# Distributed ARQ using STBC for OFDM Ad-hoc Networks

Erina Kojima Takeo Fujii Yukihiro Kamiya and Yasuo Suzuki

*Abstract*—**In ad-hoc networks, the routing protocol is a serious problem because it is complicated due to the movement of node. In this paper, in order to reduce the routing cost of ad-hoc networks, we propose a routing-less ad-hoc communication system by adopting the distributed automatic repeat request (ARQ). In the proposed system, a source node and distributed repeater nodes simultaneously transmit the same data packet to the destination node without any routing table. This operation is repeated until the source node correctly receives the response signal from the destination node. Furthermore, the repeated data in each node is encoded as a branch of Space-Time Block Code (STBC) known as cooperative diversity to obtain the diversity gain. In this paper, in order to verify the efficiency of the proposed system, we perform computer simulations and evaluate the packet success rate performance, as well as the throughput performance.**

*Index Terms*— **Ad-hoc network, STBC, ARQ, OFDM**

## I. INTRODUCTION

Ad-hoc networks are distributed network systems, consisting of many distributed mobile nodes without predetermined topology and central control units [1]. If the source node and the destination node exist within their coverage area, they can directly communicate through a hop. On the other hand, even if both nodes exist outside of their coverage areas, they can communicate each other by relaying through other nodes as multi-hop communication. In ad-hoc networks, each node should play a role of a router, which is caused by the fact that there is no central control base station. However, it is difficult to discover a route from the source node to the destination node, if the network changes its topology dynamically.

In wireless communication systems, fading and shadowing cause the degradation of the connectivity between the source node and the destination node. In order to solve these problems, antenna diversity schemes are known as one of effective methods. However, in ad-hoc networks, it is difficult to put several antennas on a small size node. In order to realize the space diversity in ad-hoc networks with small size nodes, some techniques in which plural distributed nodes are utilized as the antenna diversity branches have been proposed [2]. In this method, Space-Time Block Code (STBC) [3] is applied to the distributed nodes in order to obtain the diversity gain through the relay. Although the original STBC assumes transmitters equipped with several antennas, in this method, STBC transmission is realized by using antennas installed on different nodes. These nodes work as one of the antenna branches of STBC transmitter. However, the complicated routing is required in the method.

In this paper, in order to get the diversity gain without complicated routing process in ad-hoc networks, we propose a novel system that reduces the routing cost and realizes reliable communication. In the proposed system, the surrounding repeater nodes temporally receive and detect the packet for the destination node. When the destination node does not receive the correct data or the packet dose not arrive at the destination node, the source node and the repeater nodes retransmit the packet simultaneously to the surrounding nodes. The nodes, which can receive the packets without error in the previous slots, also transmit the packet until the source node receives the response signal from the destination node. We call this system as a distributed ARQ. Furthermore, in order to improve the performance by the diversity gain, STBC is applied when the nodes relay the packet. Here, the source node and the repeater nodes work as one of the branches of STBC, and they simultaneously retransmit one of the branch data encoded with STBC. In such simultaneous retransmission system with plural nodes, the transmit timing offset degrades the performance. In such situation Orthogonal Frequency Division Multiplexing (OFDM) is known as one of the effective modulation method for mitigating the influence of the timing offset among nodes by using Guard Interval (GI). Therefore in the proposed system, OFDM modulation is applied.

In this paper, in order to verify the efficiency of the proposed system, computer simulations are performed. The rest of this paper is organized as follows. In section 2, the routing protocols is briefly explained. Section 3 describes the basic mechanism of STBC. Section 4 describes the procedure of the proposed system. Section 5 presents the simulation results and Section 6 concludes the paper.

## II. CURRENT ROUTING PROTOCL

Routing protocols for ad-hoc networks are classified into two types. One is the table-driven protocol [4] and the other one is the on-demand protocol [5]. In the table-driven protocol, the nodes flow their topology information periodically, so that the source node discovers and controls the route toward the destination node on the basis of the topology information. Con-

The author are with the Department of Electrical and Electronic Engineering, Graduate School of Engineering, Tokyo University of Agriculture and Technology (email: kojima@suzuki-lab.tuat.ac.jp).

sequently, a route is discovered before the source node tries to transmit the data packets, and the transmission delay due to the routing is not generated. However, the control data overhead becomes large due to the fact that the topology information must be added to the data packet. Moreover, it is difficult to establish the appropriate route if the topology often changes. On the other hand, in the on-demand routing protocol, the nodes do not flow their topology information data periodically. In this protocol, the source node discovers the route when the source node tries to transmit the packet, so the control data is transmitted just on-demand. Therefore, the delay is caused by the routing. However, the on-demand protocol is adequate for the situation in which the topology is often changed in accordance with the movement of the node. In both routing protocols, routes are discovered by the surrounding nodes' topology information that changing frequently.

Thus, in this paper, we propose an ad-hoc communication system that does not need the topology information of the surrounding nodes.

## III. SPACE -TIME BLOCK CODE

In this paper, in order to obtain the diversity gain from the packet relaying using the plural nodes, the STBC cooperative diversity is applied.

Figure 1 shows the original two-branch STBC transmit diversity scheme. In STBC, at a given symbol period, two signals are simultaneously transmitted from the two antennas as shown in Table 1.

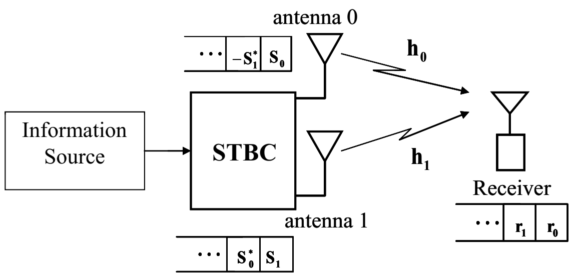


Figure 1 The two-branch transmit diversity scheme with one receiver.

TABLE 1 THE TRANSMISSION SEQUENCE FOR STBC.

| | $t$ | $t+T$ |
|---|---|---|
| antenna 0 | $\mathbf{s}_0$ | $-\mathbf{s}_1^*$ |
| antenna 1 | $\mathbf{s}_1$ | $\mathbf{s}_0^*$ |

The signal $\mathbf{s}_0$ and $\mathbf{s}_1$ are transmitted from the antenna #0 and antenna #1, respectively. During the next symbol period the signal ($-\mathbf{s}_1^*$) is transmitted from antenna #0 and the signal $\mathbf{s}_0^*$ is transmitted from antenna #1. Assuming that the fading status is constant across two consecutive symbols, the channel gain $\mathbf{h}_0$(t) for transmit antenna #0 and the channel gain $\mathbf{h}_1$(t) for transmit antenna #1 are given by,

$$\begin{aligned} \mathbf{h}_0(t) &= \mathbf{h}_0(t+T) = \mathbf{h}_0 = \alpha_0 e^{j\theta_0} \\ \mathbf{h}_1(t) &= \mathbf{h}_1(t+T) = \mathbf{h}_1 = \alpha_1 e^{j\theta_1} \end{aligned}, \quad (1)$$

where $\alpha_0$ and $\alpha_1$ are the amplitude and $\theta_0$ and $\theta_1$ are the phase of $\mathbf{h}_0(t)$ and $\mathbf{h}_1(t)$, respectively. The received signals $\mathbf{r}_0$ and $\mathbf{r}_1$ received at time $t$ and $(t+T)$ can be expressed as

$$\begin{aligned} \mathbf{r}_0 &= \mathbf{r}(t) = \mathbf{h}_0\mathbf{s}_0 + \mathbf{h}_1\mathbf{s}_1 + \mathbf{n}_0 \\ \mathbf{r}_1 &= \mathbf{r}(t+T) = -\mathbf{h}_0\mathbf{s}_1^* + \mathbf{h}_1\mathbf{s}_0^* + \mathbf{n}_1 \end{aligned}, \quad (2)$$

where $\mathbf{n}_0$ and $\mathbf{n}_1$ are the noise components. In order to separate the transmitted signals, estimated channel gain and the received signals are converted as follows,

$$\begin{aligned} \tilde{\mathbf{s}}_0 &= \mathbf{h}_0^*\mathbf{r}_0 + \mathbf{h}_1\mathbf{r}_1^* \\ \tilde{\mathbf{s}}_1 &= \mathbf{h}_1^*\mathbf{r}_0 - \mathbf{h}_0\mathbf{r}_1^* \end{aligned}. \quad (3)$$

Substituting (1) and (2) into (3), we get

$$\begin{aligned} \tilde{\mathbf{s}}_0 &= (\alpha_0^2 + \alpha_1^2)\mathbf{s}_0 + \mathbf{h}_0^*\mathbf{n}_0 + \mathbf{h}_1\mathbf{n}_1^* \\ \tilde{\mathbf{s}}_1 &= (\alpha_0^2 + \alpha_1^2)\mathbf{s}_1 - \mathbf{h}_0\mathbf{n}_1^* + \mathbf{h}_1^*\mathbf{n}_0 \end{aligned}. \quad (4)$$

These combined signals are fed into the maximum likelihood detector. The channel gain patterns in (4) are similar to the maximum ratio combining (MRC) diversity signals with two received antennas except the noise components that are lager than MRC. Therefore, STBC using two transmit antennas and one receive antenna provides the same diversity order as the MRC diversity using one transmit antenna and two receive antennas.

In the proposed system, the distributed nodes with one antenna are regarded as one of the STBC antenna branches. Figure 2 shows the simplified example of the proposed system. At first, the source node (S) broadcasts the data packet to the surrounding nodes. The destination node (D) and the repeater nodes (R1, R2) receive the data packet shown in Fig. 2 (a). In this case, the node D dose not receive the packet correctly. So the node D broadcasts the response signal in order to request the retransmission packet. Then the node S, R1 and R2 transmit the retransmission packet encoded with STBC. The transmitted encoded pattern is randomly selected from two STBC encoding patterns in each node as shown in Fig. 2 (b). As a result, the node D receives the signals from plural nodes with STBC encoding and can obtain the diversity gain.

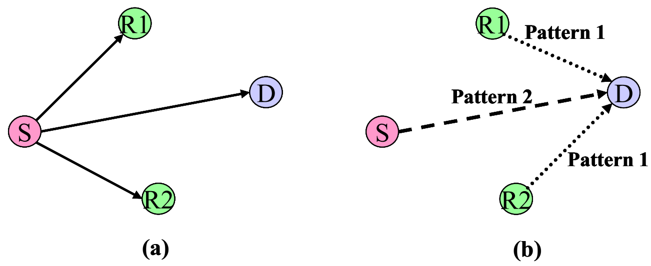


Figure 2 The simplified example of the proposed system.

## IV. PROPOSED DISTRIBUTED ARQ WITH STBC

In this section, we discuss the procedure of the proposed system, namely distributed ARQ using STBC for OFDM ad-hoc networks. In the proposed system, if the destination node can receive the packet correctly, it sends ACKnowledgement (ACK) to the source node in order to request the next packet. In contrast, if the error is detected, the destination node sends Negative ACKnowledgement (NACK) to the source node in order to request retransmitting the same data packet. In general, only the source node retransmits the error packet in

ARQ system. However, in the proposed system, the surrounding nodes that can correctly detect the packet in the previous slot also simultaneously retransmit the packet to the destination node. Moreover, STBC encoding is applied in each node. By using the surrounding node retransmission, the multi-hop communication can be realized without the additional frequency resource compared to the original multi-hop communication, and achieve the reliable communications.

Here, an example is given to facilitate understanding. Figure 3 illustrates a model for example while Fig. 4 depicts a timing chart of the nodes. Suppose that S and D are source node and destination node respectively while R1 to R9 are repeater node. In addition, $R$ is the number of retransmissions, $n$ is the number of transmissions of the control signal and $r$ is the number of transmissions of the ACK or NACK. Nodes connected by lines are capable of communication. First, the node S transmits the packet for the node D. In this case, the node D is outside of the coverage area of the node S. While the nodes R1, R4 and R7 exist within the coverage area of the node S, they can receive and detect the packet. Here, since the node D does not receive the packet, the node S cannot receive ACK or NACK from the node D. Then the node S retransmits the packet for the node D. Here, the node S transmits the control signal only one time in order to inform the first retransmission to the surrounding nodes. The control signal includes the source node ID, the destination node ID, packet ID, synchronous bits for retransmission, the number of transmission times of the packet, the number of transmissions of the control signal ($n$), the pre-determined maximum number of retransmissions ($M$) and so on. The nodes R1, R4 and R7 receive the control signal, and then the nodes S and the node R1, R4, and R7 simultaneously transmit the retransmission packet encoded with STBC. As a result, the nodes R2, R5 and R8 receive the retransmission packet with STBC diversity gain, that is, the packet can be relayed from the node S to the nodes R2, R5 and R8. However, in this case, the node D cannot receive the packet yet, and the node S still does not receive ACK or NACK.

So the source node retransmits the packet again. Here the node S transmits the control signal repeating two times in order to inform the second retransmission to the surrounding nodes. In this case the nodes R1, R4 and R7 receive the first control signal from the node S, and transmit the control signal one time ($R$-$n$=2-1). The nodes R2, R5 and R8 receives this control signal. Then the node S, the nodes R1, R4, R7, the nodes R2, R5 and R8 transmit the retransmission packet encoded with STBC and the nodes R3, R6 and R9 receive the retransmission packet. By repeating these operations, finally, the packet can be relayed from the node S to the node D. In this way, the packet passes the plural routes so the node D can obtain the diversity gain. After the node D receives and detects the packet from the node S, the node D sends ACK or NACK. It is also relayed by operating the same procedure of the relaying control signal. The node D receives the packet from the node S by 3 times retransmissions, and then it transmits the ACK or NACK repeating 4 times ($R$+1=3+1). In this case the nodes R3, R6 and R9 receive the first ACK or NACK signal from the node D, and transmit the ACK or NACK with repeating 3 times ($R$+1-$r$=3+1-1). The ACK or NACK can be relayed to the node S by repeating this procedure.

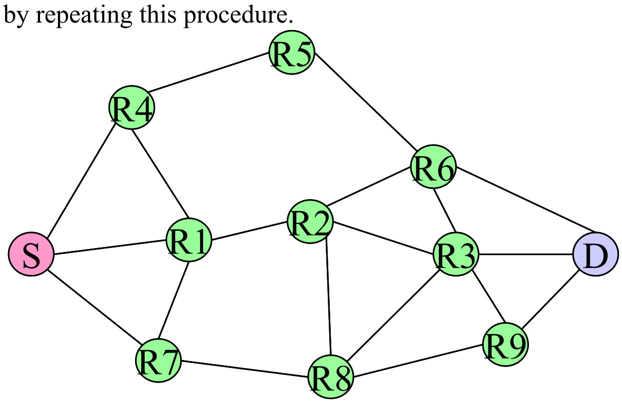


Figure 3 System model

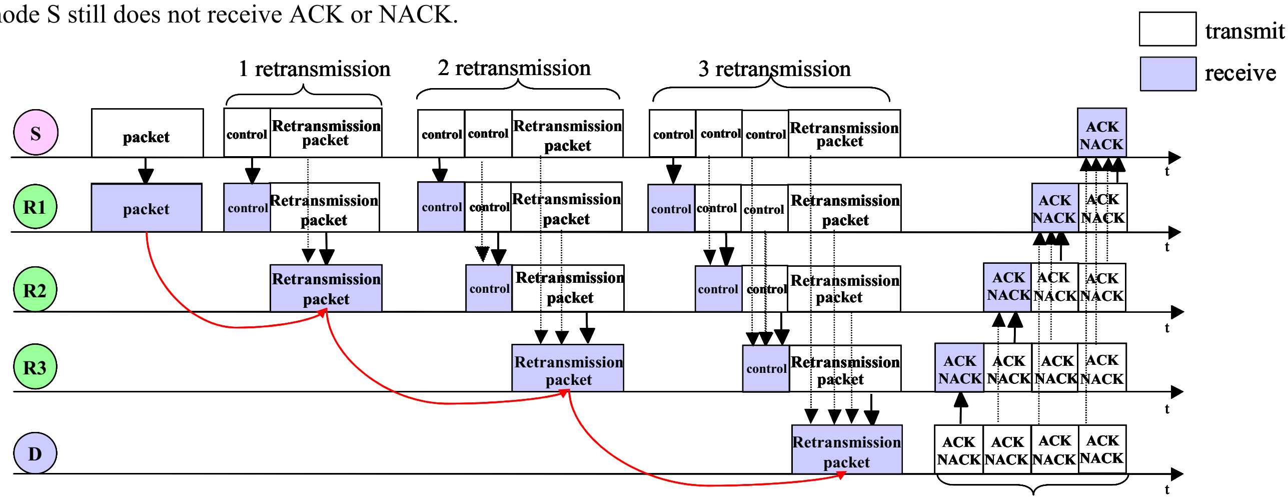


Figure 4 The procedure of the proposed system.

The specific procedure of the data transmission in the proposed system are shown as follows,

1. The source node transmits an initial packet for the destination node. In the proposed scheme, the surrounding nodes also receive and detect the signals transmitted from the source node to the destination node even if the packet is not for their own nodes. Here, these surrounding nodes are called as repeater nodes.
2. If the source node receives NACK or dose not receive ACK or NACK, it transmits the control signal with repeating *R* times.
3. The repeater nodes, which have the correct packet and receive the control signal with (*n*) times from the source node, update the database of the number of transmissions of the control signal. Then these repeater nodes synchronize the timing of transmission and transmit the control signal with repeating (*R*-*n*) times. All repeater nodes, which receive the control signal, work the same operations. In this way, the control signal can be relayed.
4. Then the source node and the repeater nodes transmit the packet encoded with one of the STBC encoding patterns. The transmitted encoded pattern is randomly selected from two STBC encoding patterns in each node.
5. The nodes that have been received the retransmission packet estimate the channel gain by using the pilot symbols encoded with the orthogonal codes between the STBC patterns. Then they demodulate the data according to the STBC decoding. Also, the nodes that did not correctly receive the packet in the previous slot can receive the STBC retransmission packet and become the new relay nodes. As a result, the paths between the source node and the destination node increase.
6. When the destination node receives the packet, it transmits the ACK or NACK. The ACK or NACK is also relayed by operating the same procedure of the relaying control signal. If the destination node can receive the packet by *R* times retransmission, it transmits the ACK or NACK repeating (*R*+1) times. The repeater nodes, which receive ACK or NACK transmitted *r* times from the destination node, transmits the ACK or NACK repeating (*R*+1-*r*) times.
7. If the source node can receive the ACK, the packet communication is completed. If the number of retransmission exceeds the number of pre-determined maximum retransmissions, the packet is disposed by compulsion. While NACK is received, or ACK or NACK is not received during the certain decided time, the operations 2 to 6 are repeated until the source node can receive the ACK or the number of repetition (*R*) becomes more than the number of pre-determined maximum retransmissions (*M*).

## V. Simulation Results

In this section, simulation results are presented to evaluate the performance of the proposed system. The simulation model is shown in Fig. 5. The distance of the source node and the destination node is *d* m. The repeater nodes are set on the random position in every packet on the range from 0 to *d* of X-axis and from –*d*/2 to *d*/2 of Y-axis. In order to avoid the duplication of the nodes around the transmitter, the range within the radius of 1 m from the location of the source node is excepted. Table 2 summarizes the parameters used in all simulations. 5-path exponential Rayleigh fading model is employed. The transmission power is fixed and the received power is changed according to the path loss. It is assumed that the channel estimation is perfect and the Inter Symbol Interference (ISI) is not taken into consideration, so timing offset of transmission from the plural nodes is not considered. We evaluate the performance of the packet success rate and throughput of the proposed system.

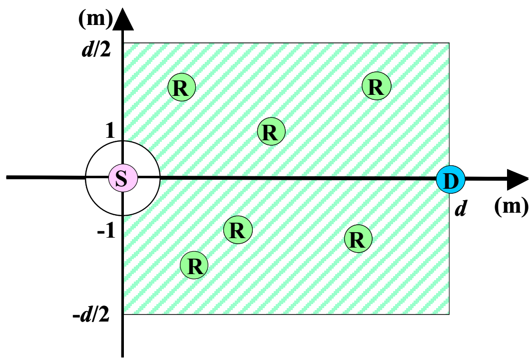


Figure 5. The simulation model.

Table 2 Simulation Parameters.

| | |
|---|---|
| Modulation Method | QPSK |
| The number of carriers | 128 |
| The number of FFT points | 128 |
| Guard Interval | 25samples |
| Channel model | 5-path exponential Rayleigh |
| Path loss exponent | 3 |
| Packet size per frame | 7680bit |
| FEC | Convolutional Code (Coding rate=1/2) |
| Noise power | -85[dBm] |
| Transmission power | 10[dBm] |
| Channel estimation pilot | Walsh-Hadamard orthogonal code |

### *A. Packet success rate performance*

First, we investigate the packet success rate performance versus the distance between the source node and the destination node. Figure 6 shows the packet success rate, when the number of repeater nodes is set to 4. We compare the performance between two systems, the first one is the OFDM retransmission without STBC and the other one is the proposed OFDM retransmission with STBC. In addition we evaluate the performance depending on the number of pre-determined maximum retransmission (*M*) which is 0 to 3. *M*=0 means no retransmission, so it implies the performance of the conventional single hop communication. It can be seen in Fig. 6. The performance is improved as increasing the number of retransmission. In particular, the proposed STBC retransmission achieves good performance rather than the OFDM retransmission without STBC. This is because the destination node and repeater nodes effectively obtain the diversity gain in the proposed system.

Next, Fig. 7 shows the packet success rate performance of the proposed distributed ARQ with STBC versus the number of nodes within the simulation area in Fig. 5 under the same simulation conditions of Fig. 6. The distance between the destination node and the source node is fixed at 60 m. In the conventional single hop communication (M=0), the packet success rate is almost zero. On the other hand, the performance is improved as increasing the number of the repeater nodes.

### B. *Throughput performance*

In this subsection, we evaluate the throughput performance. Throughput is defined as the ratio of the number of packets received at the destination node without error to the number of packets that can be transmitted overall channel. The packets are generated according to Poisson random distribution. Here, the number of repeater nodes is set to 4, and the distance between the source node and the destination node is fixed at 60 m. Figure 8 shows the throughput performance of the proposed system. We can confirm that the performance is improved by increasing the number of retransmission when it is less than 0.5. When the traffic is above 0.5, the throughput performance of the distributed ARQ is the almost the same.

## VI. Conclusion

In this paper, we have proposed a novel distributed ARQ using STBC for OFDM ad-hoc networks. By using the proposed system, the packet success rate and the throughput performance can be improved compared to the conventional single hop communication. The proposed system can relay the packet without topology information so it can achieve the routing-less communication. In addition, the proposed system can achieve reliable communication by applying ARQ with STBC to the surrounding nodes. However in the proposed system, the packets are transmitted in all direction because of flooding, so the node waste the power and frequency resource. So we have to consider MAC protocol to save the power consumption of the node. The proposed system is effective in low traffic particularly on this simulation environment.

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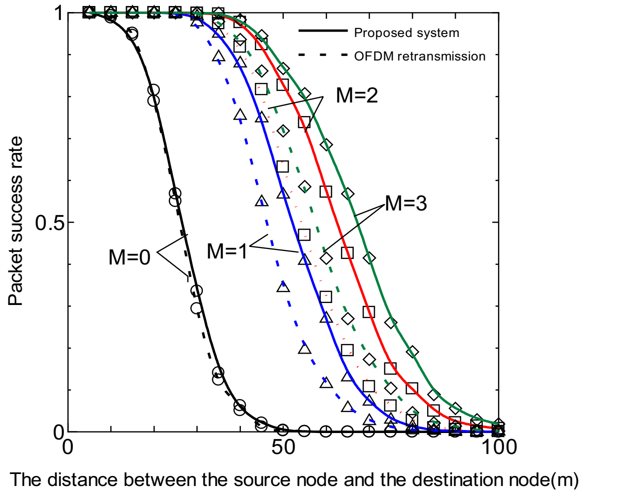


Figure 6 Packet success rate versus the distance between the source node and the destination node.

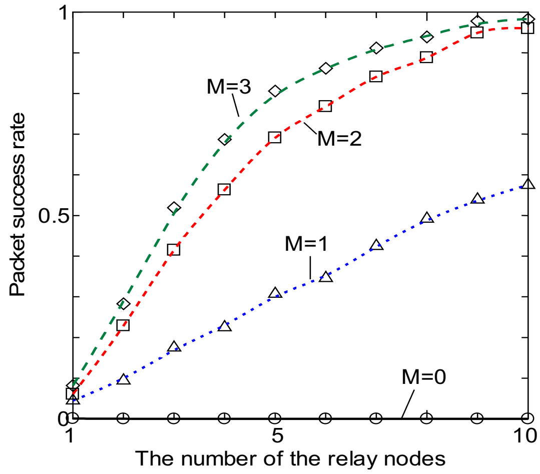


Figure 7 Packet error rate versus the number of the relay nodes.

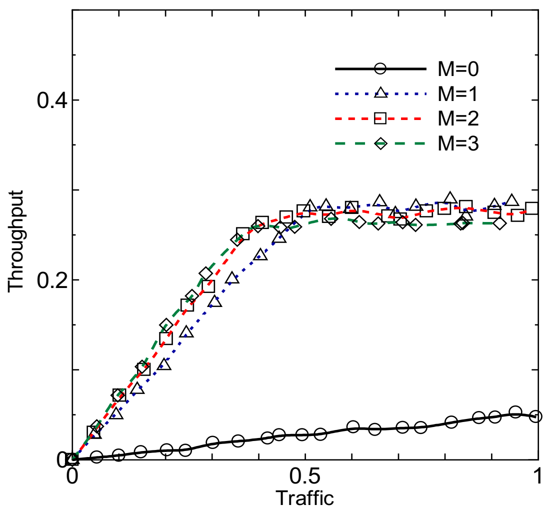


Figure 8 Throughput performance.