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Quadrature spatial modulation on full duplex and half duplex relaying network

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ABSTRACT

Improving spectral efficiency is a major challenge in the wireless relaying networks. Spatial modulation (SM) yields a good solution to improve the spectral efficiency by employing multiple antenna diversity schemes. Quadrature spatial modulation (QSM) is a modern digital MIMO transmission technique, which exploits the advantages of spatial modulation in cooperative communication. QSM promises improvement in spectral efficiency and reliability of communication is enhanced. In QSM system, inter channel interference (ICI) is evaded entirely due to the orthogonality of the two transmitted data and modulated on the real and imaginary parts of the carrier signals. A quadrature modulation technique in full-duplex and the half duplex cooperative relay network is implemented by employing decode and forward protocol. The analytical model of the system is proposed and evaluated for error performance. The Bit error rate performance of spatial modulation and quadrature spatial modulation are compared. Results show that QSM has better performance and better spectral efficiency in cooperative relay network.

1. INTRODUCTION

Cooperative diversity is a multiple antenna technique for improving or maximizing total network channel capacities for any given set of bandwidth which exploits user diversity by decoding the combined signal of the relayed signals and the direct signal in the wireless multi-hop networks. By implementing a quadrature spatial modulation in full duplex (FD) and half duplex (HD) relaying, the performance of spectral efficiency can be improved. In the relaying network operates on the decode-and-forward protocol. The signal received from the source to the destination is not considered as interference. The general successive interference cancellation (SIC) to eliminate the concurrently received signal at the destination has been avoided. In full duplex mode, SIC method is used at the destination to cancel the signals that are transmitted simultaneously from the source and relay. In case of half duplex mode, there are two signals which are transmitted at two adjacent time slots. The overall end-to-end bit error rate (BER) of the hybrid relaying network is studied.

In quadrature spatial modulation, the symbols are separated as In-phase and quadrature phase components. The real and imaginary parts of the signal constellation are transmitted in different dimensions of transmission. In the conventional spatial modulation, the real and imaginary parts are transmitted using a single transmit antenna which will avoid the inter channel interference (ICI) at the receiver input. In case of QSM system, ICI is eliminated as the real and imaginary parts are orthogonal and modulated over the real part and the imaginary parts of the carrier signal. By implementing quadrature spatial modulation technique, the performance of spectral efficiency can be improved in full duplex.

Full duplex achieves better spectral efficiency in quadrature spatial modulation than the QSM over a half duplex communication. In [1], Ruoguang Li examined the type of hybrid relay network employing Decode and forward relaying with help of bit error rate performance. Unlike the general consideration of the signal from source to destination as interference signal, a new method of successive interference cancellation (SIC) which separates the concurrently received signal at the destination is examined. In [2], the common half duplex relaying (HDR) system is compared with the full duplex relaying (FDR) where there is a potential increase in the spectral efficiency by using the same frequency for receiving and retransmitting simultaneously. In [3] T. Riihonen proposed a hybrid relaying scheme where the relay works opportunistically by switching between the FD and HD modes. The work is analyzed for both AF and DF relaying protocols, combining the transmit power adaption techniques in order to maximize the instantaneous and average spectral efficiencies. In [4], the network throughput is considerably improved by means of an optimal transmission scheduling scheme for hybrid half duplex and full duplex relay selection is proposed.

In [5], S.Tedik studied a FD system and derived a BER expression for the source, relay and destination nodes. It is a conventional practice that the S-D signal is treated as an interference in a full duplex relaying network. It can be also said that the assumption in FD network is that there is no direct $S \rightarrow D$ link. The primary reason for this assumption is the inability of the FD system to coherently combine the received signal at the destination by using maximum ratio combining (MRC). So, a sophisticated signal processing technique becomes mandatory to further utilize the direct link signal [6].

Compared to spatial modulation, quadrature spatial modulation achieves a better spectral efficiency. The channel estimation errors are less in QSM system than the conventional

SM system while the spectral efficiency achieved is considerably higher without losing most of SM's inherit advantages [7]. The author in [8] also proved that the MIMO schemes such as Alamouti and other SMUX are inferior to QSM for the desired spectral efficiency. In the use of in-phase and quadrature phase components in a different dimension of transmission gives QSM [9]. These Orthogonal real and imaginary components of a data symbol are transmitted using one or two antennas simultaneously. In [10], the combination of the cooperative relaying with the proposed QSM improves the overall spectral efficiency and enhances the overall communication reliability.

The concept of spatial modulation (SM) scheme for massive multiuser MIMO (MU-MIMO) system is analyzed in [11]. The authors in [12-14] have shown the performance analysis of QSM system by means of asymptotically tight expressions. The Quadrature Shift keying (QSSK), a special case of QSM which uses pragmatic SNR values are evaluated with asymptotically tight expressions and analyzed [12-14].

In [15], Islam Abu Mahady studied the performance of QSM-MIMO cognitive radio system in the presence of mutual primary-secondary co-channel interference and the average bit error rate (ABER) over Rayleigh fading channel is obtained. A closed form expression is also obtained for the average pair-wise error probability (PEP) of the secondary system is derived to get a tight bound expression. Further [16-19] illustrates the need for relaying in adhoc scenario of wireless sensor networks. Jun Tang et. al in [20] have given the advantage of using the sparse data for systems with huge amount of data hence the usage of schemes like QSM may have an advantage.

The average rate and outage probability of full duplex two-way and one-way relaying using a two relaying protocol amplify-and-forward protocol and decode-and-forward protocol are implemented. The application of physical layer network coding and analog network coding is evaluated in full duplex two-way relaying to achieve better performance than the full duplex one-way relaying.

The remaining portion of the paper is organized as follows: The section 2 gives a brief note on the Spatial and Quadrature modulation system. Section 3 discusses the analytical model for BER for QSM based full duplex and half duplex relaying. The simulation performance is obtained in the section 4 and the conclusion is given in the section 5.

2. MODULATION SCHEMES

A brief introduction to the conventional spatial modulation and the Quadrature spatial modulation is presented.

2.1 Spatial modulation

Very recently the spectral efficiency demand has paved for the Spatial Modulation concept for MIMO systems which is better than the Alamouti and other schemes. The targeted data rates are achieved at a reduced complexity and cost of multiple–antenna schemes without worsening the system performance. The less complex transceivers for communication achieving a high spectral efficiency are attained by adopting the simple modulation and coding mechanisms as given below:

First, in a multiple antenna system only one transmit–antenna is activated at a time for the transfer of data at any signaling time instance. The main advantage of such scheme is the complete avoidance of ICI which is a major problem at the relays. Also, there is no synchronization among the transmitting antenna and only one RF chain is used for data transmission. But in conventional MIMO schemes where the multiple–antennas has to be employed to get a better diversity order causing interference.

Secondly, the spatial position of each transmitting antenna in an antenna–array is used as a source of information. The data to be transmitted is considered as small blocks and each block conveys a one–to–one mapping between each antenna index and a block of information bits to be transmitted. A coding mechanism called transmit–antenna index coded modulation is used. The information is implicitly conveyed by the position of the transmit–antenna giving a good multiplexing gain for the SM systems. Despite the fact that only one reception apparatus is dynamic, SM can likewise accomplish high information throughput.

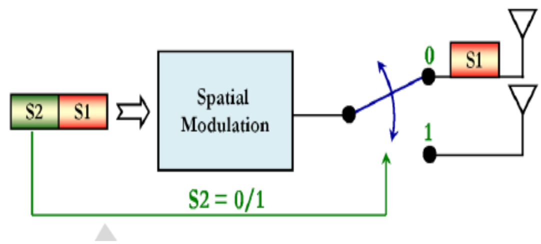

Figure 1. Spatial modulation technique

2.2 Quadrature spatial modulation

QSM is a technique for preparing the flag before transmission. The spatial constellation symbols of the QSM are denoted as in-phase and quadrature components. The symbols of SM are split here and are included in another dimension. The single antenna is not used here like SM to transmit data symbols. In the first dimension, the real part is transmitted and the other imaginary part is transmitted in another dimension or antenna. It merits specifying that, in regular SM, these two sections are transmitted from a solitary transmit reception apparatus to keep away from ICI at the collector input. Be that as it may, in a QSM framework, ICI is likewise maintained a strategic distance from altogether since the two transmitted information are orthogonal and regulated on the real part and the imaginary part of the signal. In other words, one part is transmitted on the cosine carrier and the other part is transmitted on the sine carrier. However, additional base-two logarithms of the number of transmit antenna bits can be transmitted in QSM, as compared with a conventional SM system.

3. DEVELOPMENT OF ANALYTICAL MODEL

The analytical expression for the full duplex relaying system and the half duplex system is proposed for employing the quadrature modulation system.

3.1 Full duplex relaying

In the FD mode of relaying, at any time slot t, the source S sends a signal $x_S(t)$ and it is received by both the relay R and the destination D. The relay R retransmits the received the signal from the source S as $x_R(t)$ which is decoded based on the previously received signal $y_R(t-1)$. Hence, the signal received at relay and destination can be expressed as:

$$y_R^{FD}(t) = \sqrt{P_S}h_{SR}x_S(t) + \sqrt{P_R}h_{RR}x_R(t) + n_R(t) \quad (1)$$

$$y_D^{FD}(t) = \sqrt{P_S}h_{SD}x_S(t) + \sqrt{P_R}h_{RD}x_R(t) + n_D(t) \quad (2)$$

SINR (signal-to-interference and noise ratio) is usually defined for a particular receiver (or user). In particular, for a receiver located at some point *x* in space (usually, on the plane), then its corresponding SINR is given by

$$SINR = \frac{P}{I+N} \quad (3)$$

where *P* is the power of the incoming signal of interest, *I* is the interference power of the other (interfering) signals in the network and *N* is noise term which may be a constant or random variable. The received SINR at the relay is given by:

$$\zeta^{FD}_{2SR} = \frac{|h_{SR}|^2 P_S}{\theta P_R + N_o} \quad (4)$$

where θP_R is the Residual self interference (RSI) power

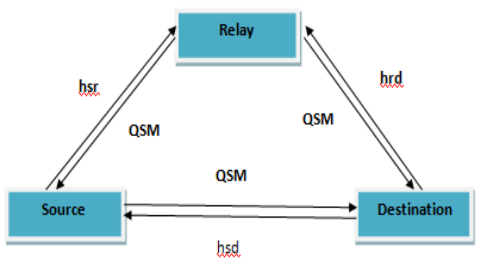

Figure 2. Relaying employing QSM

As discussed earlier, the signal from source to destination has to be avoided in FD mode. Hence, a SIC is implemented which considers the decoding of the received signals from source and relay logically based on the signal strengths. The stronger signal is considered with high priority and the other as an interfering signal. Usually, the signal from the R is stronger due to its location advantage as per our consideration. Hence, the SINR at the destination in the first phase of transmission in SIC is given as:

$$\zeta^{FD}_{2RD} = \frac{|h_{RD}|^2 P_R}{|h_{SD}|^2 P_S + N_o} \quad (5)$$

The signal obtained in the first phase is assumed to have cancelled the Interference perfectly. During the second phase there is only signal from the source at destination and hence the signal-to-noise ratio (SNR) at the destination can be reframed as:

$$\zeta^{FD}_{2SD} = \frac{|h_{SD}|^2 P_S}{N_o} \quad (6)$$

3.2 Half duplex relaying

In the HD mode, the reception and transmission of information happens at two different schedules. During the initial time slot 't' the source S transmits the signal $x_S(t)$ which is received by both the relay and destination. And during the next time slot 't+1', the transmission is done by the relay node only. The R transmits the re-encoded signal $x_R(t+1)$, to destination D. The source S is in idle state during the second phase. Hence, the received signals at the relay and destination can be expressed as:

$$y_R^{HD}(t) = \sqrt{P_S}h_{SR}x_S(t) + n_R(t) \quad (7)$$

$$y_D^{HD}(t) = \sqrt{P_S}h_{SD}x_S(t) + n_R(t) \quad (8)$$

$$y_D^{HD}(t+1) = \sqrt{P_R}h_{RD}x_R(t+1) + n_D(t+1) \quad (9)$$

respectively. From the convention the SNR of the $S \to R$ link and S→ D link during the first time slot can be defined as:

$$\zeta^{HD}_{2SR} = \frac{|h_{SR}|^2 P_S}{N_o} \quad (10)$$

$$\zeta^{HD}_{2SD} = \frac{|h_{SD}|^2 P_S}{N_o} \quad (11)$$

respectively. At the time slot *t*+1, the $R \to D$ link SNR is given as

$$\zeta^{HD}_{2RD} = \frac{|h_{RD}|^2 P_R}{N_o} \quad (12)$$

The average Pairwise error probability of the QSM system can be written as:

$$Pe(g_n \to \hat{g}_k) = \frac{1}{2}\left(1 - \sqrt{\frac{\frac{\zeta}{2}}{1+\frac{\zeta}{2}}}\right) \quad (13)$$

$$PEP = \frac{1}{2}\left(1 - \sqrt{\frac{\frac{\zeta}{2}}{1+\frac{\zeta}{2}}}\right) \quad (14)$$

The above equations are modified with the assumption of independence of the channels, noise and RSI. Then the PEP of S→ R channel can be rewritten as:

$$PEP_{SR}^{FD} = \frac{1}{2}\left(1 - \sqrt{\frac{\frac{\zeta_{SR}}{2}}{1+\frac{\zeta_{SR}}{2}}}\right) \quad (15)$$

where $\bar{\zeta}_{SR} = \frac{\lambda_{SR}P_S}{\theta P_r + N_o}$

While the implementation of SIC makes the analysis to be divided into two phases. The expressions correspondingly change the PEP and can be given as:

$$PEP_{RD}^{FD} = \frac{1}{2}\left(1 - \sqrt{\frac{\frac{\zeta_{RD}}{2}}{1+\frac{\zeta_{RD}}{2}}}\right) \quad (16)$$

$$PEP_{SD}^{FD} = \frac{1}{2}\left(1 - \sqrt{\frac{\frac{\zeta_{SD}}{2}}{1+\frac{\zeta_{SD}}{2}}}\right) \quad (17)$$

where

$$\bar{\zeta}_{RD} = \frac{1}{2}\left(\frac{\lambda_{RD}P_R}{\lambda_{SD}P_r+N_o}\right)$$

$$\bar{\zeta}_{SD} = \frac{1}{2}\left(\frac{\lambda_{SD}P_S}{N_o}\right)$$

It is noted that the error during the first phase of communication from source to relay and destination can be considered as a complement event for decoding of SIC at the destination detect the signals successfully. Similarly, the error that is present in the second phase is advantageous to detect stronger and weaker signals at the destination. The corresponding PEPs at the destination are given by:

$$BER^{1st} = 1-(1-BER_{SR}^{FD})(1-BER_{RD}^{FD}) \quad (18)$$

$$BER^{2nd} = 1-(1-BER_{RD}^{FD})(1-BER_{SD}^{FD}) \quad (19)$$

Now, the overall error is seen when the detection in both phases are wrong. Obviously the end to end PEP of the FD system can be expressed as:

$$BER_{overall}^{FD} = BER^{1st} * BER^{2nd} \quad (20)$$

The equation (18) can be elaborated as:

$$BER^{1st} = 1-\left(1-\frac{1}{2}\left(1-\sqrt{\frac{\frac{\zeta_{SR}}{2}}{1+\frac{\zeta_{SR}}{2}}}\right)\right)\left(1-\frac{1}{2}\left(1-\sqrt{\frac{\frac{\zeta_{RD}}{2}}{1+\frac{\zeta_{RD}}{2}}}\right)\right) \quad (21)$$

$$BER^{1st} = 1-\frac{1}{4}\left(1+\sqrt{\frac{\frac{\zeta_{SR}}{2}}{1+\frac{\zeta_{SR}}{2}}}\right)\left(1+\sqrt{\frac{\frac{\zeta_{RD}}{2}}{1+\frac{\zeta_{RD}}{2}}}\right) \quad (22)$$

Equation (19) can be written as:

$$BER^{2nd} = 1-\left(1-\frac{1}{2}\left(1-\sqrt{\frac{\frac{\zeta_{RD}}{2}}{1+\frac{\zeta_{RD}}{2}}}\right)\right)\left(1-\frac{1}{2}\left(1-\sqrt{\frac{\frac{\zeta_{SD}}{2}}{1+\frac{\zeta_{SD}}{2}}}\right)\right) \quad (23)$$

$$BER^{2nd} = 1-\frac{1}{4}\left(1+\sqrt{\frac{\frac{\zeta_{RD}}{2}}{1+\frac{\zeta_{RD}}{2}}}\right)\left(1+\sqrt{\frac{\frac{\zeta_{SD}}{2}}{1+\frac{\zeta_{SD}}{2}}}\right) \quad (24)$$

Hence, the overall PEP performance of full duplex is obtained as:

$$BER_{overall}^{FD} = \left[1-\frac{1}{4}\left(1+\sqrt{\frac{\frac{\zeta_{SR}}{2}}{1+\frac{\zeta_{SR}}{2}}}\right)\left(1+\sqrt{\frac{\frac{\zeta_{RD}}{2}}{1+\frac{\zeta_{RD}}{2}}}\right)\right]\left[1-\frac{1}{4}\left(1+\sqrt{\frac{\frac{\zeta_{RD}}{2}}{1+\frac{\zeta_{RD}}{2}}}\right)\left(1+\sqrt{\frac{\frac{\zeta_{SD}}{2}}{1+\frac{\zeta_{SD}}{2}}}\right)\right] \quad (25)$$

In case of the HD mode, the corresponding expressions of the PEP can be obtained in a very similar manner. The overall error occurs when both direct transmission and relay transmission are wrong and the overall end-to-end PEP in the HD mode can be expressed as:

$$BER_{overall}^{HD} = BER_{SD}^{HD}.[1-(1-BER_{SR}^{HD})(1-BER_{RD}^{HD})] \quad (26)$$

The PEP of S→ R channel can be expressed as:

$$BER_{SR}^{HD} = \frac{1}{2}\left(1-\sqrt{\frac{\frac{\zeta_{SR}^{HD}}{2}}{1+\frac{\zeta_{SR}^{HD}}{2}}}\right) \quad (27)$$

As the techniques involve SIC, the analysis has to be divided into two parts. The corresponding expressions of the PEP are given as:

$$BER_{SD}^{HD} = \frac{1}{2}\left(1-\sqrt{\frac{\frac{\zeta_{SD}^{HD}}{2}}{1+\frac{\zeta_{SD}^{HD}}{2}}}\right) \quad (28)$$

$$BER_{RD}^{HD} = \frac{1}{2}\left(1-\sqrt{\frac{\frac{\zeta_{RD}^{HD}}{2}}{1+\frac{\zeta_{RD}^{HD}}{2}}}\right) \quad (29)$$

Substituting equation (28) and (29) in (26)

$$BER_{overall}^{HD} = \frac{1}{2}\left(1-\sqrt{\frac{\frac{\zeta_{SD}^{HD}}{2}}{1+\frac{\zeta_{SD}^{HD}}{2}}}\right)\left[1-\left(1-\frac{1}{2}\left(1-\sqrt{\frac{\frac{\zeta_{SR}^{HD}}{2}}{1+\frac{\zeta_{SR}^{HD}}{2}}}\right)\right)\left(1-\frac{1}{2}\left(1\sqrt{\frac{\frac{\zeta_{RD}^{HD}}{2}}{1+\frac{\zeta_{RD}^{HD}}{2}}}\right)\right)\right] \quad (30)$$

The overall BER performance of half duplex is expressed as:

$$BER_{overall}^{HD} = \frac{1}{2}\left(1-\sqrt{\frac{\frac{\zeta_{SD}^{HD}}{2}}{1+\frac{\zeta_{SD}^{HD}}{2}}}\right)\left[1-\frac{1}{4}\left(1+\sqrt{\frac{\frac{\zeta_{SR}^{HD}}{2}}{1+\frac{\zeta_{SR}^{HD}}{2}}}\right)\left(1+\sqrt{\frac{\frac{\zeta_{RD}^{HD}}{2}}{1+\frac{\zeta_{RD}^{HD}}{2}}}\right)\right] \quad (31)$$

3.1 Performance of QSM

Now, considering the performance analysis of Quadrature spatial modulation, it can be shown that:

$$\zeta = \begin{cases} \frac{E_S(\sigma_h^2-\sigma_e^2)}{2N_0+\sigma_e^2E_S} & if\ h_{l\Re} \neq \hat{h}_{l\Re}, h_{l\Im} \neq \hat{h}_{l\Im} \\ \frac{E_S(\sigma_h^2-\sigma_e^2)}{4N_0+\sigma_e^2E_S} & if\ h_{l\Re} = \hat{h}_{l\Re}, h_{l\Im} \neq \hat{h}_{l\Im}\ (or)\ h_{l\Re} \neq \hat{h}_{l\Re}, h_{l\Im} = \hat{h}_{l\Im} \end{cases} \quad (32)$$

There arise three different Scenarios based on the definition of σ_e^2 which are discussed below:

1) *Fixed* σ_e^2 : Without loss of generality, here it is considered, $h_{l\Re} \neq \hat{h}_{l\Re}, h_{l\Im} \neq \hat{h}_{l\Im}$. Which yields an asymptotic average PEP as:

$$BER \approx \frac{4^{N_r}2^{N_r-1}\Gamma(N_r+0.5)}{\sqrt{\Pi}(N_r)!} \times \left[\frac{\frac{1}{2}(|x_\Re|^2+|\hat{x}_\Re|^2)}{(\sigma_h^2-\sigma_e^2)\left(|x_\Re|^2+|\hat{x}_\Re|^2+|x_\Im|^2+|\hat{x}_\Im|^2\right)}\right]^{N_r} \quad (33)$$

From the equation (33), it is evident that BER is not function of $\frac{E_S}{N_0}$ which shows that increasing the signal to noise ratio (SNR) will have no effect on the error performance and the diversity gain is zero.

2) *Variable channel estimation error* $\sigma_e^2 = \frac{1}{E_S/N_0}$: The channel estimation error is the reciprocal of the SNR, such a case yields the asymptotic BER as:

$$BER \approx \frac{4^{Nr}2^{Nr-1}\Gamma(N_r+0.5)}{\sqrt{\Pi}(N_r)!}\left(\frac{1}{E_S/N_0}\right)^{N_r} \times \left[\frac{1+\frac{1}{2}(|x_{\Re}|^2+|\hat{x}_{\Re}|^2)}{\sigma_h^2\left(|x_{\Re}|^2+|\hat{x}_{\Re}|^2+|x_{\Im}|^2+|\hat{x}_{\Im}|^2\right)}\right]^{N_r} \quad (34)$$

where diversity gain of N_r is obtained in this case. Thus increasing the SNR enhances the BEP performance of the system.

3) *Perfect channel estimation* $\sigma_e^2 = 0$: It is an ideal system where the channel is perfectly known at the receiver. The asymptotic PEP reduces to

$$BER \approx \frac{4^{Nr}2^{Nr-1}\Gamma(N_r+0.5)}{\sqrt{\Pi}(N_r)!}\left(\frac{1}{E_S/N_0}\right)^{N_r} \times \left[\frac{1+\frac{1}{2}(|x_{\Re}|^2+|\hat{x}_{\Re}|^2)}{\sigma_h^2\left(|x_{\Re}|^2+|\hat{x}_{\Re}|^2+|x_{\Im}|^2+|\hat{x}_{\Im}|^2\right)}\right]^{N_r} \quad (35)$$

A diversity gain of N_r is achieved but the probability of error in equation (34) will be less than that of equation (35) due to the perfect knowledge of the channel.

4. SIMULATION RESULTS

In this section, simulation results for the Bit error rate of quadrature spatial modulation and spatial modulation are shown. Figure 3 shows the bit error rate of quadrature spatial modulation based on full duplex. In this channel estimation with zero variance noise, shows better performance than the channel estimation with variance 1/SNR. And two transmitting antennas are used for transmission, one for real part and another for imaginary part of symbols. The above graph shows at 5 dB, 3 bits got error out of 1500 bits in channel estimation with zero variance noise. In 7 dB channel estimation with variance 1/SNR shows, out of 1500 bits 3 bits got error. Finally, in QSM full duplex channel estimation with sigma =0 shows better performance.

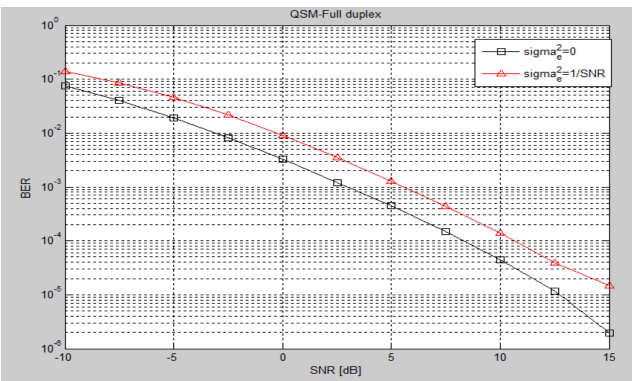

Figure 3. BER of QSM based FD

Figure 4 shows the bit error rate of quadrature spatial modulation based on half duplex. In this channel estimation with zero variance noise shows better performance than the channel estimation with variance 1/SNR. And two transmitting antennas are used for transmission, one for real part and another for imaginary part of symbols. The above graph shows at 5 dB, 2 bits got error out of 900 bits in channel estimation with zero variance noise. In 7 dB channel estimation with variance 1/SNR shows, out of 900 bits 2 bits got error. Finally, in QSM half duplex channel estimation with zero variance noise is superior.

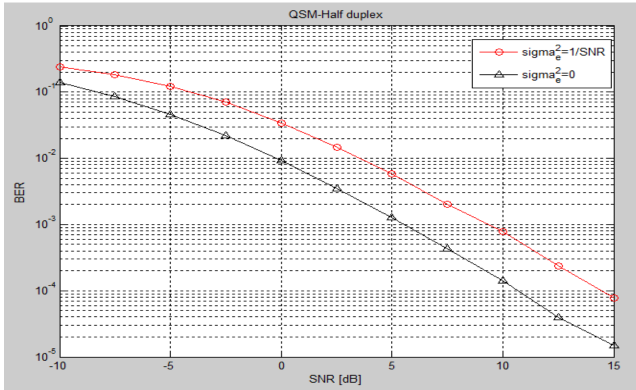

Figure 4. BER of QSM based HD

Figure 5 shows the bit error rate of spatial modulation based on full duplex. In this channel estimation with zero variance noise shows better performance than the channel estimation with variance 1/SNR. One transmitting antenna is used for transmitting both the real and imaginary part of symbols. In this at 5 dB, out of 980 bits, 2 bits got error at channel estimation with zero variance noise. In 13 dB channel estimation with variance 1/SNR shows, out of 990 bits, 2 bits got error. Finally, SM full duplex shows better performance at channel estimation with zero variance noise.

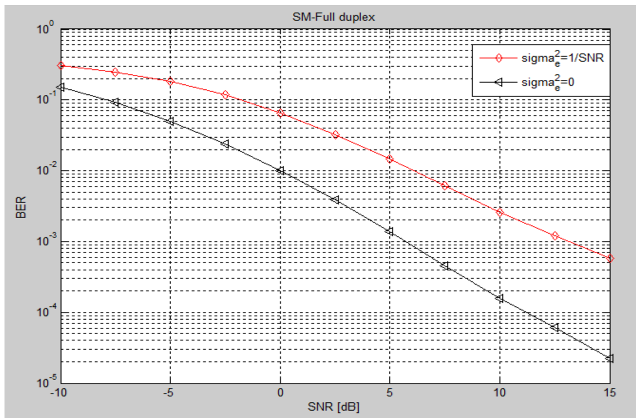

Figure 5. BER of SM based full duplex system performance

Figure 6 shows the bit error rate of spatial modulation based on half duplex. In this channel estimation with zero variance noise outperforms the channel estimation with variance 1/SNR. One transmitting antennas are used for transmitting both the real and imaginary part of symbols. At 5 dB, in channel estimation with zero variance noise, 1 bit got error out of 90 bits. In 8 dB channel estimation with variance 1/SNR, out of 90 bits 1 bit got error. Finally, in SM full duplex shows better performance at channel estimation with zero variance noise.

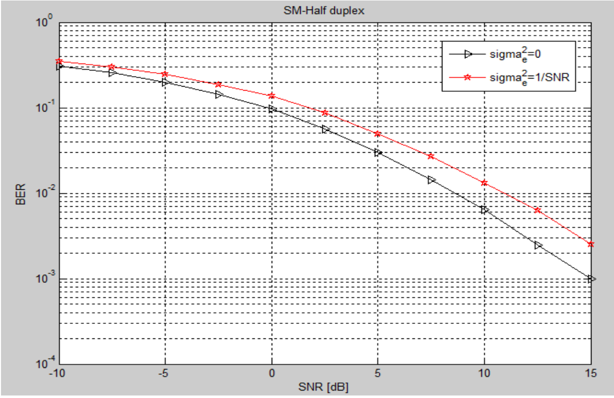

Figure 6. BER of SM based Half duplex system performance

Figure 7 shows the comparison of QSM and SM in FD and HD at $Sigma_e^2 = 0$. In this graph quadrature spatial modulation with full duplex shows the good performance. At 5 dB, in QSM full duplex out of 980 bits, 2 bits got error and in QSM half duplex out of 90 bits, 2 bits got error. At 5 dB, in SM full duplex out of 1500 bits 3 bits got error and in SM half duplex out of 90 bits, 1 bit got error. For QSM two transmitting antennas are required to transmit a symbol and for spatial modulation one antenna is sufficient to transmit a symbol.

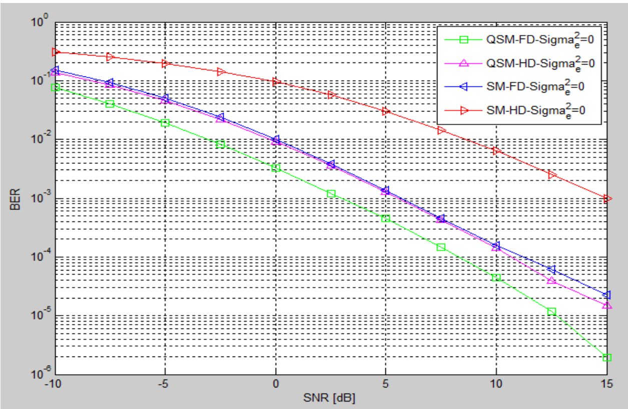

Figure 7. Comparison of QSM and SM System in FD and HD at $Sigma_e^2 = 0$

Figure 8 shows the comparison of QSM and SM in FD and HD at $Sigma_e^2 = 1/SNR$. At 7 dB, in QSM full duplex out of 1500 bits 3 bits got error and in QSM half duplex out of 900 bits, 2 bits got error. At 13 dB, in SM full duplex out of 990 bits, 2 bits got error and in 8 dB, SM half duplex out of 90 bits, 1 bit got error. For QSM two transmitting antennas are required to transmit a symbol and for spatial modulation one antenna is sufficient to transmit a symbol.

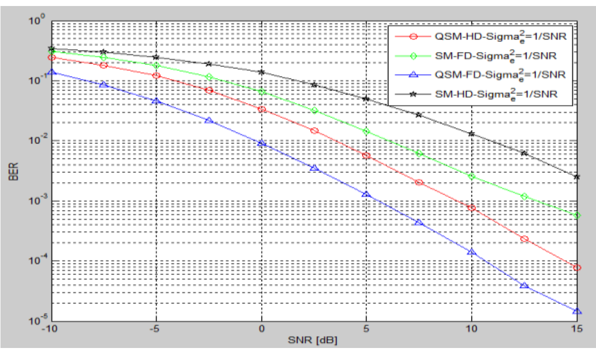

Figure 8. Comparison of QSM and SM in FD and HD at $Sigma_e^2 = 1/SNR$

5. CONCLUSION

Spatial modulation paves way for increased diversity in cooperative networks but with limited spectral efficiency. The QSM technique has an advantage as it capitalize the in-phase and quadrature phase components being transmitted in different dimensions avoiding ICI. The Orthogonality of the real and imaginary parts of a symbol is transmitted using QSM decode-and-forward cooperative system and performing ML decoding at the receiver. The QSM technique in full duplex and half duplex are implemented by employing DF protocol and the analytical model of the system is also proposed. By using this technique, the channel estimation of full duplex shows better performance than the spatial modulation. The simulation results show reduced bit error rate for QSM implementation. The performance of spectral efficiency can be improved by reducing the bit error rate.

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