

Performance Relay Assisted Wireless Communication Using VBLAST

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Abstract

In this paper, performance of relay assisted wireless link is evaluated using VBLAST in the presence of rayleigh fading where source is equipped with two transmit antennas, relay is equipped with multiple transmit and multiple receive antennas, and destination has multiple receive antennas. The input information are modulated using QPSK or 16 QAM or 64 QAM modulator and modulated information are encoded using VBLAST and then split into $(n_T)_s$ streams which are simultaneously transmitted through $(n_T)_s$ transmit antennas of source. Relay decodes the rayleigh fading effected signal and re-encodes using VBLAST and forwards for destination. It is observed that relay with 2 transmit antennas and 2/3/4/5/6 receive antennas provides 9-11.5 dB gains compared to direct link. And there are around 3 dB to 11 dB gains for increasing number of receiving antennas at relay and destination from 2 to 3/4/5/6.

Keywords: VBLAST, MIMO, decode and forward, relay, wireless communication.

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1. Introduction

Relaying is considered as a promising technique for next generation wireless communication systems due to its ability of improving coverage and performance. There are mainly two types of relays: Amplify and Forward (AF) and Decode and Forward (DF). AF simply amplifies the incoming signal and forwards it to the destination without any attempt to decode it. AF relay is easy to implement but can not achieve high performance gain, whereas DF decodes the incoming signal, re-encodes it, and then retransmits it to the destination. Although the complexity of DF is high but can obtain high performance gain [1]. So we have used DF to show the performance of our proposed system.

On the other hand, multiple transmit and/or receive antennas promises very high data rates on a scattering-rich wireless channel, especially when propagation environment or channel is known at the receiver. Two types of transmission techniques are used in the MIMO system. One is transmit diversity in which different duplicates of the same transmission sequence are transmitted through different transmission antennas. One of the typical transmit diversity technique is Space Time Block Coding (STBC) [2-6]. The other one is transmitting multiplexing in which different transmission sequences are transmitted through different transmission antennas. The typical transmitting multiplexing technique is Bell Labs Layered Space-Time (BLAST) [7, 8]. In this paper we have used VBLAST to show the performance of our system. In VBLAST, independent data streams sharing both frequency bands and time slots are transmitted from multiple antennas and jointly detected at the receiver. It has been shown that the theoretical capacity approximately increases linearly as the number of antennas is increased.

Relay assisted wireless communication has been widely studied using Space Time Block Coding (STBC) [9-13]. We also published several papers on relay assisted wireless communication using STBC [14-18]. But relay assisted wireless communication using VBLAST has not been studied much. Reference [19, 20] investigated the relay assisted system with imperfect channel state information (CSI) using VBLAST. In this paper, we investigate the performance of relay assisted wireless communication where source is equipped with two transmit antennas, relay is equipped with multiple transmit and multiple receive antennas and destination is equipped with multiple receive antennas with perfect CSI using VBLAST.

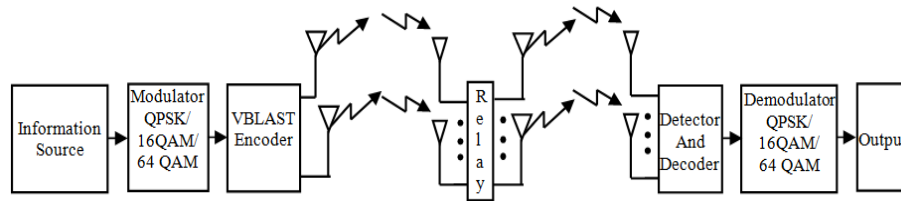


Figure 1. System Block Diagram

2. System Model

It is considered that the source is equipped with $(n_T)_s$ transmit antennas and relay is equipped with $(n_T)_r$ transmit and $(n_R)_r$ receive antennas and destination (base station) is also equipped with $(n_R)_d$ receiving antennas as shown in Figure 1. The antennas at each terminal are sufficiently spaced such that the links between the transmit and receive antenna pairs are uncorrelated. The encoding and decoding techniques of the system are discussed in detail below:

2.1. Encoding at Source using VBLAST

Data are modulated by a QPSK or 16 QAM or 64 QAM modulator and the modulated symbols are demultiplexed into $(n_T)_s$ separate streams, using a serial-to-parallel converter, and each stream is transmitted from an independent transmit antenna. Suppose signals s_i , $i = 1, 2, \dots, n$ are transmitted simultaneously using $(n_T)_s$ transmit antennas. It is considered that number of transmit antennas at source is two, i.e. $(n_T)_s = 2$; because it is not possible to deploy large number of antennas onto a small mobile handset due to size, complexity, power or other constraints. The transmission sequences of two transmit antennas of each user are shown in Table 1.

Table 1. The Transmission Sequence for Two Transmission Antennas using VBLAST of User's Handset

Antenna-I/Layer-I	Antenna-II/Layer-II
s_1	s_2
s_3	s_4

2.2. Received Signal at Relay:

The signal received at antenna j of relay can be written as:

$$y_j^{SR} = \sum_{i=1}^n P_{i,j}^{SR} \alpha_{i,j} s_i + \eta_j \quad (1)$$

Where y_j^{SR} is the $(n_R)_r \times 1$ dimension complex vector of received symbols.

$p_{i,j}^{SR}$ is path loss from transmit antenna i of source to receive antenna j of relay and $p_{i,j}^{SR} \propto \frac{1}{d_{SR}^2}$.

$\alpha_{i,j}$ is the $(n_T)_s \times (n_R)_r$ dimension channel matrix.

s_i is the $(n_T)_s \times 1$ dimension complex vector of transmitted sub-streams, each assumed to have zero-mean, uncorrelated random variables with variance equal to σ_s^2 .

η_j is the $(n_R)_r \times 1$ dimension complex vector representing the additive receiver noise, assumed to have zero-mean, uncorrelated random variables with variance σ_n^2 .

if $H_i = p_{i,j}^{SR} \alpha_{i,j}$, then (1) can be rewrite as:

$$y_j^{SR} = \sum_{i=1}^n H_i s_i + \eta_j \quad (2)$$

The receiver can be configured with different types of detection techniques such as ZF, MMSE and ML for VBLAST. In ZF technique, each sub-stream in turn is considered to be the desired signal and the remaining data streams are considered as "interferers". Nulling of the interferers is performed by linearly weighting the received signals so that all interfering terms are cancelled. Main steps of ZF are as follows [21]:

2.2.1. ZF

Step 1: Ordering - The purpose of the ordering is to decide which transmitted symbol to detect at each stage of the decoding. The symbols with highest SNR are selected first and then select the symbols in the order of decreasing SNR.

Step 2: Interference cancellation - The goal of the interference cancellation is to remove the interference from the already detected symbols. i.e. subtract the detected symbol \hat{s}_1 from the received vector y .

Consider At stage l of the algorithm, when s_l is being detected, symbols s_1, s_2, \dots, s_{l-1} have been already detected. Let us assume a perfect decoder, that is the decoded symbols $\hat{s}_1, \hat{s}_2, \dots, \hat{s}_{l-1}$ are the same as the transmitted symbols s_1, s_2, \dots, s_{l-1} . One can subtract $\sum_{i=1}^{l-1} s_i \alpha_i$ from the received vector y to derive an equation that relates remaining undetected symbols to the received vector, i.e.,

$$y_l = y - \sum_{i=1}^{l-1} s_i H_i = \sum_{i=l}^L s_i H_i + \eta, \quad l = 2, 3, \dots, L-1. \quad \square \quad (3)$$

In fact, by using induction in addition to the convention $y_l = y$, one can show that:

$$y_{l+1} = y_l - s_l H_l, \quad n = 1, 2, \dots, L-2. \quad (4)$$

Therefore, at the l^{th} stage of the algorithm after detecting the l^{th} symbol as \hat{s}_l , its effect is canceled from the equation by:

$$y_{l+1} = y_l - \hat{s}_l H_l \quad (5)$$

Step 3: Interference Nulling - Interference Nulling is the process of detecting s_l from y_l by first removing the effects of undetected symbols. Basically, in this step the l^{th} symbol is detected by nulling the interference caused by symbols $s_{l+1}, s_{l+2}, \dots, s_L$.

So, we would like to separate the $s_l H_l$ from y_l . This can be done through multiplying y_l by an $m \times 1$ vector W_l that is orthogonal to interference vectors $H_{l+1}, H_{l+2}, \dots, H_L$ but not orthogonal to H_l . In other words, W_l should be such that:

$$\begin{aligned} H_i W_l &= 0, & i &= l+1, l+2, \dots, L, \\ H_l W_l &= 1. \end{aligned} \quad (6)$$

In fact, W_l is called the zero-forcing nulling vector with minimum norm. Such a vector is uniquely calculated from the channel matrix H . To calculate W_l from H , for $m \geq n$, first we should replace the rows $1, 2, \dots, l-1$ of H by zero. Let us denote the resulting matrix by Z . Then, W_l is the l^{th} column of Z^+ , the Moore-Penrose generalized inverse, pseudo-inverse, of Z . Using the error free detection formula for y_l in (3) and W_l in (6), we have:

$$y_l \cdot W_l = s_l + \eta \cdot W_l \quad (7)$$

The noise in (7) is still Gaussian and the symbols s_l can be easily decoded.

Step 4: Slicing - Making a symbol decision. i.e. s_l can be sliced to the nearest QAM constellation point, these sliced signals are denoted by \hat{s} . The decoded symbol \hat{s}_l is the closest constellation point to $y_l \cdot W_l$.

Step 5: Iteration - Going to the first step to detect the next symbol

2.2.2. ML

ML is a method that compares the received signal with all possible transmitted signals and estimates s according to the maximum Likelihood principle. Suppose a matrix C gives all possibilities in s that could occur (the dimensions of C are $n \times K$ where $K = M^n$ and M represents the number of constellation points) Then, the receiver should store a matrix Z such that:

$$Z = H \cdot C = [z_1 \dots z_k] \quad (8)$$

At the receiver, the most likely transmitted signal is determined, as the one for which $\|y - z_j\|^2$ is minimal (with $1 \leq j \leq k$, i.e., the signal s_j that corresponds with the vector z_j which lays closed to the received vector is said to be the most likely signal to be transmitted. Thus \hat{s} is chosen to be the j^{th} column of C . This can be rewritten to the following formula where s_{ml} represents the maximum likelihood detection of the transmitted signal s :

$$\hat{s} = s_{ml} = \arg \min_{s_j \in \{s_1 \dots s_k\}} \|y - Hs_j\|^2 \quad (9)$$

Note that in the case of ML, it is not required that $n \leq m$. The detected symbols are demodulated by 64QAM demodulator and send to turbo decoder to get the output.

2.3. Re-encoding at Relay Using Turbo -VBLAST:

The detected symbols at relay are denoted by \hat{s}_i . VBLAST encoder of relay encodes the decoded symbols according to the Table 2, 3 and 4 for two, three and four transmit antennas respectively and then transmitted simultaneously using n transmit antennas.

Table 2. The Transmission Sequence for Two Transmission Antennas of Relay using VBLAST

Antenna-I / Layer-I	Antenna-II / Layer-II
\hat{s}_1	\hat{s}_2
\hat{s}_3	\hat{s}_4

Table 3. The Transmission Sequence for Three Transmission Antennas of Relay using VBLAST

Antenna-I / Layer-I	Antenna-II / Layer-II	Antenna-III / Layer-III
\hat{s}_1	\hat{s}_2	\hat{s}_3
\hat{s}_4	\hat{s}_5	\hat{s}_5
\hat{s}_6	\hat{s}_7	\hat{s}_8

Table 4. The Transmission Sequence for Four Transmission Antennas of Relay using VBLAST

Antenna-I/ Layer-I	Antenna-II/ Layer-II	Antenna-III/ Layer-III	Antenna-IV/ Layer-IV
\hat{s}_1	\hat{s}_2	\hat{s}_3	\hat{s}_4
\hat{s}_5	\hat{s}_5	\hat{s}_6	\hat{s}_7
\hat{s}_8	\hat{s}_9	\hat{s}_9	\hat{s}_{10}
\hat{s}_{11}	\hat{s}_{12}	\hat{s}_{13}	\hat{s}_{14}

3.5. Received Signal and Decoding at Destination:

The received signal at antenna j of destination can be represented as:

$$y_j^{RD} = \sum_{i=1}^n P_{i,j}^{RD} a_{i,j} \hat{s}_i + \eta_j \tag{10}$$

where y_j^{RD} is the received symbols at destination.

p_i^{RD} is path loss from transmit antenna i of relay to receive antenna and $d_{i,j} \propto \frac{1}{d_{RD}^2}$

$a_{i,j}^{d,s}$ is the channel from relay to destination.

\hat{s}_i is the transmitted information from relay.

η_j is the noise of receiver of destination.

If, $A_i = P_{i,j}^{RD} a_{i,j}$, then (10) can be rewrite as:

$$y_j^{RD} = \sum_{i=1}^n A_i \hat{s}_i + \eta_j \tag{11}$$

The received symbols at destination are detected by ZF or ML as mentioned in the section 2.2.1 and 2.2.2.

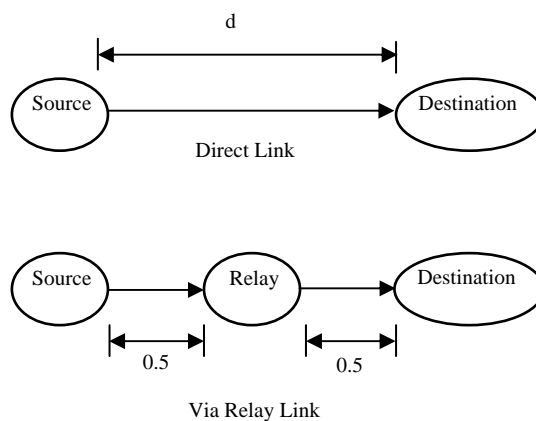


Figure 2. Direct Link and Via Relay Link

3. BER Performance Evaluation

In this section, computer simulation is carried out to show the BER performance of the proposed system. The results are evaluated for several combinations of Tx and Rx antennas with and without relay. 64 QAM is used for simulation. It is considered that relay is placed at the middle of source and destination. We used two terms in Figure 3 to Figure 7: Direct Link (DL) and Via Relay Link (VRL). DL means that information pass from source to destination without relay. On the other hand, VRL means that information pass from source to relay and then from relay to destination as shown in Figure 2.

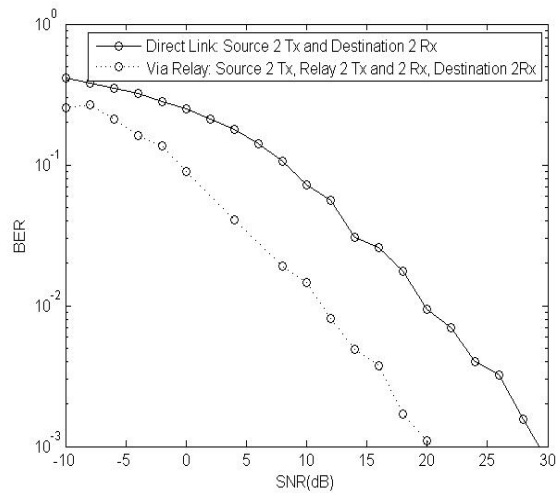


Figure 3. BER Performance Comparison for Direct Line with 2Tx & 2Rx and Via Relay Link with 2Tx & 2Rx

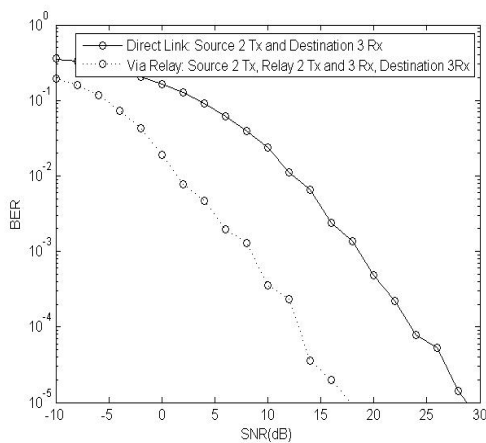


Figure 4. BER Performance Comparison for Direct Line with 2Tx & 3Rx and Via Relay Link with 2Tx & 3Rx

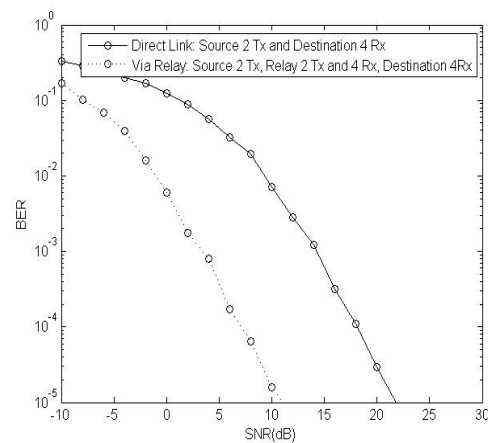


Figure 5. BER Performance Comparison for Direct Line with 2Tx & 4Rx and Via Relay Link with 2Tx & 4Rx

Figure 3 shows the performance of DL and VRL where source has 2 Tx, relay has 2 Tx and 2 Rx and destination has 2 Rx. it is observed that VRL provides 9 dB coding gain compared to DL at 10^{-3} .

Figure 4 shows the performance of DL and VRL where source has 2 Tx, relay has 2 Tx and 3 Rx and destination has 3 Rx. it is observed that VRL provides 11 dB coding gain compared to DL at 10^{-5} .

Figure 5 shows the performance of DL and VRL where source has 2 Tx, relay has 2 Tx and 4 Rx and destination has 4 Rx. it is observed that VRL provides 11dB coding gain compared to DL at 10^{-5} . And there are around 6dB gains for increasing Rx antennas of relay from 3 to 4.

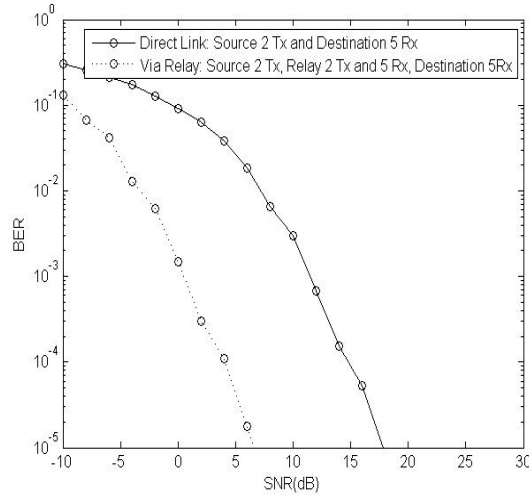


Figure 6. BER Performance Comparison for Direct Line with 2Tx & 5Rx and Via Relay Link with 2Tx & 5Rx

Figure 6 shows the performance of DL and VRL where source has 1 Tx, relay has 2 Tx and 5 Rx and destination has 2 Rx. it is observed that VRL 11 dB coding gain compared to DL at 10^{-5} . There are around 11dB gains for increasing Rx antennas of relay from 3 to 5. And there are around 6dB gains for increasing Rx antennas of relay from 4 to 5.

Figure 7 shows the performance of DL and VRL where source has 2 Tx, relay has 2 Tx and 6 Rx and destination has 6 Rx. it is observed that via relay link provides 11.5 dB coding gain compared to direct link at 10^{-5} . There are around 7dB gains for increasing Rx antennas of relay from 4 to 6. And there are around 3 dB gains for increasing Rx antennas

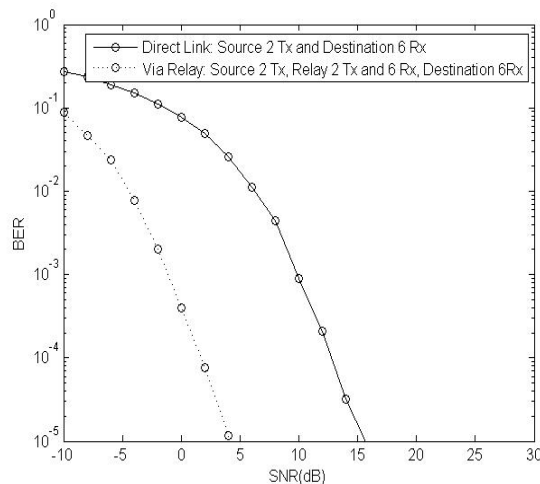


Figure 7. BER Performance Comparison for Direct Line with 2Tx & 6Rx and Via Relay Link with 2Tx & 6Rx

4. Conclusion

From the simulations results, it is observed that relay assisted wireless communication using VBLAST makes a significant difference over direct wireless communication. It is possible to get 9 to 11.5dB gain by placing relay between source and destination. And there are around 3dB to 11dB gains for increasing number of receiving antennas of relay and destination from 2 to 3/4/5/6.

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