Collision Warning System in Dynamic Cooperative Environment with Alamouti STBC Algorithm

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Abstract— **Emergency Medical Services (EMS) accident notification time is often delayed in areas with sparse cellular coverage and non-periodic communication access points. It is possible to mitigate such coverage gaps using cooperative communication which, by its distributed nature, does not rely on fixed base stations in remote areas. In the event of a collision EMS notification can be relayed through surrounding cellular equipped vehicles. This paper proposes a cooperative environment using Amplify and Forward (AF) protocol to communicate with the nearest accessible base station to transmit a collision message or even video for the first responders. The intent of the paper is to analyze the performance of different modulation techniques in this dynamic surrounding using Alamouti Space-Time Block coding (STBC) scheme for achieving spatial diversity. Use of multiple relay antennas is used to improve the diversity. Data is encoded using a space–time block code, and then split into n streams which are simultaneously transmitted using n transmit antennas. The paper examines if the cooperative relaying technique outweighs the advantages of a fixed relay system due to the dynamic nature of the highway.**

Keywords - ***Cooperative communication, Amplify-and-forward protocol, Alamouti STBC scheme, Multiple input Multiple output.***

I. Introduction

It is critical to get immediate medical care in case of an accident, especially in a remote location without a full cellular coverage. Sometimes it is not economically feasible to install and maintain full coverage of remote highways. The adaptive cooperation technique makes use of vehicles as relays in the vicinity to pass on the message to the nearest base tower. The wireless channel suffers attenuation due to destructive addition of multipath received at the Base Transmission Tower (BTS). The Rayleigh channel makes it difficult for the receiver to reliably determine the transmitted signal unless some less attenuated replica of the signal is provided to the receiver. Cooperation strategies have been recently developed in order to exploit space-time diversity even with single antenna terminals [11]. Amplify-and-Forward (AF) processing scheme based on the Alamouti space-time (ST) code, chosen because of its decoding simplicity. These terminals cooperate in order to form a virtual Multiple Input Multiple Output (MIMO) array and bring "cooperative diversity" and give better performance than point to point communication which is a Single Input Single output (SISO) which only uses the direct link [11]. By applying AF Alamouti processing Scheme to the non-Line of Sight (NLOS) channel where the direct link is supposed to be very weak or nonexistent, it is possible to achieve spatial and receive diversity. We assume a Rayleigh, slow fading channel, so that we can consider its coefficients as constant during the transmission of at least one block [11]. The signal broadcasted by the source of the signal is received by multiple vehicles which then relay the signal backwards to their neighbors and eventually to the BTS. The multiple transmitting and receiving environments makes up a virtual MIMO system. The intent of the paper is to illustrate that diversity achieved by the cooperative environment and performance of Alamouti STBC algorithm can be improved by using higher order modulation techniques like M-ary Phase Shift Keying (MPSK) and Quadrature Amplitude Modulation (QAM).

II. Cooperative collision warning system

In cooperative communications, the terminals dispersed in the surrounding area can be thought of as distributed antennas. Through cooperation among the surrounding nodes the system diversity gain can be increased. Due to the cooperative nature, the receiver is able to estimate the signal to noise ratio (SNR) of the link. This knowledge of the received SNR and the feedback from the destination improves the overall system performance in reconstructing the original message, In a hierarchal cooperation schemes linear scaling can be achieved by constructing the network as an adaptive Ad-Hoc network, which changes dynamically. As the density of the nodes per unit area increases the throughput per node does not drop. This can be done by dividing the network in clusters and making use of MIMO techniques [3].

Collision Warning System

One of the assumptions the paper is based on is that the remote areas have sporadic cellular coverage and the available BTS installations are not always in a Line-of-Sight (LOS). This makes it nearly impossible to call for emergency services in case of an accident or a collision.

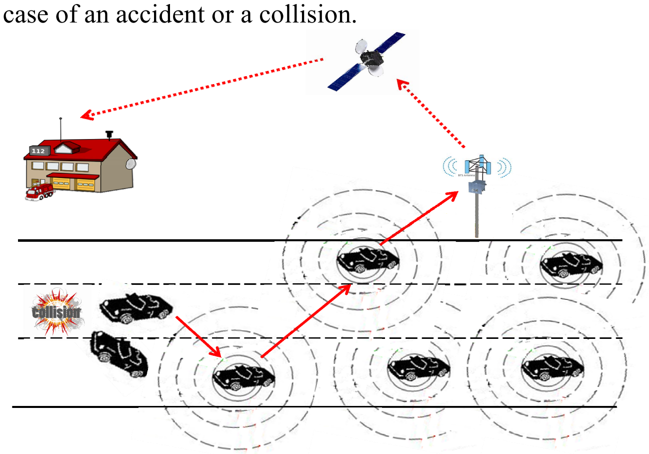

Figure 1: Cooperative collision warning system

This paper proposes an alternative for being able to notify the nearest first responder unit of the incident. One of the triggers to start a cooperative connection would be a collision in which air bags of one of the vehicles is deployed. The figure 2 illustrates a cooperative environment where in the vehicles in the vicinity of the collision automatically volunteer to act as relay, in the process of conveying the message containing the Global Positioning System (GPS) coordinates to the nearest BTS. The base station then relays the message to the over head satellite that would broadcast a 911 message to all first responder units in the surrounding area. Thus in-spite of absence of any cellular service the individuals involved in the collision would get the medical attention that would avoid any fatalities. A satellite broadcast allows the message to be accessed across several different agencies. The figure also shows a tentative path the message can take to reach the first responder unit via the BTS.

Cooperative Communication Technique

In a single relay model the relay channel contains a single node which acts as a basic relay that is in the range of the signal transmitted by the source. The source broadcasts the information that takes two separate paths, first directly to the destination and second through the relay. The relay implements a specified processing scheme and transmits it to the destination. In the AF processing scheme the relay amplifies the received signal without decoding the content and forwards it to the destination. Although In the AF cooperation scheme the relay amplifies not only the received signal but also the noise from the channel between the relay and the source. spatial diversity is gained by transmitting the signal over two spatially independent channels. The received signal at each receive antenna is a linear superposition of the *n* transmitted signals perturbed by noise.

The cooperative communication strategy is divided into two phases where the orthogonal signal is transmitted over the two independent channels. Considering the broadcast nature of the source the phase I comprise of source directly sending the information to the destination. The Phase II comprises of an intermediate relay forwarding the broadcasted information to the destination [5]. For an AF processing scheme the intermediate relay amplifies the received signal and forwards it to the destination with transmit power P_2. In the AF processing scheme the channel coefficients $h_{s,d}$, $h_{s,r}$ and $h_{r,d}$ are assumed to be known by the destination. Performance comparison of basic cooperation protocol with several modulation techniques. Where $I(x,y)$ a random variable is mutual information of the channel with inputs x and y. The transmitted symbol x, y have average energy 1. The information passage can be bifurcated into two phases, the first phase consists of source broadcasting the information to relay and the base station.

Part 1 of Phase I : Source to Relay

$$y_{s,d} = \sqrt{P_1}\, h_{s,d} \cdot x + n_{s,d} \tag{1}$$

Part 1 of Phase I : Source to Base Transmission Station

$$y_{s,r} = \sqrt{P_1}\, h_{s,r} \cdot x + n_{s,r} \tag{2}$$

Where x is the transmitted information symbol with $h_{s,d}$ and $h_{s,r}$ as the channel coefficients. The transmitted signal power at the source is assumed to be P_1. The output $y_{s,d}$ and $y_{s,r}$ are modulated as zero-sum, complex Gaussian random variable. The second phase consists of information being forwarded by the relay to the destination (BTS).

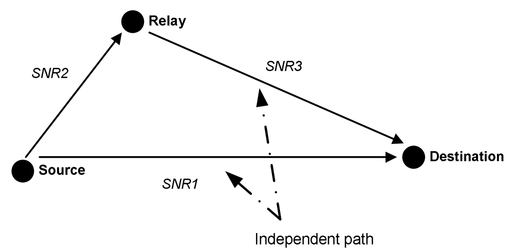

Figure 2: Single relay model

Phase II : Relay to Base Transmission Station

$$y_{r,d} = \sqrt{P_2}\, Q(y_{s,r}) \cdot x + n_{r,d} \tag{3}$$

Where the transmitted power from the relay is assumed to be P_2, with $h_{r,d}$ as the channel coefficient. $Q(y_{s,r})$ depends on the type of processing scheme (AF, DF, CC) implemented at the relay node. The equivalent noise $n_{r,d}$ at the destination is a zero mean complex Gaussian random variable.

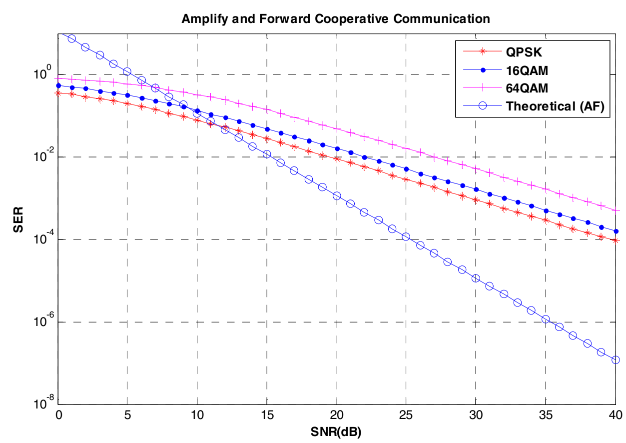

Figure 3: Performance of AF cooperative scheme

Multiple Relay cooperative Network

AF processing scheme for arbitrary N-relay wireless networks, due to the broadcast nature of the transmission the information is broadcasted, several nodes in the vicinity can act as relays that cooperate internally to send data. The wireless link between the nodes is modeled as a Rayleigh fading narrowband channel with Additive White Gaussian Noise (AWGN). As the nodes have reasonable spatial separation the channel fades for different links are assumed to be statistically independent. At all receiving terminals the additive noise is modeled as zero-mean complex Gaussian random variable with variance N_0. The relays are assumed to transmit over orthogonal channels, thus inter relay interference is not considered in the signal model. Each relay measures the received SNR, then amplifies and forwards the received signal is the SNR is higher than some threshold.

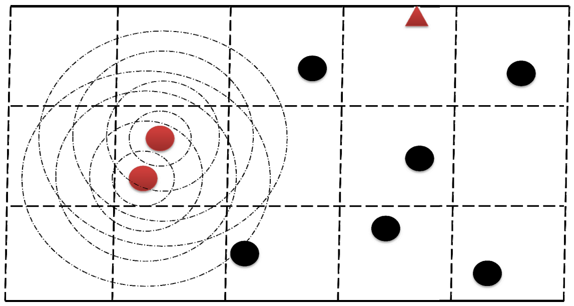

Figure 4: Division of Highway surface using square sectors

Each relay measures the received SNR, then amplifies and forwards the received signal is the SNR is higher than some threshold. Generally the nodes close to the source have a higher SNR threshold due to their proximity to the signal origin. Due to the dynamic nature of the environment the channel fading is a dynamic source of error and hence estimating the received SNR would give a very accurate judgment whether the received symbol can be successfully reconstructed with high probability. Each relay combines its channel information in the form of SNR header with the signal received from 'm' previous relays. This cooperation scenario can be implemented as $C(m)\ (1 \le m \le N-1)$.

Network Model

The network is modeled with n nodes randomly distributed in a region divided into square unit areas. Each node in the network is assumed to have information traffic to transmit and receive from other nodes. Traffic $R(n)$ for all nodes with average transmit power P_{av} with bandwidth W Hz, with carrier frequency $f_c >> W$. The channel between node i and k is represented as $h_{ik}[m]$,

$$h_{ik}(m) = \sqrt{G}\, r_{ik}^{-\alpha/2} e^{j\theta_{ik}(m)} \quad (4)$$

The phase shifts at different nodes are mutually independent. Where r_{ik} is the distance of separation between nodes. Phase shift is measured relative to the signal wavelength, so any small displacement in the node location can change the phase shift of the received signal. Since each node in the network has a traffic of $R(n)$ to be transmitted, the aggregate throughput of the network,

$$T(n) = nR(n) \quad (5)$$

The nearest neighbor multihop has a network capacity that is upper bounded $T(n) \le C(\sqrt{n})$, this limits the scaling factor for traffic rate per link to

$$R(n) \le C\left(\frac{1}{\sqrt{n}}\right) \quad (6)$$

Thus the throughput per node does not decrease as the density increases [3]. In AF protocol the signal is forwarded to BTS by simply scaling the received signal by a factor that is inversely proportional to the received power. The scaling factor at the relay for the AF scheme is given by

$$\beta_r = \frac{\sqrt{P_1}}{\sqrt{P_1 |h_{s,r}|^2 + N_0}} \quad and \quad SNR_{s,d} = \Gamma\, |h_{s,r}|^2 \quad (7)$$

Where $N_2 = n_{s,r} + n_{r,d}$. At the destination the receiver combines the signal to noise ratios from both transmitters. The final output at the destination can be represented as $y_D = a_1 y_{s,d} + a_2 y_{r,d}$

3. Spatial Diversity

In Alamouti Space Time Block Codes (STBC) to achieve space-time diversity the information is spread over across multiple antennas at the transmitter. Here the Alamouti STBC algorithm is considered in a flat fading Rayleigh multipath channel. STBCs act on a block of data. In this coding scheme, only the diversity gain is obtained, and not the coding gain. They are orthogonal and can achieve full transmit diversity specified by the number of transmit antennas. This makes STBC less complex in implementation than Trellis and Turbo codes [10].

The Alamouti STBC is an effective method to achieve spatial diversity, considering that the transmission sequence $\{x_1, x_2, x_3 \ldots\ldots x_n\}$ symbols are transmitted in groups of two from each antenna in a multiple transmitting antenna system, while maintaining the data rate constant. At the transmitter side, a block of two symbols are taken from the source data and sent to the modulator. After that, Alamouti space-time encoder takes the two modulated symbols, in this case called s1 and s2 at a time and creates encoding matrix where the symbols and are mapped to two transmit antennas in two transmit times as defined in the following:

	Time	
Space	x_1	$-x_2^*$
	x_2	x_1^*

Figure 5: Space Time Block Code matrix

The data are constructed as a matrix which has its rows equal to the number of the transmit antennas and its columns equal to the number of the time slots required to transmit the data. The Figure 5, block diagram of the transmitter side using Alamouti space-time encoder. where s_1^* is the complex conjugate of s_1 . The encoders outputs are transmitted in two consecutive transmission periods from the two transmit antennas. In the first transmission period, the signal s_1 is transmitted from antenna one and the signal s2 is transmitted from antenna two, simultaneously. In the second transmission period, the signal s_2^* is transmitted from antenna one and the signal s_1^* is transmitted from antenna two. For the i^{th} transmit antenna, each transmitted symbol gets multiplied by a randomly varying complex number c_i. The channel is assumed to remain constant over the two time slots with Gaussian probability density function at the receiver.

$$P(n) = \frac{1}{\sqrt{2\pi\sigma^2}} e^{-(n-u)^2/2\sigma^2} \quad (8)$$

Where noise is represented by n and the deviation factor $\sigma^2 = N_0/2$. The slot A and slot B of the received signal can be characterized as

$$y_1 = [h_1 \quad h_2]\begin{bmatrix} x_1 \\ x_2 \end{bmatrix} + n_1 \ and \ \ y_2 = [h_1 \quad h_2]\begin{bmatrix} -x_1^* \\ x_2^* \end{bmatrix} + n_2$$

Where y_1, y_2 are received symbols and x_1, x_2 are transmitted symbols and n_1, n_2 are the noise coefficients over the two time slots. Using Alamouti STBC scheme the signal is transmitted via multiple antennas. For an Alamouti scheme with two transmitters and single receiver

$$P_{STBC} = \frac{1}{2} - \frac{1}{2}\left(1 + \frac{2}{E_b/N_0}\right)^{-1/2} \quad (10)$$

Bit error rate can be expressed as

$$Pe_{STBC} = P_{STBC}^2\,[1 + 2(1 - P_{STBC})] \quad (11)$$

In this system there are n_T transmit antenna and a single receive antenna. The channel can be said to be a vector with coefficients.

$$H = [h_1, h_2, h_3 \ldots\ldots\ldots. h_n] \quad (12)$$

For the AF processing scheme the instantaneous mutual information as a function of the fading coefficients

$$I_{AF} = \frac{1}{2}\log(1 + \gamma_1 + \gamma_2) \quad (13)$$

$$I_{AF} = \frac{1}{2}\log\left(1 + \Gamma\left|h_{s,d}\right|^2 + f\left(\Gamma\left|h_{s,r}\right|^2, \Gamma\left|h_{s,d}\right|^2\right)\right) \quad (14)$$

Where the $\Gamma\left|h_{s,d}\right|^2$ is the varying SNR from source to destination using LOS and $\left|h_{s,r}\right|^2$ is the for the NLOS channel via the relay. With an additional link via the relay, half of the bandwidth is lost in cooperation by allocating an extra channel to the relay. But The outage expression decays as Γ^{-2}, which means that the AF processing scheme achieves diversity of 2. when signals are received, they are first combined and then sent to the maximum likelihood detector where the decision rules are applied. the structure of space-time block encoder for $2T_x$ / $1R_x$ antenna [10]. In general, STB code is defined by n_T x p transmission matrix S, where n_T represents the number of transmit antennas and p represents the number of time periods needed to transmit one block of coded symbols. The ratio between the number of symbols that space-time block encoder takes as its input (k) and the number of space-time coded symbols transmitted from each antenna defines the rate of a space-time block code. The rate of any space-time block codes with two transmit antennas is equal to one[10]. The channel coefficients for the space-time system with two transmit and two receive antennas.

	R_{X_1}	R_{X_2}
T_{X_1}	h_1	h_3
T_{X_2}	h_2	h_4

Figure 6: Spatial transmit and receive diversity matrix

Here, h_1 and h_2 are channel coefficient, Tx_1 & Tx_2 are two transmit antenna and Rx_1 & Rx_2 are two receive antenna. The creation of any space-time block code matrix depends on the type of the transmitted signal. The receiver receives y_1 and y_2 denoting the two received signals over the two consecutive symbol periods for time t and t+T. The received signals can be expressed by:

$$\begin{bmatrix} y_1 \\ y_2 \end{bmatrix} = \begin{bmatrix} s_1 & -s_1^* \\ s_2^* & s_2 \end{bmatrix}\begin{bmatrix} h_1 \\ h_2 \end{bmatrix} + \begin{bmatrix} n_1 \\ n_2 \end{bmatrix} = \begin{bmatrix} h_1 s_1 - h_2 s_1 + n_1 \\ h_1 s_2^* + h_2 s_1^* + n_2 \end{bmatrix} \quad (15)$$

As the nodes increase in the network with $n_T = 4$ transmit antenna orthogonal STB code with constellation similar to

$$S = \begin{bmatrix} s_1 & s_2 & s_3 & s_4 \\ -s_2^* & s_1^* & -s_4^* & s_3^* \\ s_1 & s_2 & -s_3 & -s_4 \\ -s_2^* & s_1^* & s_4^* & -s_3^* \end{bmatrix} = \begin{bmatrix} \boldsymbol{A} & \boldsymbol{B} \\ \boldsymbol{A} & -\boldsymbol{B} \end{bmatrix} \quad (16)$$

Where A and B are Alamouti blocks. The symbols of the data matrix S are redefined to be linear combinations of complex "base" symbols, d_1, d_2, d_3 and d_4. The bases can be encoded with transmit energy normalization.

$$s_{1,2} = \frac{d_{1,3} + d_{2,4}}{\sqrt{2}} \qquad s_{3,4} = \frac{d_{1,3} - d_{2,4}}{\sqrt{2}} \quad (17)$$

The space–time codes provide the best possible tradeoff between constellation size, data rate, diversity advantage, and trellis complexity [12]. STBC algorithm generalizes the transmission scheme to an arbitrary number of transmit antennas and is able to achieve the full diversity. For complex constellations, space–time block codes can be constructed for any number of transmit antennas, with remarkably simple decoding algorithms based only on linear processing at the receiver [12].

4. PERFORMANCE METRICS

The performance equations for each modulation technique using Alamouti STBC algorithm are used in obtaining the figure7 and 8. The '*no diversity*' is the theoretical reference result which is given as:

$$P_{Theory} = \frac{1}{2}\left(1 - \frac{1}{\sqrt{1 + N_o/E_b}}\right) \quad (18)$$

where P_{theory} is the probability of error versus E_b/N_o which is defined as a numerical value of SNR. This equation will be used as a baseline for the 2Tx-1Rx and 1Tx-2Rx. The general theory equation is formulated in terms of Q-function, equation (21) is an approximation that will be used to plot figure7. For this case, the energy symbol is the same as energy bit. To obtain the rest of the modulation scheme, A generalized equation is derived for the three modulation schemes (QPSK, 16QAM, and 64QAM) and is plotted in figure7 for 2Tx / 1Rx.

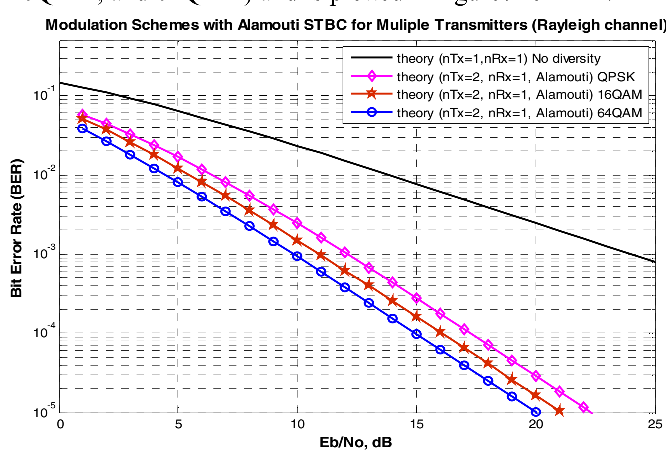

Figure 7:Modulation scheme with Alamouti STBC for n Transmitter

For MPSK, the probability of error can be defined as:

$$P_{MPSK} = \frac{1}{2}\left(1 - \frac{1}{\sqrt{1 + \frac{2N_0}{E_b\, log2(M)}}}\right) \quad (19)$$

where P_{MPSK} is defined as the probability of the M-ary PSK signal. This equation holds true for all M-ary PSK signal cases due to the uniform signal constellation in the unit circle. For universal Alamouti codes, the following equation is used:

$$P_{MPSK_{Alamouti}} = P_{MPSK}^2\left(1 + 2(P_{MPSK})\right) \quad (20)$$

Where $P_{MPSK,Alamouti}$ is the probability of error using Alamouti codes, that applies to all modulation signals. Alamouti STBC is an orthogonal scheme that can achieve full transmit diversity nT= 2. As the rows of the matrix are orthogonal. minimum distance between any two transmitted codes remains the same, since the codeword distance matrix for the Alamouti has two identical Eigen values and the minimum squared Euclidean distance in a single constellation is equal to the minimum Eigen value[10]. For the MQAM constellation signal,

$$P_{MQAM} = 4\left(1 - \frac{1}{\sqrt{M}}\right)\left[Q\left(\sqrt{\frac{6\,E_s/N_o}{M-1}}\right) - Q^2\left(\sqrt{\frac{6\,E_s/N_o}{M-1}}\right)\right] \quad (21)$$

where E_s is defined as the symbol energy. The equation relies on b = $\log_2$ M, where b is even. The Q-function can be represented as the error complementary function and vice versa. The energy symbol can be expressed as energy bit using $E_S = E_b \log_2 M$. The BER versus Eb/No (dB) performance for M-ary QAM Alamouti space-time diversity on Rayleigh fading channels is evaluated. For figure 7, the no diversity is used as a reference.

$$P_{MQAM_{Alamouti}} = P_{MQAM}^2\left(1 + 2(P_{MQAM})\right) \quad (22)$$

Notice the factor of two is gone due to the fact that it only has one transmitter compared to the previous equation. To find the probability of error, equation (3) can be used. For the MQAM, The equation compared to the first one is factor of 2.

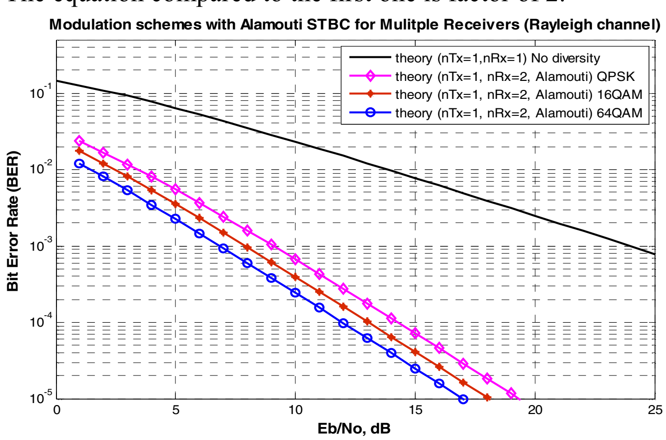

Figure 8: Modulation Schemes with Alamouti STBC for multiple receivers

The figure 8 shows the Alamouti scheme BER versus Eb/No performance with QPSK, 16-QAM and 64-QAM modulation with no diversity as the reference. From the simulation result, its shown that Alamouti scheme has better performance implementing the higher order modulation techniques versus a no diversity system. If figure 7 is compared to figure 8, there is a improvement in performance for 1Tx / 2Rx scheme. This occurs due to 2Tx adding noise that results in increase of noise figure, which can interfere in receiving signals compared to 1Tx / 2Rx.

5. SUMMARY

In remote locations it makes it very difficult to get immediate medical attention, especially in a collision. But an alternative solution is to use a cooperative communication technique to relay the message to the first responders via satellite. Due to the dynamic nature of the highway and privacy concerns AF processing scheme is best suited versus a Decode and Forward (DF) scheme while relaying the message from node to node. Due to presence of multiple relays a virtual MIMO environment is generated, where in Alamouti STBC algorithm can be used to achieve spatial and receive diversity. The paper shows that the performance of higher order modulation techniques with multiple transmitting and receiving antennas is much better than a SISO system with no diversity. The performance can be improved even more if a coded cooperation (CC) technique can be used with encryption. This approach gives us an economically viable solution to communicating in remote areas.

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