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Comparative Analysis of Multiple and Single Antenna Applications in Mobile Wireless Communication.

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ABSTRACT

The performance of multiple-antenna and single antenna systems as applicable in mobile wireless communication are compared. The method applied involves matrix computation based on the system model. The expressions derived were used to evaluate the system performance with zero-forcing (ZF) equalizer at the receiver. MATLAB Toolbox version 7.0 was used to carry out error performance simulation for the different transmitting and receiving antenna configurations in a Raleigh fading environment. The result showed in terms of BER performance that multiple antenna technique is capable of combating multi-path effects due to the low error rate they exhibited. The diversity modes employed by the multiple antennas were also analysed by comparing their E_b/N_o (Energy per bit to noise power spectral density ratio). Transmit diversity technique with multiple antennas at the base station and a single antenna at the remote end was further shown to be a better candidate for the next generation of wireless communication than the single-input single-output system.

Keywords: Multiple-antenna, Single-antenna, Diversity, Wireless communications

INTRODUCTION

Multiple-antenna systems have received much interest in recent times by researchers working on such configurations as Single-input Multiple-output (SIMO), Multiple-input Single-output (MISO) and Multpile-input Multiple-output (MIMO). Many analytical works on any of these have been based on their proposed 4G/LTE (Long Term Evolution) application in wireless communication.

The present generation (3G) of mobile wireless communication in most countries makes effective use of sectoral antennas. Such antennas are mounted at specfic heights on towers located at different Base Tranceiver Stations (BTS). Each tower contains an array of antennas usually three, positioned in such a manner that each of them radiates RF signals to cover a sector of 120^o. Towards a paticular sector the antenna is purely directive as it propagates into space (channel). Such antenna functions as a Single-input Single-output (SISO) system.

Multipe antenna systems have been suggested as a possible replacement of SISO systems in the next generation of mibile wireless communication but its ability to combat interference due to multipath propagation effects is not well comprehended and therefore needs to be investigated. This is the main thrust of this paper. It intends to achieve this by carring out a comparative analysis of the BER (Bit-Error-Rate) performance of multiple antenna techniques to that of single antennas.

LITERATURE REVIEW

Many papers have been presented on the workings of multiple antenna systems such as MIMO. Some special detection algorithms have been proposed in order to exploit the high spectral capacity offered by MIMO channels. This magnitude of spectral efficiency is exploited using a wireless communication architecture known as VBLAST (Vertical Bell Laboratory Layered Space-Time). Some approaches for improving the efficiency of MIMO systems were proposed by Foschini et al, (1998), which inspired two further contributions using BLAST architecture.

BLAST is an extraordinary bandwidth-efficient approach to wireless communication which takes advantage of the spatial dimension by transmitting and detecting a number of independent co-channel data streams using multiple, essentially co-located antennas. The V-BLAST is an extension of the BLAST technique which has a detection algorithm procedure that extracts the component of the transmitted vector according to a certain ordering (Jayalakshmy et al, 2011).

The detection technique is aimed to provide better performance using QAM (Quadrature Amplitude Modulation).This modulation scheme is one of several methods used in performance analysis of MIMO systems. This method is in contrast with the approach used in this study. In this work performance analysis is carried out using BPSK (Binary Phase Shift Keying) modulation scheme.The multipe antennas are evaluated in a reliable manner in which verifications are carried out theoretically in a real time simulated environment.

OBJECTIVE OF THE STUDY

The main goal of this paper is:

To verify and compare the performance of the different multi-antenna techniques to that of single antenna by carrying out error performance simulation.

METHOD

Dynamic radio channel measurements play an essential role in the analysis of performance of multiple antenna systems. To carry out this process, one way is to manufacture the antenna prototypes and carry out an analytic study on their performance in all typical usage environments. However, to carry out measurements in such numerous environments is a time-consuming and difficult process.

Other methods are available to evaluate multipe antennas in a reliable manner in which verifications can be carried out theoretically where real time scenerios are simulated. This is the approach adopted in this work. Here, diversity techniques are considered only for the multiple-antenna systems.

In pursuance of this, the approach is in two stages:

1. Mathematical approach in determining the properties of MIMO wireless communication fading channel including other multi-antenna systems in a non-isotropic scattering environment based on a narrowband model.
2. Carry out simulations and comparisons using MATLAB Tool box version 7.0 at R.F signal processing. The bit-error-rate (BER) characteristics of the various transmitting and receiving antennas are simulated and compared.

Modelling of a MIMO Channel

Multipath Consideration

Assume a practical scenario where there is a mobile terminal that has a wireless connection, equiped with *M* antennas and is connected to a base station with *N* antennas. This results to *NxM* (MIMO) system. The signals from the *N* transmit antennas are transmitted to the receiver. Due to reflections and scattering of the transmitted signals from the base-station, the signals received by the mobile terminal will be a multiple of many reflected signals that may be constructive or destructive. Thus multipath fading results.

Also the environment (cars, people) around the user is either quasi-stationary or mobile, or the user may be in motion, therefore the channel through which the signal propagates from the transmitting antennas to the receiving antennas will be time-varying. Apart from the scattering effect of the environment, there are also interfering signals which is common with wireless communications.

The block diagram of a simple MIMO system is shown in Fig 1 with N number of transmit and M number of receive antennas. The figure shows:

a. Input signal vector **S**
b. Transmit antennas $t_1 \ldots . t_N$
c. Channel
d. Receive antennas $r_1 \ldots . r_M$
e. Output vector ***Y***

Due to multipath propagation from the transmitter to the receiver, the received signal S_i at antenna i through channel h_i is $h_i S_i$plus previously transmitted symbols. Therefore, the MIMO channel model generally can be written as

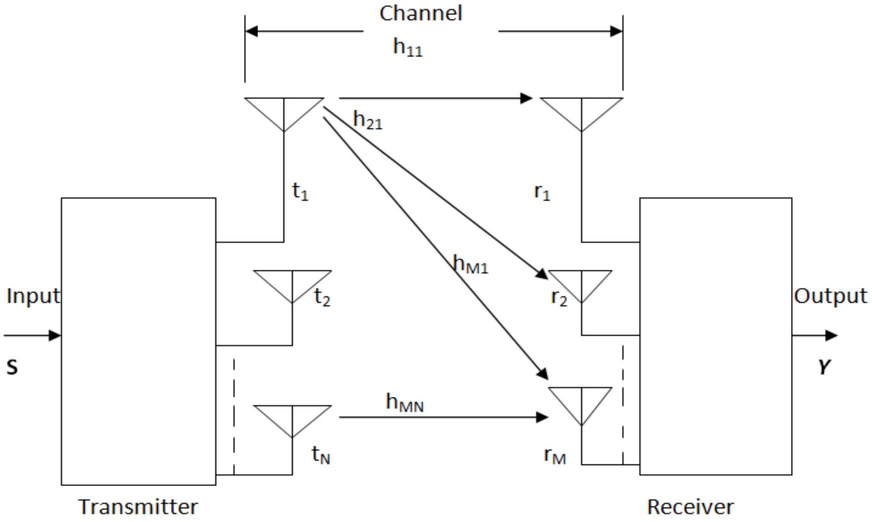

Figure 1. NxM MIMO System

$$Y_n = h_n S_n \ldots\ldots\ldots\ldots\ldots\ldots (1)$$

Where the nth element of h is the transfer function from the transmitter i to the receiver n.

Fig 1, illustrates the most common configuration in which the transmitter and receiver are connected via different antennas. Other options include connections to different polarizations of single antenna, different beams in a multi-beam antenna (beamforming), a multimode antenna (smart antenna) and a switched beam antenna (switching combining).

Co-Channel Interference Consideration

Assume also multiple users U_m and main user $U_{m+1}$are active and sharing the common radio space in all dimensions, time, frequency and space. Then $U_m$are the interferers with the particular transmission of the desired user. These interfering signals are called co-channel interference(CCI)

For a MIMO communication system with CCI from users U_m and desired user$h_n S_n$, equation 1 now results to

$$\boldsymbol{Y}_n = h_n S_n + \sum_{i=1}^{Um} h_i S_i + n_r \text{.................... (2)}$$

Where $\boldsymbol{Y}_n$is the received signal vector, $h_n S_n$is the product of the transmitted symbol and the corresponding channel for the desired user. $\sum_{i=1}^{Um} h_i S_i$ are the channels and transmitted symbols for the interfering users. n_r is the receiver noise.

Narrowband Model

For a narrowband model, the channel co-efficients are constant during the transmission of several symbols. By definition narrowband applies to system where the bandwidth of the transmitted signal is much less than the coherence bandwidth of the channel. All the frequency components of the transmitted signals suffer the same attenuation and phase difference as they propagate through the channel.

Narrowband channel is characterized by flat fading and apply well to environments where there are significant scatterers close to the transmitter or receiver and no distant reflector or scatterers are present. Hence the main motivation of this choice of model.

Assuming that all CCI channels as described can be accommodated by a narrowband. Using equation 2, the channel which represents the scattering effect of the environment and through which the signal propagates can be simply written as

$$\boldsymbol{H} = h_n, \quad \text{or } \boldsymbol{Y}_n = \boldsymbol{H} S_n \text{.................... (3)}$$

where $\boldsymbol{H}$is the NxM channel matrix comprising all the channel coefficients h_{11}, h_{12} ....h_{MN}described by $N_t$and M_r (total number of transmitting and receiving antennas respectively). The input-output relationship can now be expressed using equations 2 and 3 as:

$$\boldsymbol{Y}_n = \boldsymbol{H} S_n + \sum_{i=1}^{Um} \boldsymbol{H}_i S_i + n_r \text{.................... (4)}$$

If the receiver noise plus the interfering signal are regarded as unwanted signals, then both can be lumped together. Equation 4 can be written to represent the output as a combination of all the signals via the different channels as:

$$\boldsymbol{Y} = \boldsymbol{HS} + \boldsymbol{V} \text{ .... (5)}$$

Where $\boldsymbol{Y}$ is the received vector $(y_1, y_2, \ldots\ldots yn)$

$\boldsymbol{S}$ is the transmitted vector $(S_1, S_2, \ldots. S_n)$

$\boldsymbol{V}$ is the noise vector $(v_1, v_2 \ldots. v_n)$ comprising the receiver noise and other forms of interference. This will be regarded as additive white Gaussian noise (AWGN).

$\boldsymbol{H}$is the narrowband channel matrix and represents the scattering effect of the channel. This is written as:

$$\boldsymbol{H} = \begin{bmatrix} h_{11} & h_{12} \cdots & h_{1N} \\ \vdots & \ddots & \vdots \\ h_{M1} & h_{M2} \cdots & h_{MN} \end{bmatrix} \text{.................... (6)}$$

For a multiple antenna system with 2Tx, 2Rx antennas and an equalizer at the receiver unit as shown in Figure 2, the input signal $\boldsymbol{S}$ isprocessed such that S_1, S_2 are transmitted by antennas t_1 and t_2 respectively. The output is obtained as

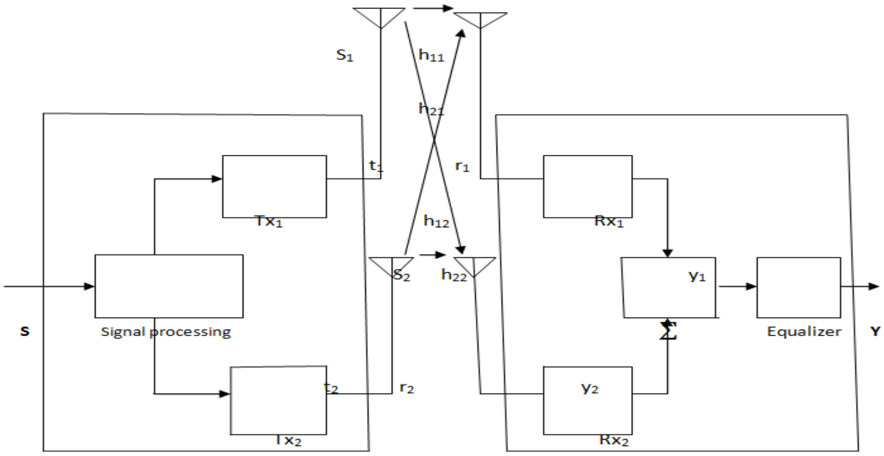

Figure 2. A simple 2 transmit and 2 receive MIMO System

$$y_1 = h_{11}S_1 + h_{12}S_2 + v_1 \ldots\ldots\ldots\ldots\ldots\ldots (7)$$

$$y_1 = h_{21}S_1 + h_{22}S_2 + v_1 \ldots\ldots\ldots\ldots\ldots\ldots (8)$$

Where h_{11} is the channel from t_1 to r_1

h_{12} is the channel from t_2 to r_1

h_{21} is the channel from $t_1$to r_2

h_{22} is the channel from t_2 to r_2

S_1, S_2 are the transmitted symbols

$\boldsymbol{v_1}$,$\boldsymbol{v_2}$ are the noise vectors on $r_1$and r_2 respectively.

Equations 7 and 8 are represented in matrix notation as:

$$\begin{bmatrix} \boldsymbol{y_1} \\ \boldsymbol{y_2} \end{bmatrix} = \begin{bmatrix} h_{11} & h_{12} \\ h_{21} & h_{22} \end{bmatrix} \begin{bmatrix} S_1 \\ S_2 \end{bmatrix} + \begin{bmatrix} \boldsymbol{v_1} \\ \boldsymbol{v_2} \end{bmatrix} \ldots\ldots\ldots\ldots\ldots\ldots (9)$$

The general form of a MIMO channel mode using equation 9 is:

$$\boldsymbol{Y} = \boldsymbol{HS} + \boldsymbol{V} \ldots\ldots\ldots\ldots\ldots\ldots (10)$$

Where $\boldsymbol{Y}$ = output vector

$\boldsymbol{H}$ = Channel matrix

$\boldsymbol{S}$ = Signal matrix

$\boldsymbol{V}$ = Noise matrix

SISO system (no diversity)

A case of one transmit antenna and one receive antenna(single-input single-output) is shown in Figure 3.

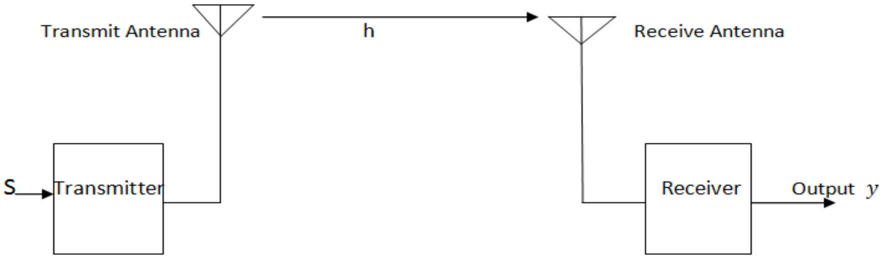

Figure 3. A simple Single-input Single output (1Tx,1Rx), No-Diversity scheme

The received signal takes the form:

$$y = hs + v \ldots\ldots\ldots\ldots\ldots\ldots (11)$$

With BPSK modulation , the transmitted bits are either 1 or 0, and remain unchanged except there is a phase variation of the carrier frequency from positive to negative values. Assume signal energy per bit transmitted is E_b, then with BPSK modulation, the transmitted signals are either $+\sqrt{E_b}$ or $-\sqrt{E_b}$ for 1 or 0 bits respectively.

If h is known at the receiver antenna then the instantaneous bit energy to noise ratio is

$$y = \mid h \mid^2 \frac{\mathrm{E_b}}{\mathrm{N_o}} \ldots\ldots\ldots\ldots\ldots\ldots (12)$$

Where $\mid h \mid^2$ is the channel power of a single transmit and receive antenna and $\frac{\mathrm{E_b}}{\mathrm{N_o}}$ is the energy per bit to noise power spectral density ratio.

SIMO system (Receive diversity technique with MRC)

A receive diversity technique with maximal-ratio-combining is illustrated in Fig 4. It is a SIMO system with one antenna transmitting and multiple antennas receiving. Assume a $N_t \; x \; M_r$ system where $M_r = 2$ as shown.

At each receive antenna the channel h_i is known, therefore for the ith receive antenna, the instantaneous energy per bit as in equation 12 is defined as

$$y_i = |h_i|^2 \frac{E_b}{N_o} \ldots\ldots\ldots\ldots\ldots\ldots (13)$$

Where $|h_i|^2$ is the channel power across the ith receive antenna.

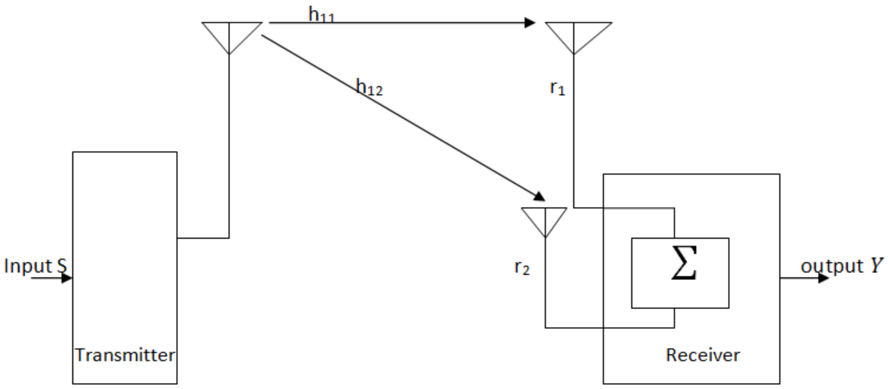

Figure 4. A simple SIMO (1Tx,2Rx) Receive Diversity MRC scheme

With M receive antennas the sum of the channel powers is

$$\mid h_{11} \mid^2 + \ldots + |h_{m1}|^2 \text{ or } P_{ch} = \sum_{i=1}^{m} \mid h_i \mid^2 \ldots\ldots\ldots\ldots\ldots\ldots (14)$$

With maximal-ratio-combining (MRC), the effective E_b/N_o for the desired paths is

$$\boldsymbol{Y} = \sum_{i=1}^{m} \mid h_i \mid^2 \frac{E_b}{N_o} \quad \text{or} \quad \boldsymbol{Y} = M\gamma_i \ldots\ldots\ldots\ldots\ldots\ldots (15)$$

Where γ_i is the bit-energy-to-noise ratio of the ith receive antenna and M the total number of receive antennas.Therefore the effective bit-energy-to-noise ratio in an M receive antenna case is M times the bit energy to noise ratio for a single antenna case.

MISO *System (Transmit diversity with alamoutI STBC)*

This is a multiple-input single-output scheme. For a simple system, $N_t = 2$ and $M_r = 1$. The technique employs Alamouti STBC (Agubor et al.,2013) as illustrated in Fig 5. The scheme has an input vector **S** witha transmission sequence (S_1, S_2) transmitted in two symbol periods t and $t+T$. The symbols are grouped such that we have S_1S_2 and $-S_2^*S_1^*$ respectively, where $*$ is the complex conjugate operation (Alamouti 1998). The encoding sequence is as indicated in Table 1. It defines the channel parameters for each period or timeslot.

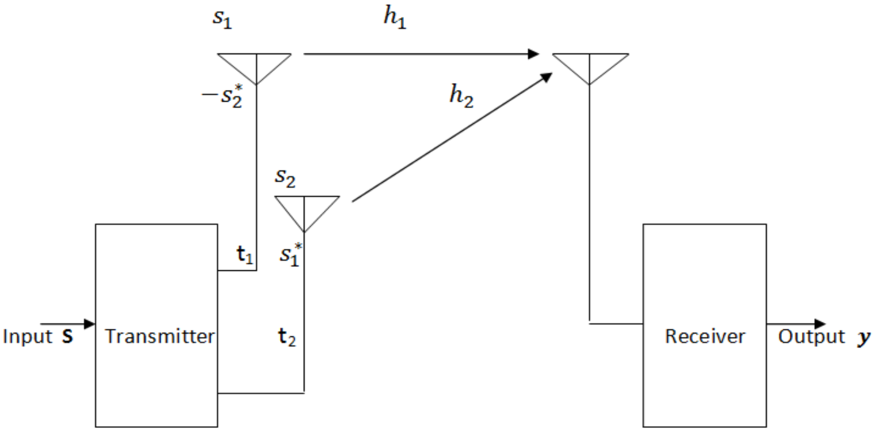

Figure 5. A simple MISO (2Tx,1Rx) Transmit Diversity Alamouti STBC scheme

Table 1. Channel Parameters for Transmot diversity Alamouti STBC

Period	*Transmit Antenna 1 and 2*	*Receive Antenna*
t	S_1 S_2	h_1S_1 h_2S_2
t+T	$-S_2^*S_1^*$	$-h_1S_2^*$, $h_2S_1^*$

At time slot t and $t+T$ the received signals are:

$$y_1 = h_1S_1 + h_2S_2 + v_1 \text{ .... } (16)$$

$$y_2 = h_2S_1^* - h_1S_2^* + v_2 \text{ .... } (17)$$

In matrix notation:

$$\begin{bmatrix} y_1 \\ y_2 \end{bmatrix} = \begin{bmatrix} h_1 & h_2 \\ h_2^* & -h_1^* \end{bmatrix} \begin{bmatrix} S_1 \\ S_2 \end{bmatrix} + \begin{bmatrix} v_1 \\ v_2 \end{bmatrix} \text{ .... } (18)$$

Where y_1, y_2 are the received signals on the first and second time slots,

h_1 is the channel from first transmit antenna to the receive antenna,

h_2 is the channel from second transmit antenna to the receive antenna,

S_1, S_2 are the transmitted symbols,

v_1, v_2 is the noise on both the first and second time slots.

The channel matrix is $\boldsymbol{H}$and is obtained as

$$\boldsymbol{H} = \begin{bmatrix} \boldsymbol{h_1} & \boldsymbol{h_2} \\ \boldsymbol{h_2} & -\boldsymbol{h_1^*} \end{bmatrix} \text{................... } (19)$$

In Figure 2, the equalizer is implemented as a Zero-forcing equalizer due to its effectiveness in combating Intersymbol-interference (ISI) and the interest on it for IEEE 802.11n application (Mark et al., 2003). It functions by bringing down the ISI to zero and is constructed by having

$$C(f) = \frac{1}{F(f)} = F^{-1}(f) \text{ .... } (20)$$

$$\text{or } C(f)F(f) = 1 \text{ .... } (21)$$

where $C(f)$is the ZF equalizer and $F(f)$ the frequency response of the channel $\boldsymbol{H}$. The inverse of $\boldsymbol{H}$should be choosen such that it satisfies the equation (Jiang et al., 2011)

$$\boldsymbol{H}^{+}\boldsymbol{H} = \boldsymbol{I} \text{ .... } (22)$$

Where $\boldsymbol{H}^{+}$ is the pseudo-inverse of $\boldsymbol{H}$orthe equalization matrix and for a full rank matrix is defined as

$$\boldsymbol{H}^{+} = (\boldsymbol{H}^{\mathbf{H}}\boldsymbol{H})^{-1}\boldsymbol{H}^{\mathbf{H}} \text{ .... } (23)$$

$\boldsymbol{I}$ is the identity matrix with '0' diagonal elements

To detect the transmitted symbol we solve for $\begin{bmatrix} S_1 \\ S_2 \end{bmatrix}$, therefore the inverse of $\boldsymbol{H}$must be known. For a general mxn matrix ,the pseudo-inverse is defined as

$$\boldsymbol{H}^{+} = (H^{H}H\ )^{-1}H^{H}$$

$$\boldsymbol{H}^{\boldsymbol{H}}\boldsymbol{H} = \begin{bmatrix} h_1 & h_2^{*} \\ h_2 & -h_1^{*} \end{bmatrix} \begin{bmatrix} h_1 & h_2 \\ h_2^{*} & -h_1^{*} \end{bmatrix}$$

$$= \begin{bmatrix} |\,h_1\,|\,2+|\,h_2\,|\,2 & h_1h_2 - h_1h_2 \\ h_1h_2 - h_1h_2 & |\,h_2\,|\,2+|\,h_1\,|\,2 \end{bmatrix}$$

$$= \begin{bmatrix} & |\,h_1\,|\,2+|\,h_2\,|\,2 0 & \\ 0 & & |\,h_2\,|\,2+|\,h_1\,|\,2 \end{bmatrix} \text{ .... } (24)$$

Since $H^{H}H = I$, therefore$(H^{H}H)^{-1}$isthe inverse of the diagonal elements.Thus

$$(H^{H}H)^{-1} = \begin{bmatrix} \frac{\mathbf{1}}{|\boldsymbol{h}_1|2+|\boldsymbol{h}_2|2} & \mathbf{0} \\ \mathbf{0} & \frac{\mathbf{1}}{|\boldsymbol{h}_2|2+|\boldsymbol{h}_1|2} \end{bmatrix} \text{ .... } (25)$$

From the received signal, the equalized or detected symbols $\hat{S}_1, \hat{S}_2$ can be obtained as:

$$\begin{bmatrix} \hat{S}_{\mathbf{1}} \\ \hat{S}_{\mathbf{2}} \end{bmatrix} = (H^{H}H\ )^{-1}H^{H}\begin{bmatrix} y_1 \\ y_2 \end{bmatrix} = (H^{H}H\ )^{-1}H^{H}\left(H\begin{bmatrix} \boldsymbol{S}_{\mathbf{1}} \\ \boldsymbol{S}_{\mathbf{2}} \end{bmatrix} + \begin{bmatrix} \boldsymbol{v}_{\mathbf{1}} \\ \boldsymbol{v}_{\mathbf{2}} \end{bmatrix}\right) \text{ .... } (26)$$

$$\begin{bmatrix} \hat{S}_{\mathbf{1}} \\ \hat{S}_{\mathbf{2}} \end{bmatrix} = \begin{bmatrix} \boldsymbol{S}_{\mathbf{1}} \\ \boldsymbol{S}_{\mathbf{2}} \end{bmatrix} + (H^{H}H\ )^{-1}H^{H}\begin{bmatrix} \boldsymbol{v}_{\mathbf{1}} \\ \boldsymbol{v}_{\mathbf{2}} \end{bmatrix} \text{ .... } (27)$$

The above equation indicates that the transmitted symbols S_1, S_2 can be recovered which is the same as the equalized symbols $\hat{S}_1, \hat{S}_2$ and the noise terms will have no serious effect on the detection of these symbols because they have been nulled as indicated in equation 24

MIMO System (Second-order diversity with STBC)

A case of two antennas transmitting and receiving on either side of the transmission link is used to determine the diversity order with the application of Alamouti STBC. This is illustrated in Fig 6. At a given symbol period t, two consecutive transmit vectors S_1 ,S_2 are transmitted from two transmit antennas t_1 and t_2 respectively. During the next symbol period $t+T$, $-S_2^*, S_1^*$ are also transmitted from t_1 and t_2 . This sequence is tabulated as earlier shown in Table 1.

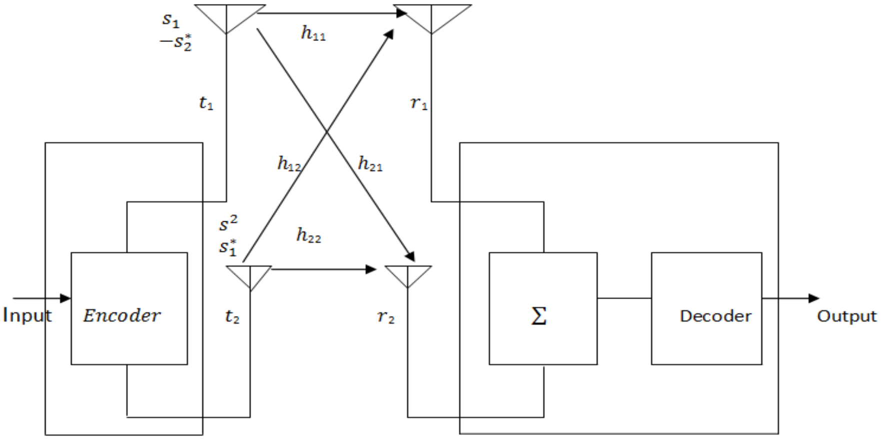

Figure 6. A simple MIMO (2Tx2Rx) Second-Order Diversity scheme with STBC

Table 2. STBC encoding sequence of two symbol periods

Symbol Period	*Transmit Antenna 1*	*Transmit Antenna 2*
t	S_1	S_2
t+T	$-S_2^*$	S_1^*

Table 2 shows the encoding of the information carring symbols. For each transmit vector $\boldsymbol{S}$, two symbols are transmitted twice, therefore the total equivalent bit rate is 1 symbol per transmit vector. The channel parameters are used to defined the signal paths between the transmit and receive antennas (Table 3).

Table 3. Channel parameters for second-order diversity

Symbol Period	*Transmit Antenna 1*	*Transmit Antenna 2*
$S_1, \quad S_2$	$h_{11}S_1, \ h_{12}S_2$	$h_{22}S_2, \ h_{21}S_1$
$-S_2^*, \quad S_1^*$	$-h_{11}S_2^*, h_{12}S_1^*$	$h_{22}S_1^*, \ -h_{21}S_2^*$

Table 4. Signal outputs at $\boldsymbol{t}$ and $\boldsymbol{t+T}$

Period	*Transmit Antenna 1*	*Transmit Antenna 2*
t	y_1	y_2
$t+T$	y_3	y_4

Table 4 defines the notations of the received outputs at each given period from the two receivers. As indicated in the table, the received vector component $\boldsymbol{Y}$ has the following components as

$$y_1 = h_{11}S_1 + h_{12}S_2 + v_1 \dots\dots\dots\dots\dots\dots \text{(28)}$$

$$y_2 = h_{21}S_1 + h_{22}S_2 + v_2 \text{.................. (29)}$$

$$y_3 = h_{12}S_1^* - h_{11}S_2^* + v_3 \text{.................... (30)}$$

$$y_4 = h_{22}S_1^* - h_{21}S_2^* + v_4 \text{.................... (31)}$$

In matrix notation

$$\begin{bmatrix} y_1 \\ y_2 \\ y_3 \\ y_4 \end{bmatrix} = \begin{bmatrix} h_{11} & h_{12} \\ h_{21} & h_{22} \\ h_{12}^* & -h_{11}^* \\ h_{22}^* & -h_{21}^* \end{bmatrix} \begin{bmatrix} S_1 \\ S_2 \end{bmatrix} + \begin{bmatrix} v_1 \\ v_2 \\ v_3 \\ v_4 \end{bmatrix} \text{.................... (32)}$$

The channel matrix is:

$$\boldsymbol{H} = \begin{bmatrix} h_{11} & h_{12} \\ h_{21} & h_{22} \\ h_{12}^* & -h_{11}^* \\ h_{22}^* & -h_{21}^* \end{bmatrix}$$

To recover the transmitted signals we multiply the received vector $\boldsymbol{Y}$ with the pseudo-inverse $H^{+}=(H^{H}H)^{-1}\, H^{H}$, where

$$\boldsymbol{H^H H} = \begin{bmatrix} h_{11} & h_{21} h_{12}^* h_{22}^* \\ h_{12} & h_{22} - h_{11}^* - h_{21}^* \end{bmatrix} \begin{bmatrix} h_{11} & h_{12} \\ h_{21} & h_{22} \\ h_{12}^* & -h_{11}^* \\ h_{22}^* & -h_{21}^* \end{bmatrix}$$

$$= \begin{bmatrix} |h_{11}|^2 + |h_{21}|^2 + |h_{12}|^2 + |h_{22}|^2 & 0 \\ 0 & |h_{11}|^2 + |h_{21}|^2 + |h_{1`2}|^2 + |h_{22}|^2 \end{bmatrix} \quad (33)$$

As in equation 24, $\boldsymbol{H^H H = I}$**,** hence the inverse is the inverse of the diagonal elements.

$$\boldsymbol{(H^H H)^{-1}} = \begin{bmatrix} \frac{1}{|h_{11}|^2+|h_{21}|^2+|h_{12}|^2+|h_{22}|^2} & 0 \\ 0 & \frac{1}{|h_{11}|^2+|h_{21}|^2+|h_{1`2}|^2+|h_{22}|^2} \end{bmatrix} \qquad (34)$$

From the received signals, the equalized symbols can be expressed as in equations 26 and 27, i.e.

$$\begin{bmatrix} \hat{S}_1 \\ \hat{S}_2 \end{bmatrix} = \left(\boldsymbol{H^H H}\right)^{-1} \boldsymbol{H^H} \begin{bmatrix} \boldsymbol{y_1} \\ \boldsymbol{y_2} \\ \boldsymbol{y_3} \\ \boldsymbol{y_4} \end{bmatrix}$$

$$= \left(\boldsymbol{H^H H}\right)^{-1} \boldsymbol{H^H\ H} \left(\begin{bmatrix} \boldsymbol{S_1} \\ \boldsymbol{S_2} \end{bmatrix} + \begin{bmatrix} \boldsymbol{v_1} \\ \boldsymbol{v_2} \\ \boldsymbol{v_3^*} \\ \boldsymbol{v_4^*} \end{bmatrix} \right) \text{.................... (35)}$$

$$= \begin{bmatrix} \boldsymbol{S_1} \\ \boldsymbol{S_2} \end{bmatrix} + \left(\boldsymbol{H^H H}\right)^{-1} \boldsymbol{H^H\ H} \begin{bmatrix} \boldsymbol{v_1} \\ \boldsymbol{v_2} \\ \boldsymbol{v_3^*} \\ \boldsymbol{v_4^*} \end{bmatrix} \text{.................... (36)}$$

Equation 36 is identical to that obtained using transmit diversity technique with STBC (2Tx1Rx) i.e. equation 27. Equation 36 is expressed as a matrix multiplication which is a linear operation. Since the estimate of the transmitted symbol with maximal-ratio-combining(MRC) is identical to that obtained from transmit diversity Alamouti STBC scheme, the BER of second-order diversity$(2Tx2Rx)$ MIMO should be the same with that of Alamouti STBC (2Tx1Rx). Also since the matrix $\boldsymbol{H^H H}$ is an identity matrix it therefore implies that no interference occurs between the received symbols S_1 and S_2 after the equalization.

SIMULATION RESULT

Description of the Simulation Environment

The simulation set-up covers the downlink from the base transceiver station(BTS) to the mobile or remote terminal. From the BTS the signal via the transmit antennas propagates through the channel. The signals received at the antennas of the mobile terminal are combined and equalized.

The main aim of the simulation is to generate BER results that will allow for effective comparison by simulating over a range of E_b/N_O.

Simulation Model

The Matlab script performs the following:

a. Generate random binary data stream
b. Transmit the data
c. Multiply data with channel matrix
d. Generate Additive White Gaussian Noise (AWGN)
e. Add the generated AWGN to the received data
f. For N >1, group data into pair of two symbols
g. Code with Alamouti Space-Time-Block-Code and repeat steps (ii) to (v)
h. Equalize the received symbols
i. Calculate the BER
j. Repeat for multiple values ofE_b/N_O and plot the result.

ASSUMPTIONS

The following assumptions were made:

a. The transmit power for each antenna is the same
b. For all systems the channel is known at the receiver.

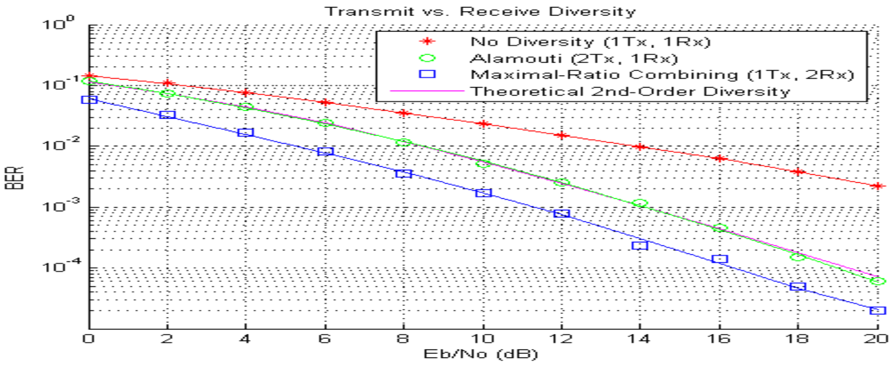

Figure 7. Diversity gain for 1Tx,1Rx; 1Tx,2Rx; 2Tx,1Rx; and2Tx,2Rx antennas

Description

The simulation result is shown in Fig 7. It has BER on the y-axis and E_b/N_O on the x-axis. Four plots representing the different diversity techniques are shown.

I. No diversity (1Tx,1Rx): This plot indicates the performance of a Single-input Single-output scheme. This method does not employ any diversity technique. It is the topmost curve on the graph and shows a gradual slope as the E_b/N_O increases. The plot terminates at BER of $1.1\mathrm{x}10^{-3}$.

II. Alamouti (2Tx,1Rx): This is the second plot on the graph. It shows the BER performance for a Multiple-input Single-output scheme with Alamouti STBC. This method employs transmit diversity technique. Part of the curve falls bellow BER of 10^{-3} level. It originates from BER 10^{-1} and terminates at $2.5\mathrm{x}10^{-5}$.

III. Second-order diversity : This plot is the third on the graph and represents a 2Tx,2Rx scheme employing a second-order diversity technique.The plot coincides with that of Alamouti (2Tx,1Rx) and also maintains same point of origin of BER 10^{-1}. It terminates at BER $3.3\mathrm{x}10^{-5}$

IV. Maximum-ratio combining (1Tx,2Rx) : This is the fourth plot and shows the performance of Receive diversity technique with maximum- ratio combining (MRC). The plot terminates at BER 1.

DISCUSSIONS

Combating Multipath Effect

The path between base stations and mobile terminals of terrestrial mobile communications is characterized by various obstacles and reflections. The effect is multipath fading which raises the error rate of the received data (Chauhan et al, 2011).

I. Assume a receiver BER threshold level of 10^{-3} above which the mobile wireless system will fail to operate because of signal deterioration. Therefore communication can be effected at below this threshold. In Fig 7, the Single-input Single-output technique has its curve above this point. Therefore this system will be prone to partial failures as the received signals fluctuate around this threshold. At a particular time, since the receiver is mobile or quasi-stationary, it may shift away from line of good reception. In this case the system will be operating at or above the threshold which will result to an abrupt termination of the already established call (drop calls).

II. In another case the receiving mobile unit may appear to have been switched off (number switched off) or the voice will appear faint and muffled. These conditions may last as long as the receiver remains within the region where effects of multipath propagation are very much pronounced. This can be remedied if the receiver moves away from that position to another as is always the case when one experiences signal fading after a communication link has been established. To improve on the performance of this system the E_b/N_O has to be increased to enable it operate at regions below the threshold. The multiple antenna techniques show very good performance when compared to the single antenna system at the same threshold point. The curves for 2Tx1Rx, 1Tx 2Rx and 2Tx2Rx fall below the 10^{-3} BER at E_b/N_O of 14dB, 11dB and 14dB respectively.

III. At a threshold of 10^{-4} BER, multiple antenna techniques have performances well above that of single antenna as seen in Fig 7. The figures also show that the receiver BER threshold can be decreased further to 10^{-5} , 10^{-6}, etc, with only minimal increase inE_b/N_O.This aspect makes this technique suitable in situations where error-free transmission of large volumes of data are involved.

Table 5. System Perfomance Comparison

S.No	*mxn*	*Diversity Technique*	*BER*
1	1Tx1Rx(SISO)	No diversity	High
2	1Tx2Rx(SIMO)	Receive diversity	Lowest
3	2Tx1Rx(MISO)	Transmit diversity	Low
4	2Tx2Rx(MIMO)	Second-order diversity	Low

CONCLUSION

The simulation considered BPSK modulation with result showing BER performance curves for all systems including SISO. The comparison for each technique was based on their respective BER performance obtained from the result which showed that multiple antenna systems have good BER performance than single antenna system. It was shown that Transmit diversity which uses two (or multiple) antennas at the base station and one (single) receive antenna at the remote terminal, had a performance similar or identical to using two transmit antennas at the base station and two receive antennas at the remote terminal.

An added advantage of Transmit diversity is that it can be implemented in systems with multiple antennas at the base station for both transmit and receive purposes. Reciprocity property of antennas makes this possible. In such a case Transmit diversity (downlink transmission) can be used with receive diversity (uplink transmission) to achieve large diversity gain making multiple-antenna technique a better option for next generation wireless communications.

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