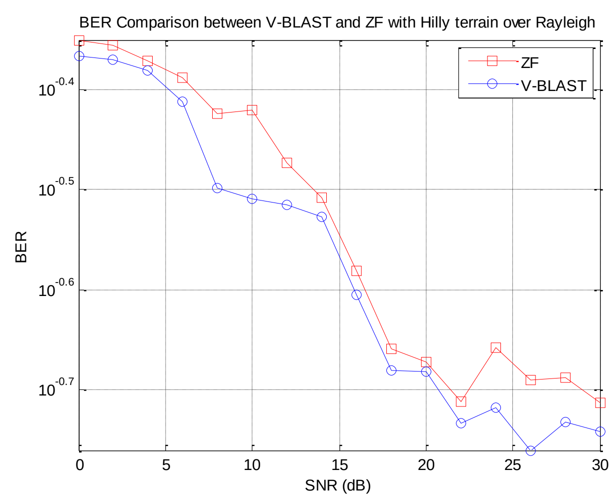

Fig. 19. BER comparison of LTE 2x2-MIMO with Kalman filter between the V-BLAST algorithm and ZF linear detector over Hilly terrain environment and Rayleigh channel

E. Capacity comparison between LTE V-BLAST MIMO and LTE SISO

In this subsection, we will measure the capacity of proposed system (LTE V-BLAST 2x2/4x4-MIMO with Kalman filter) and LTE SISO. Both systems use 4-QAM with AWGN environment over Rayleigh channel.

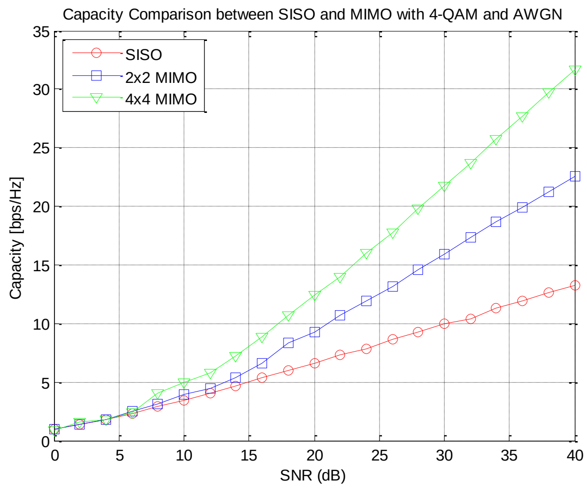

Fig. 20. The capacity of LTE V-BLAST MIMO with Kalman filter vs. LTE SISO with 4-QAM and AWGN environment over Rayleigh channel

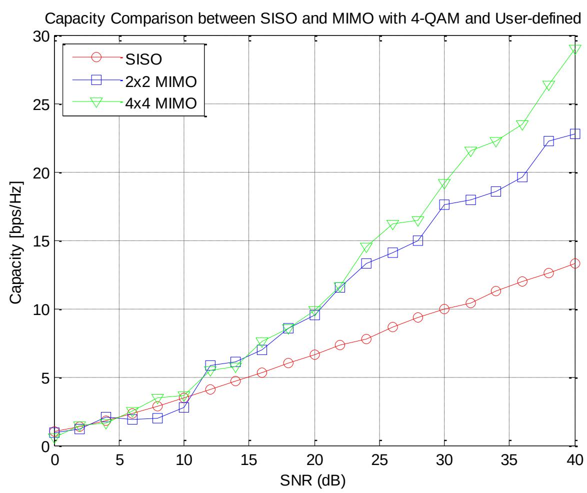

Fig. 21. The capacity of LTE V-BLAST MIMO with Kalman filter vs. LTE SISO with 4-QAM and User-defined environment over Rayleigh channel

As shown in Fig. 20, the capacity of the LTE V-BLAST 2x2-MIMO and 4x4-MIMO with Kalman filter system are 1.6 times and 2.2 times larger than LTE SISO respectively. The MIMO capacity is not exactly twice because of some positions in the LTE physical resource block are reserved for pilots (reference signals) which are increased with the number of antennas. As stated in (Cho et al., 2010; Arbi et al., 2015), the system capacity relies on the structure of the channel, SNR and number of transmitted antenna as shown in (12).

$$C_{mimo} = \log_2 \det\left(\mathbf{I}_{Nr} + \frac{\mathrm{SNR}}{\mathrm{N_t}}\mathbf{HH}^H\right) \qquad (12)$$

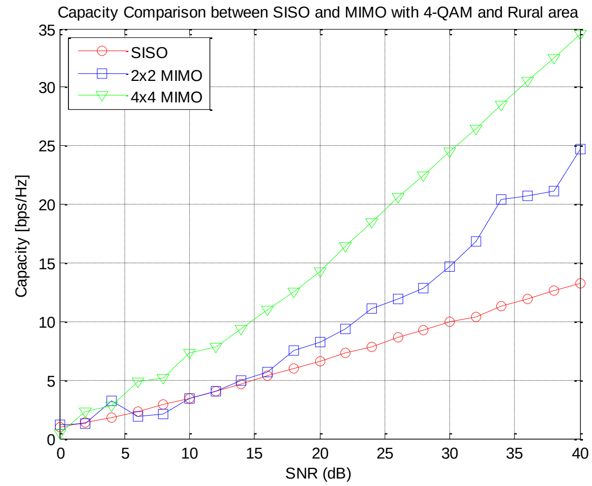

Fig. 22. The capacity of LTE V-BLAST MIMO with Kalman filter vs. LTE SISO with 4-QAM and Rural area environment over Rayleigh channel

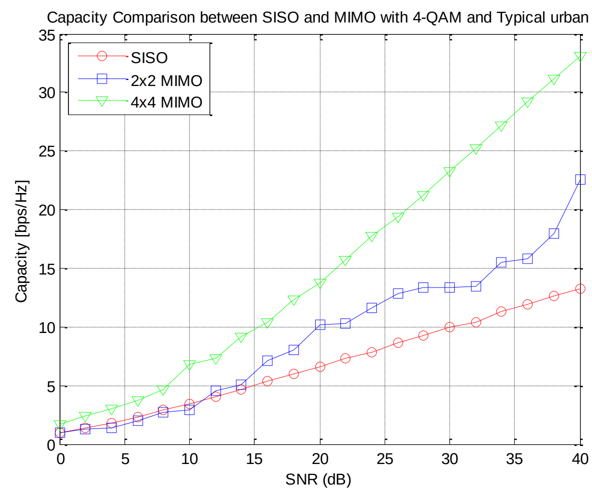

Fig. 23. The capacity of LTE V-BLAST MIMO with Kalman filter vs. LTE SISO with 4-QAM and Typical urban environment over Rayleigh channel

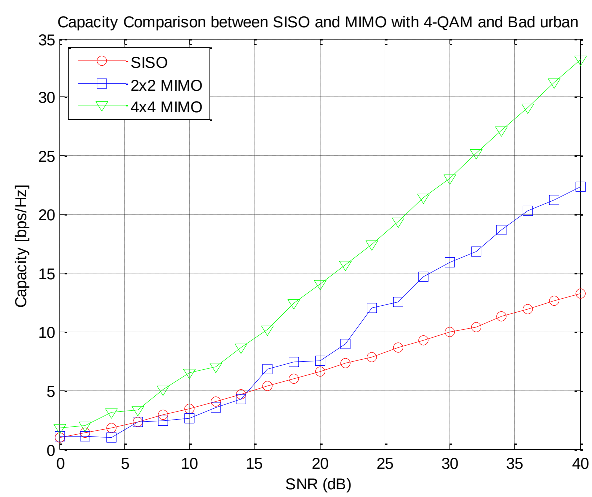

Fig. 24. The capacity of LTE V-BLAST MIMO with Kalman filter vs. LTE SISO with 4-QAM and Bad urban environment over Rayleigh channel

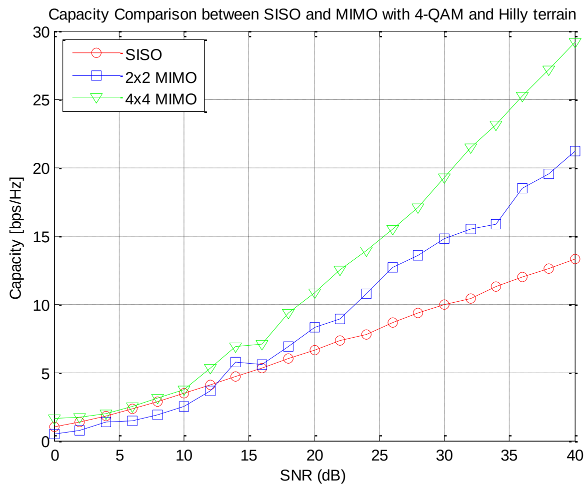

Fig. 25. The capacity of LTE V-BLAST MIMO with Kalman filter vs. LTE SISO with 4-QAM and Hilly terrain environment over Rayleigh channel

As in Fig. 21, 4x4-MIMO and 2x2-MIMO have approximately same capacity for all SNR values, which are lower than 23 dB, and then 4x4-MIMO has a better capacity than 2x2-MIMO for higher SNR values. Fig. 22 shows that the maximum capacity of 4x4-MIMO system has been achieved in Rural area environment. The 4x4-MIMO system has very high capacity in the other multipath environments such as Typical urban, Bad urban, and Hilly terrain. Therefore, our proposed receiving model for LTE MIMO system achieves highest performance with higher number of multipath environments in terms of higher capacity and lower BER calculation.

F. LTE V-BLAST MIMO capacity for different environments

In this subsection, the capacity of LTE V-BLAST 2x2/4x4-MIMO with Kalman filter has been calculated for various environments over Rayleigh channel. The proposed receiving model utilizes 4-QAM modulation order.

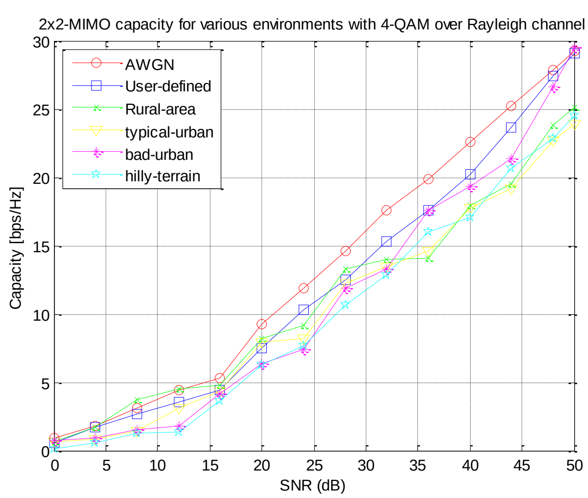

Fig. 26. The capacity of LTE V-BLAST 2x2-MIMO with Kalman filter for different environments with 4-QAM over Rayleigh channel

From Fig. 26, the proposed receiving model of LTE V-BLAST 2x2-MIMO with Kalman filter attains highest capacity in AWGN environment because it is a simple environment with just a LoS component and lowest BER level.

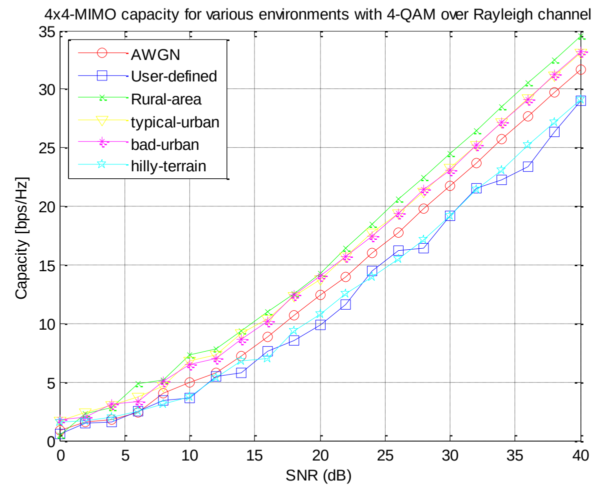

Fig. 27. The capacity of LTE V-BLAST 4x4-MIMO with Kalman filter for different environments with 4-QAM over Rayleigh channel

It is clearly seen that LTE V-BLAST 4x4-MIMO with Kalman filter has highest capacity in Rural area environment than other environments. As we previously discussed in subsection B and subsection E, our proposed receiving model for LTE MIMO system achieves highest performance in multipath environments.

X. CONCLUSION

The V-BLAST technique is an optimal receiving algorithm with high multiplexing gain, which just requires CSI to be available at the receiver. The pre-coding is not important. This means that there is no requirement for feedback of CSI to the transmitter. This enables high bandwidth and reduces the computational complexity of transmitted and received devices with longer battery lifetime of mobile units. This paper studied the physical layer of LTE network. This work has been aimed to improve the LTE MIMO system capacity and reliability by using a new combination of the V-BLAST algorithm with Kalman filter, which have many merits in terms of complexity, power and interference. The simulation results gave a clear picture about LTE V-BLATS MIMO with Kalman filter performance. The proposed receiving model achieved highest reliability and capacity in multipath environments. Furthermore, the results show that the LTE MIMO system with the V-BLAST technique and Kalman filter has a less BER calculation than ZF linear detector over all environments. In the future work, other cost functions can be introduced to control additional computing-related resources such as complexity, BER and bandwidth.

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