An HARQ scheme with antenna switching for V-BLAST system

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Abstract

Bell-labs layered space-time (BLAST) achieves high spectral efficiency in rich scattering environments by transmitting independent data streams via each transmit antenna. However, this high spectral efficiency is significantly reduced if the signals ate the receiver go through correlated channels. In this paper, we propose a hybrid automatic request (HARQ) scheme to alleviate the adverse effect of the channel correlation by simply switching the transmission in retransmission. With the proposed scheme, we can achieve significant improvement over the correlated channels with negligible complexity increase.

Key words: BLAST, V-BLAST, HARQ, antenna switching, channel correlation.

1. Introduction

It is well known that multi-input multi-output (MIMO) wireless channels have significantly higher capacities than single-input single-output wireless channels [1]. Bell-labs layered space-time (BLAST) is a communication technique for achieving high spectral efficiencies in highly scattering environments using multiple transmit and receive antennas [2].

The initial diagonal BLAST (D-BLAST) architecture is theoretically capable of approaching the open loop spectral efficiency, but at a high complexity cost [2]. A simplified version known as vertical BLAST (V-BLAST), which still achieves large portion of that efficiency, was later developed [3]. In V-BLAST, every transmit antenna transmits an equal-rate independently encoded streams of data. This independence enables the utilization of interference rejection and cancellation techniques with the aided advantage that the multiple streams are precisely synchronized at the receiver [4][5]. Therefore, a V-BLAST receiver can be regarded as a multi-stage synchronous multiuser detector. This type of successive cancellation methods has already proved very effective. This well-known V-BLAST detector consists of two components: a linear transformation and an ordered successive interference canceller. The linear transformation eliminates interferences from other data streams and can be based on a zero-forcing (ZF) or minimum mean square error (MMSE) criterion. Following the linear transformation, the symbols of the stream with highest signal to noise ratio (SNR) are detected, and its signal is subtracted from the sufficient statistics. Using this revised sufficient statistic vector, the linear transformation and ordered successive interference cancellation are repeated until all streams have been detected.

V-BLAST systems transmit parallel data streams, using multiple antennas, simultaneously and on the same frequency. With multipath propagation, these different streams can be separated at the receiver because of their distinct spatial signatures. Remarkably, in its original form, BLAST does not require the transmitter to possess any channel information: only the receiver is required to estimate the channel. Nonetheless, if rich scattering environment is guaranteed, the spectral efficiency attainable-in this open loop form- is very close to the spectral efficiency supported by the channel. These high spectral efficiencies are resulted from the fact that a scattering environment makes the signal from each transmitter appear highly uncorrelated at each of the receive antennas. However, this high spectral efficiency is significantly reduced if the signals at the receiver go through correlated channels.

Hybrid automatic request (HARQ) is an error control technique that is combination of channel coding and ARQ. HARQ is an implicit link adaptation technique and requires link layer acknowledgements for retransmission decisions. There are two types of HARQ scheme: Chase combining [6] and incremental redundancy (IR) [7]. Chase combining simply repeats the entire coded packet when retransmission is required. The receiver combines thesed multiple copies of the transmitted packet weighted by the received SNR and thus diversity gain is obtained. Incremental redundancy or HARQ type-II/III are another implementation of HARQ technique that additional redundant information is incrementally transmitted if the packet is not delivered successfully. While the HARQ type-III is self-decodable for each retransmission, the HARQ type-II is not. Chase combining and IR schemes improve the throughput by obtaining diversity gain with different ways.

In this paper, we propose an antenna switching for V-BLAST system to achieve more diversity gain when retransmission is occurred. In section 2, we explain the system and channel model. In section 3, we describe the proposed transmission scheme in detail. In section 4, we show the performance of the proposed scheme over uncorrelated and correlated fading channels with simulation results. Finally, we conclude this paper in section 5.

2. System and channel models

We consider a discrete-time complex baseband model for a single-user link, assuming perfect synchronization. Received signals are sampled at the symbol rate and the receiver structure is symbol-spaced. It is assumed that the channel is stationary over the symbol period. Perfect channel estimation at the receiver is assumed.

We use NxM matrix to represent a configuration with M transmit and N receive antennas. The sampled channel response from the m-th transmit antenna to the n-th receive antenna at time k is assumed to be frequency non-selective and denoted by $h_{nm}(k)$.

The signal transmitted at time k is the M-dimensional vector $\mathbf{s}(\mathbf{k})=[s_1(k)\cdots s_M(k)]$ with covariance matrix

$$E[\mathbf{s}(\mathbf{k})\mathbf{s}^{\mathbf{H}}(\mathbf{k})]=\frac{P_T}{M}\mathbf{I}^{\mathbf{MxM}} \quad (1)$$

where P_T is the total transmit power which is held constant irrespective of the number of transmit antennas M, $\mathbf{I}^{\mathbf{MxM}}$ is M-dimensional identity matrix and $s_j(k)$ is the transmitted symbol from the j-th antenna. The receiver additive white Gaussian noise (AWGN) can be expressed as an N-dimensional vector **n(k)** with covariance matrix

$$E[\mathbf{n}(\mathbf{k})\mathbf{n}^{\mathbf{H}}(\mathbf{k})]=\sigma^2\,\mathbf{I}^{\mathbf{NxN}}$$

(2)

Then we can represent the N-dimensional received vector **x(k)** as

$$\mathbf{x}(\mathbf{k})=\mathbf{H}(\mathbf{k})\mathbf{s}(\mathbf{k})+\mathbf{n}(\mathbf{k})$$

(3) where $\mathbf{x}(\mathbf{k})=[x_1(k)\cdots x_N(k)]$ which $x_i(k)$ is the received symbol in the i-th antenna and **H(k)** is the NxM channel response matrix at time k whose element is $h_{nm}(k),\ n=1,\cdots,N$ and $m=1,\cdots M$.

The receiver consists of M successive stages. At each stage, the best data stream-in the ZF or MMSE sense-is extracted, detected, and canceled out. The following is the V-BLAST detector description:

- Compute the linear transformation.
- Determine the component with the lowest MSE.
- Decide the corresponding symbol.
- Remove the contribution of this component and reduce the size of remaining matrices and vectors.
- Repeat above steps until all M components have been detected

3. Proposed transmission scheme

In Fig. 1, we show the proposed transmission scheme. The information symbol is channel encoded and passed through serial to parallel processor. In antenna switching processor, the data stream is assigned to transmit antenna by a retransmission rule. Then, each data stream is transmitted over a frequency non-selective fading channel and corrupted by an AWGN. The received data is processed by a V-BLAST processor, combined in the antenna de-switching and HARQ combining block, and recovered. If recovered data has errors, negative acknowledgement (NACK) should be signaled to the transmitter. Otherwise, ACK should be signaled to the transmitter.

As stated in the previous section, V-BLAST system achieves capacity gain in the rich scattering environment. However, if there exists correlation in the transmission channel, the performance is severely degraded. When HARQ scheme is adopted into the V-BLAST system, this problem is significantly improved. The data symbol is transmitted other antenna in the retransmission than that in the initial or previous transmission.

Let's assume the V-BLAST system with two transmit antennas for convenient explanation. We choose the Chase combining as HARQ technique. The HARQ operation is as follows: Assume that the first transmission fails. The data stream sent in antenna 1 in the initial transmission is transmitted in antenna 2 in the second transmission. Similarly, the data stream sent in antenna 2 in the initial transmission is transmitted in antenna 1 in the second transmission. When the second transmission also fails, the data stream is transmitted in the same way as the first transmission. To summarize, the antenna to transmit each data stream is changed whenever retransmission is occurred. By transmitting data stream via the different antenna, spatial diversity can be obtained in addition to time diversity due to HARQ operation. Hence, this can improve the throughput by reducing the adverse effect of channel correlation.

We describe a general retransmission rule for the V-BLAST system with M transmit antennas as follows:

```
Step 1: Initialization
  RetNum = 0
  for k=1:M
    k-th data stream is transmitted in antenna k(0)
  end
Step 2: Retransmission
  while (NACK is received)
    RetNum = RetNum + 1
    if RetNum mod M is equal to zero
      Go to step 1
    else
      for k=1:M
        for n=0:(RetNum-1) mod M
          k-th data stream is transmitted in antenna k_i ≠ k(n)   (4)
        end
        k(RetNum mod M) = k_i
      end
    end
Step 3: Go to step 1.
```

The variable *RetNum* is the number of retransmission, incremented to one whenever retransmission is happened, to transmit the current packet and mod means modulo operation. There are more than one methods to search the transmit antenna for k-th data stream satisfying the condition (4). There is only one restriction on the antenna assignment. When the number of retransmission, *RetNum*, becomes multiple of the number of transmit antennas, *M*, the k-th data stream is transmitted in the antenna which was used at the first transmission.

4. Results and discussions

We evaluate the performance of the proposed scheme using computer simulation. The simulation environments are as follows:

- Antenna configuration: (2, 2) and (4, 4) where (*M*, *N*) denotes *M* transmit and *N* receive antennas
- Single path fading channel
- Carrier frequency: 2 GHz
- Mobile speed: 3 km/h and 120 km/h
- Channel coding: turbo code with coding rate 1/2
- Frame size: 394
- Frame duration: 2 ms
- Modulation: QPSK
- Perfect channel estimation
- Total transmit power: 80 % of the base station power
- HARQ type: Chase combining
- Maximum number of retransmissions: 10
- Retransmission delay: 6 frames (= 12 ms)
- Channel correlation matrix for (2, 2) configuration:

$$\begin{pmatrix} 1 & a \\ a^* & 1 \end{pmatrix} \quad (5)$$

where $a = 0.4640 + 0.8499i$ and * is the complex conjugate operation. This correlation matrix represents that angle of arrival (AOA) is 20°, angle spread (AS) is 5°, and distance between base station antennas is half wavelength.

- Channel correlation matrix for (4, 4) configuration:

$$\begin{pmatrix} 1 & a & b & c \\ a^* & 1 & a & b \\ b^* & a^* & 1 & a \\ c^* & b^* & a^* & 1 \end{pmatrix} \quad (6)$$

where $a = 0.4640 + 0.8499i$, $b = -0.4802 + 0.7452i$, and $c = -0.7688 + 0.0349i$. This correlation matrix represents that AOA is 20^{O}, AS is 5^{O}, and distance between base station antennas is half wavelength.

The antenna switching rule for (2, 2) configuration is that $(1 \to 1, 2 \to 2)$ for the initial transmission and $(2 \to 1, 1 \to 2)$ for the second transmission where $(1 \to T_1, 2 \to T_2, \cdots, k \to T_k, M \to T_M)$ denotes that *k*-th data stream transmit in the T_k-th transmit antenna. The antenna switching rule for (4, 4) configuration is that $(1 \to 1, 2 \to 2, 3 \to 3, 4 \to 4)$ for the initial transmission, $(1 \to 2, 2 \to 3, 3 \to 4, 4 \to 1)$ for the second transmission, $(1 \to 3, 2 \to 4, 3 \to 1, 4 \to 2)$ for the third transmission, and $(1 \to 4, 2 \to 1, 3 \to 2, 4 \to 3)$ for the fourth transmission. It is assumed that this rule is known to both the transmitter and the receiver.

Fig. 2 and Fig. 3 show the throughput performance of the proposed scheme for (2, 2) configuration over an uncorrelated and a correlated fading channels when mobile speed varies. As shown in Fig 2(a) and Fig. 3(a), the throughput of the proposed scheme over the uncorrelated channel is almost same as that of the conventional HARQ scheme. It is seen that more throughput gain can be obtained when the mobile moves slowly. We can see that the proposed scheme improves the throughput over the correlated channel significantly as shown in Fig. 2(b) and Fig. 3(b). At $\frac{I_{or}}{I_{oc}}$ of –10 dB, more than 30 % throughput improvement can be achieved. We can also see that the improvement is relatively low in the high $\frac{I_{or}}{I_{oc}}$ region.

Fig. 4 and Fig. 5 show the throughput performance of the proposed scheme for (4, 4) configuration over an uncorrelated and a correlated fading channels when mobile speed varies. In Fig. 4(a) and Fig 5(a), the throughput of the proposed scheme is almost same as that of the conventional scheme similar to (2, 2) configuration. Similar to results of Fig. 2 and Fig. 3, the improvement is relatively high in the region of low $\frac{I_{or}}{I_{oc}}$ and significant gain is shown in the correlated channel. From Fig. 4(b) and Fig 5(b), more than 20 % gain of throughput can be achieved at $\frac{I_{or}}{I_{oc}}$ of –5 dB.

From the result from Fig. 2 to Fig 5, the performance degradation of V-BLAST system over a correlated channel can be mitigated with the proposed scheme. That is, undesirable impact of the channel correlation can be reduced by simply switching the transmit antenna whenever retransmission is occurred. The complexity increase to implement the proposed scheme is almost negligible.

5. Conclusions

We propose a HARQ scheme in the V-BLAST system to simply switch the transmit antenna for each retransmission. The proposed scheme significantly mitigates the performance degradation of the V-BLAST system over a correlated channel. That is, more diversity gain due to different antenna assignment lessens the adverse effect of the channel correlation. Furthermore, negligible complexity increase is required.

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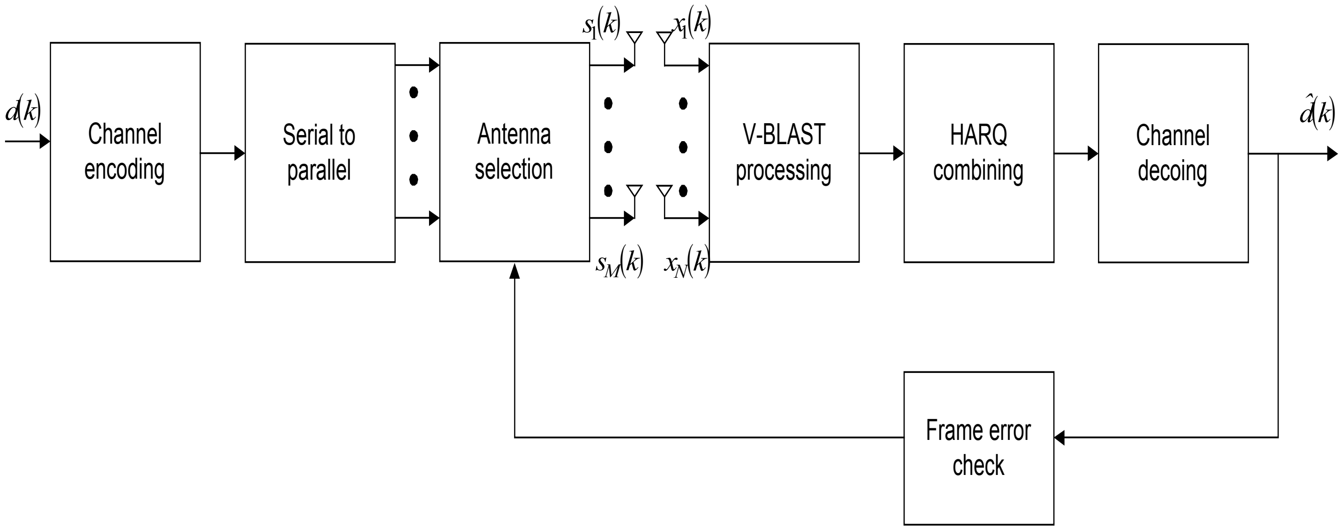
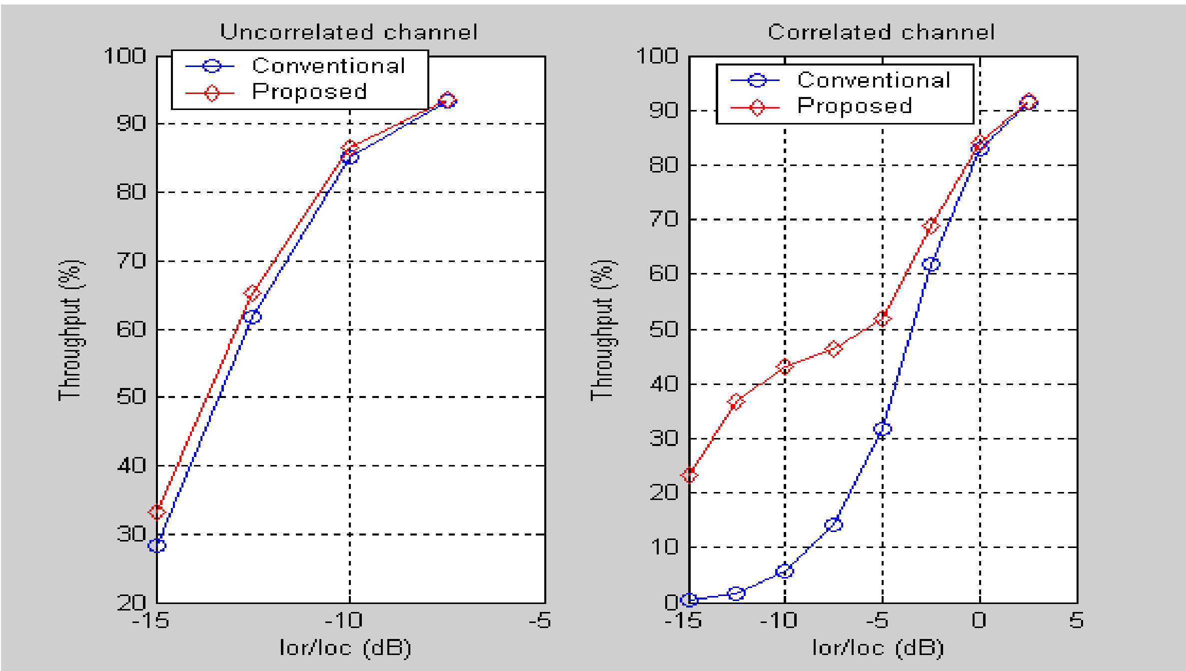
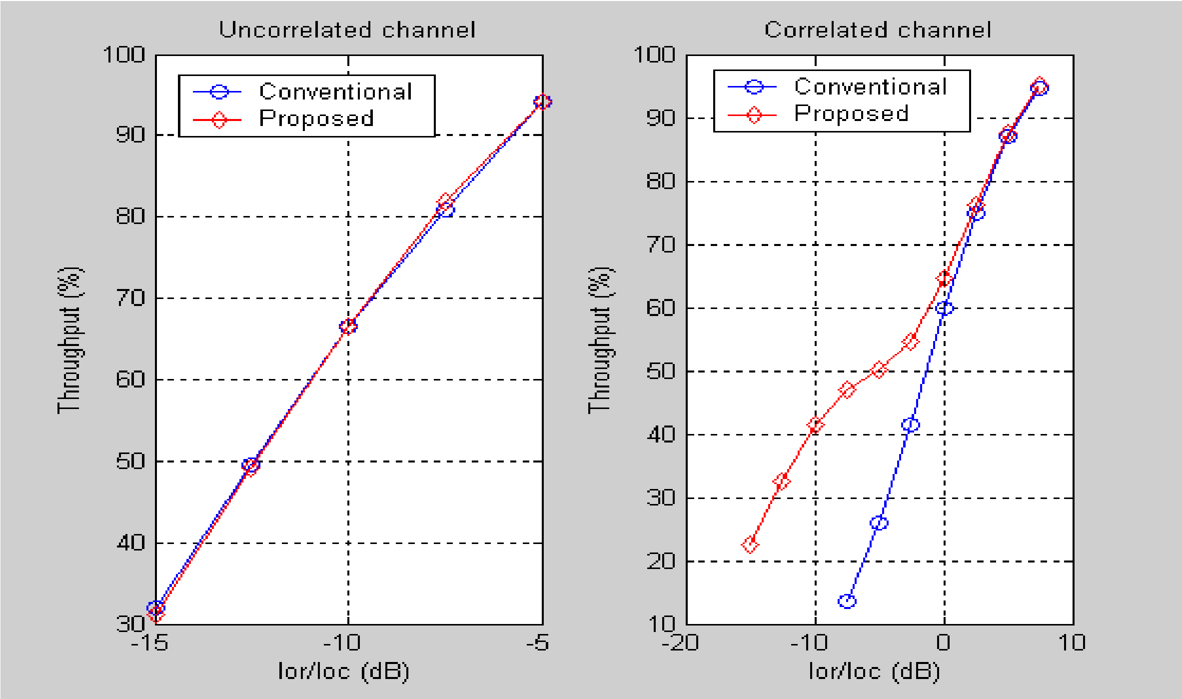


Fig. 1. The proposed transmission system.



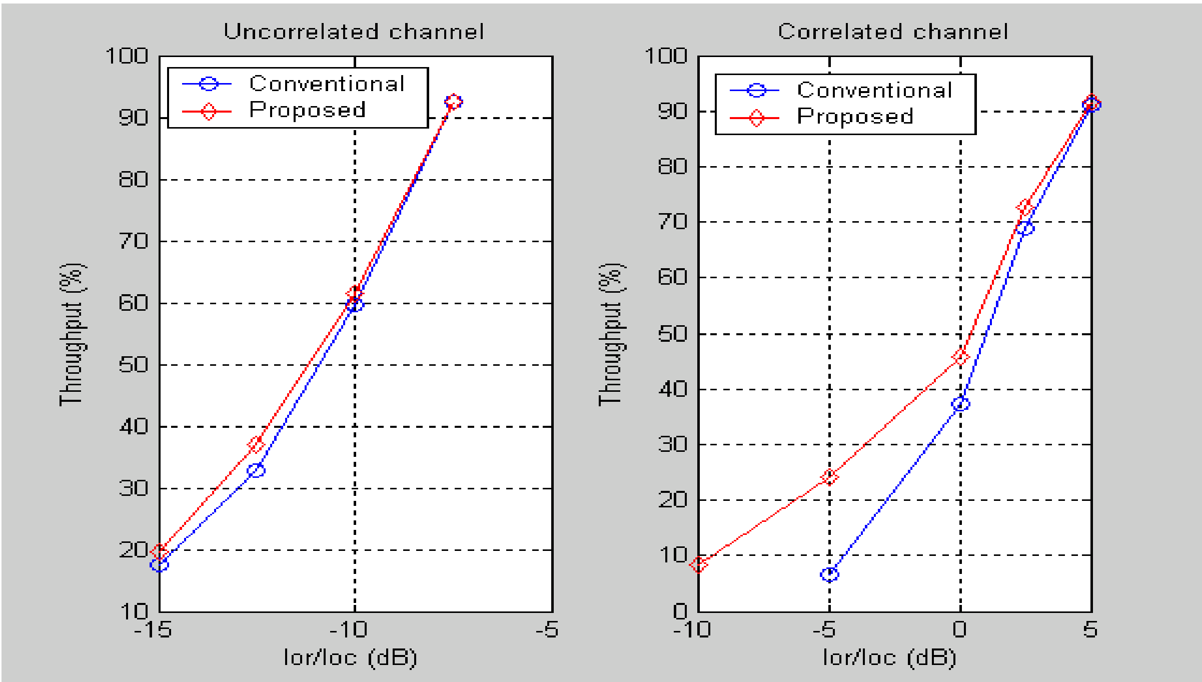
(a) (b)

Fig. 2. Performance comparison between the proposed and the conventional schemes for (2, 2) configuration in terms of throughput when mobile speed is 3 km/h. (a) Throughput performance over an uncorrelated channel. (b) Throughput performance over a correlated channel



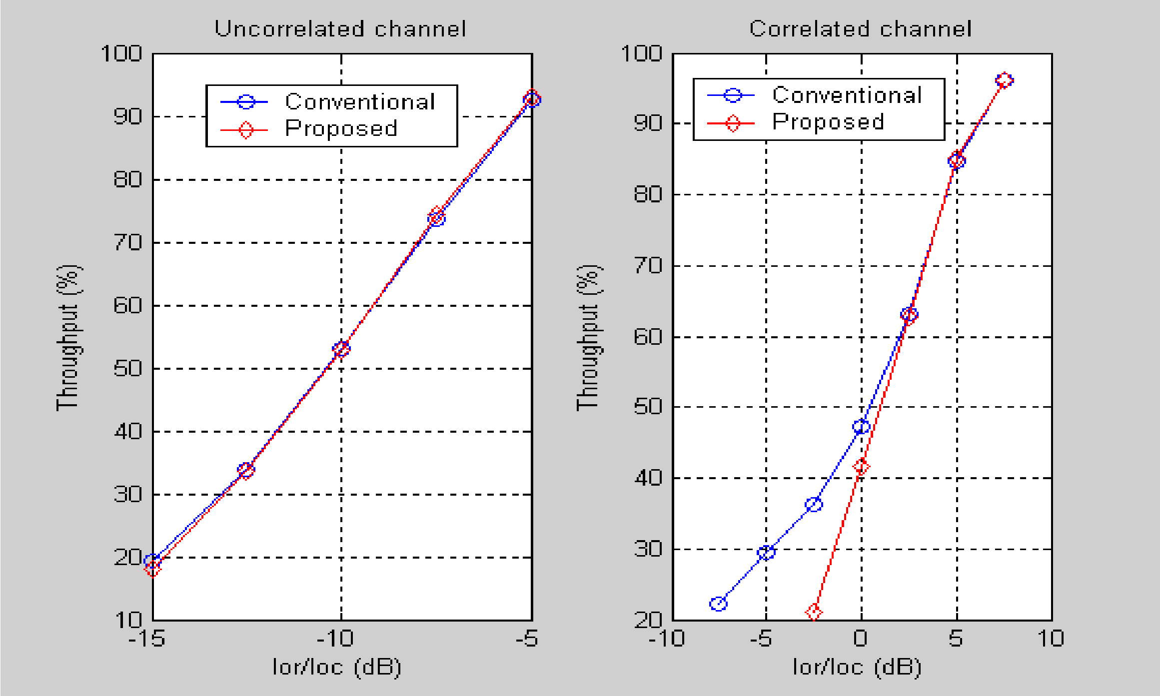
(a) (b)

Fig. 3. Performance comparison between the proposed and the conventional schemes for (2, 2) configuration in terms of throughput when mobile speed is 120 km/h. (a) Throughput performance over an uncorrelated channel. (b) Throughput performance over a correlated channel



(a) (b)

Fig. 4. Performance comparison between the proposed and the conventional schemes for (4, 4) configuration in terms of throughput when mobile speed is 3 km/h. (a) Throughput performance over an uncorrelated channel. (b) Throughput performance over a correlated channel



(a) (b)

Fig. 5. Performance comparison between the proposed and the conventional schemes for (4, 4) configuration in terms of throughput when mobile speed is 120 km/h. (a) Throughput performance over an uncorrelated channel. (b) Throughput performance over a correlated channel