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BIT ERROR RATE OF TWO–USER COOPERATIVE DIVERSITY IN FREQUENCY SELECTIVE RAYLEIGH FADING CHANNEL

Chirawat Kotchasarn — Kazi M. Ahmed — R. M. A. Premanandana-Rajatheva *

This paper presents the analysis of cooperative diversity performance over the uplink frequency selective Rayleigh fading channel. The time division multiple access (TDMA) scheme and the half-duplex mode of transmission are assumed. The network architecture is defined as symmetrical structure. We analyze the bit error rate of BPSK two-user cooperative diversity with amplify-and-forward, decode-and-forward, selection relaying, and incremental relaying protocols and investigated the effects of various interuser SNRs on the performance. The result shows that the higher interuser SNRs, the better bit error rate performance. From the bit error rate performance comparison of all relaying protocols illustrates that the incremental relaying protocol give the best performance. This is the result of limited feedback in the incremental relaying protocol from the destination yield a great improvement on the system performance.

K e y w o r d s: frequency selective Rayleigh fading channel, relaying protocols, cooperative diversity

1 INTRODUCTION

The strong demand for providing services with ever increasing data rates at moderate costs for future wireless networks call for advanced strategies at various layers. A frequently considered concept is the use of relay nodes to help transmit information from a source node to its destination. Cooperative diversity has recently emerged as an alternative way to achieve spatial diversity when the users cannot afford multiple transmit antennas. The main idea is to share the resources (such as time, frequency, etc.) among cooperative users and each user serves as a relay, for transmissions of other users' information. The user cooperation diversity can be used as relaying, enabling the relay mobile to simultaneously transmit its own independent information. It provides higher throughput and robustness to channel variations for both the transmitting and relaying mobiles. There is no cost, in terms of transmit power, associated with transmitting to both the ultimate receiver and partner [7].

In [5], presented an information-theoretic model, for which achievable rate regions and outage probabilities are examined. The several strategies protocol employed by the cooperating radios, including fixed relaying, selection relaying and incremental relaying. The results shown that except fixed decode-and-forward, all of cooperative diversity protocols are efficient in the sense that they achieve full diversity. Thus, using distributed antennas, we can provide the powerful benefits of space diversity without need for physical arrays.

Amplify-and-forward networks have been discussed [2], where it is shown how such schemes can be understood as distributed MIMO systems. More recently, [5] proposed various cooperative protocols for the three-terminal case. The conducted analysis from the perspective of outage probabilities for limited bandwidth and constrained end-to-end delay shows that relaying may suffer from repetition coding and the necessity of providing orthogonal resources for reception and transmission at the relays. The discussion focuses on symmetric networks. The analysis captures the significant parameters SNR, path loss, spectral efficiency, and network geometry.

The concept of coded cooperation, where the relay mobile is allowed to perform channel coding, was introduced [3] and the idea of space-time code and turbo code were exploited [4]. Coded cooperation provides significant performance gains for a variety of channel conditions. In addition, by allowing different code rates and partitions, coded cooperation provides a great degree of flexibility to adapt to channel conditions. Another related work is multi user space-time coding in cooperative network where Alamouti's space-time block code was applied in a wireless relay system [1].

In this paper, we represent the cooperative diversity performance in frequency selective Rayleigh fading channel over the uplink scheme with relaying protocols. Both of fixed and adaptive relaying protocols are analyzed at various values of interuser SNRs. In our case, the time division multiple access (TDMA) scheme and the half-duplex mode of transmission are considered. We analyzed bit error rate performance of amplify-and-forward, decode-and-forward, selection relaying, and incremental relaying protocol on the two-user cooperative diversity. We also compare the performance of various relaying protocols at different values of interuser SNRs.

* Telecommunication Program, School of Advanced Technologies Asian Institute of Technology, P.O. Box 4, Klong Luang, Pathumthani, 12120 ,Thailand Email: Chirawat.Kotchasarn@ait.ac.th

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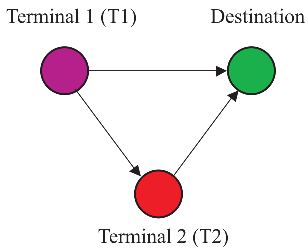

Fig. 1. Cooperative diversity system model

T1 Tx and T2 Rx	T2 Tx and T1 Rx	T1 and T2 Relay
N/3	N/3	N/3

Fig. 2. Time division multiple access scheme for two cooperative users

2 SYSTEM AND CHANNEL MODEL

A cellular system in which two cooperative users (mobile station: MS) are transmitted their information to the same destination (base station: BS), as shown in Fig. 1. Both users share the same frequency band and the mobile of each user cannot transmit and receive signal at the same time. All terminals are equipped with single antenna transmitters and receivers, half-duplex mode transmission.

The multiple access scheme is shown in the Fig. 2. This model is called time division multiple access scheme (TDMA).The total time frames are divided into three parts. The first time frame belongs to the first user information. The second time frame belongs to the second user information. The third time frame is shared between both users and is used to relay each other's message. This partitioning is more efficient since the transmissions share both time and frequency resources in the relaying frame. In our case, we consider in three time slots and index by $n = 1, 2 \dots, N$ and each slots occupies $N/3$.

In the first time frame, the first user's mobile transmits its own message and the destination receiver and the second user's mobile receive the signal. At the destination receiver, we get a direct transmission and the received signal, $y_{1d}[n]$, given by

$$y_{1d}[n]{=}a_{1d}x_1[n] + z_d[n] \tag{1}$$

where $x_1[n]$ is a symbol transmitted from the first user at the n^{th} symbol interval, $n = 1, 2, \dots, N/3$. The AWGN at the destination is denoted by $z_d[n]$. At the second user's mobile, the received signal, $y_{12}[n]$, is written as

$$y_{12}[n] = a_{12}x_1[n] + z_2[n] \tag{2}$$

where $z_i[n]$, $i = 1, 2$ is the AWGN from the other users.

In the second time frame, the roles of the first and the second users are interchanged. Hence, at the destination receiver and at the first user's mobile, the received signals $y_{2d}[n]$ and $y_{21}[n]$, are written as

$$y_{2d}[n] = a_{2d}x_2[n] + z_d[n] \tag{3}$$

$$y_{21}[n] = a_{21}x_2[n] + z_1[n] \tag{4}$$

$x_2[n]$ denotes a symbol transmitted from the second user at the n^{th} symbol interval, $n = N/3 + 1,\ N/3 + 2, \dots, 2N/3$.

Finally, in the third time frame, both users' mobiles act as relays and transmit the relay signals at the same time. This is called a relay transmission. The signal at the destination is a linear combination of signals from each user can be explained as

$$y_d[n] = a_{1d}x_1[n] + a_{2d}x_2[n] + z_d[n] \tag{5}$$

where $x_1[n]$,$x_2[n]$ are relayed symbols transmitted from the first and the second user, at the n^{th} symbol interval $n = N/3 + 1, \dots, 2N/3$, respectively.

Each user's mobile can be an information source or a relay terminal at a specific time frame. The interuser channels (channels among users) and between the users and the destination are independent of each other. The channels are subject to frequency selective fading. Perfect channel state information in the receivers and perfect synchronization are assumed. In this case, a discrete-time filter a is expressed with a delay operator q^{-1} as [9]

$$\begin{aligned} a\left[q^{-1}\right]u\left(t\right) &= \left(a_0 + a_1q^{-1} + \dots + a_dq^{-d}\right)u\left(t\right) \\ &= a_0u\left(t\right) + a_1u\left(t-1\right) + \dots + a_du\left(t-d\right) \end{aligned} \tag{6}$$

$$\begin{aligned} \left(a\left[q^{-1}\right]\right)^* = a^*\left[q\right] &= \left[a_0 + a_1q^{-1} + \dots + a_dq^{-d}\right]^* \\ &= a_0^* + a_1^*q + \dots + a_d^*q^d \end{aligned} \tag{7}$$

where $u(t)$ is the input sequence and $(.)^*$ denotes the complex conjugate and time-reversal operation. A time-reversal space-time block code, which is employed for cooperative relaying in this model, is denoted by sequence block C as [10]

$$\boldsymbol{C} = \begin{bmatrix} c_1 & -c_2^* \\ c_2 & c_1^* \end{bmatrix} \tag{8}$$

The transmission scheme with this code can be described as following: At first, the sequence c_1 is transmitted through the first antenna and the time-reversal version of sequence $-c_2$ is transmitted via second antenna, and then the sequence c_2 is transmitted on the first antenna and time-reversal version of sequence c_1 is transmitted on second antenna. The second transmitted sequence x_i $(i = 1, 2)$ of the source. The cooperative diversity in frequency selective fading channel with Alamouti scheme shows in Fig. 3.

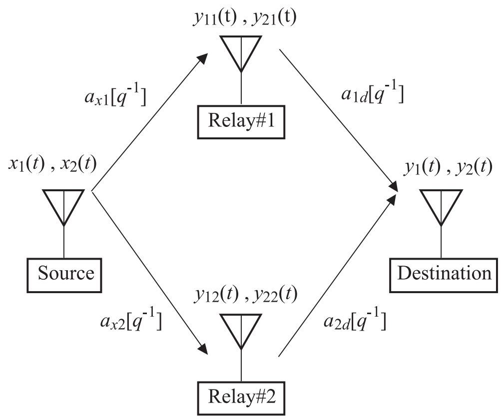

Fig. 3. Cooperative diversity in frequency selective fading channel.

From above assumptions, the receive signals sequence y_{ij} at the j^{th} relay terminals are given by:

$$y_{1j}\left(t\right)=a_{xj}\left[q^{-1}\right]x_1\left(t\right)+n_{1j}\left(t\right) \tag{9}$$

$$y_{2j}\left(t\right)=a_{xj}\left[q\right]x_2\left(t\right)+n_{2j}\left(t\right) \tag{10}$$

where $a_[xj]$ $(j=1,2)$ and n_{ij} are the channel impulse response between the source and the j^{th} relay terminal and AWGN sequence at j^{th} relay terminal. The jth relay terminal encodes the received sequences with the code associated with the j^{th} row of the sequence block x and transmits the encoded version. Therefore,

$$y_{11}\left(t\right)=a_{x1}\left[q^{-1}\right]x_1\left(t\right)+n_{11}\left(t\right) \tag{11}$$

$$y_{12}\left(t\right)=a_{x2}\left[q^{-1}\right]x_1\left(t\right)+n_{12}\left(t\right) \tag{12}$$

$$y_{21}\left(t\right)=a_{x1}\left[q\right]x_2\left(t\right)+n_{21}\left(t\right) \tag{13}$$

$$y_{22}\left(t\right)=a_{x2}\left[q\right]x_2\left(t\right)+n_{22}\left(t\right) \tag{14}$$

The received sequences y_i of the destination can be written as

$$y_1\left(t\right)=a_{1d}\left[q^{-1}\right]y_{11}\left(t\right)-a_{2d}\left[q^{-1}\right]y_{22}^*\left(t\right)+n_1\left(t\right) \tag{15}$$

$$y_2\left(t\right)=a_{1d}\left[q\right]y_{21}\left(t\right)+a_{2d}\left[q\right]y_{12}^*\left(t\right)+n_2\left(t\right) \tag{16}$$

where y_i and n_i are the received sequence and AWGN sequence at the destination respectively and a_{jd} indicates the effects of the channel between the j^{th} relay terminal and the destination and amplify operation at the j^{th} relay terminal.

Substitute (11) and (14) in (15), the received signal is given as

$$\begin{aligned}&y_1(t)=a_{1d}[q^{-1}][a_{x1}[q^{-1}]x_1(t)+n_{11}(t)]\\&-a_{2d}[q^{-1}][x_2^*(t)a_{x2}^*[q]+n_{22}^*(t)]+n_1(t)\\&y_1(t)=a_{x1}[q^{-1}]a_{1d}[q^{-1}]x_1(t)-a_{x2}^*[q]a_{2d}[q^{-1}]x_2^*(t)\\&+a_{1d}[q^{-1}]n_{11}(t)-a_{2d}[q^{-1}]n_{22}^*(t)+n_1(t)\end{aligned} \tag{17}$$

and substitute (12) and (13) in (16), the received signal is written as

$$\begin{aligned}&y_2(t)=a_{1d}[q][a_{x1}[q]x_2(t)+n_{21}(t)]\\&+a_{2d}[q][a_{x2}^*[q]x_1^*(t)+n_{12}^*(t)]+n_2(t)\\&y_2(t)=a_{2d}[q]a_{x2}^*[q]x_1^*(t)+a_{1d}[q]a_{x1}[q]x_2(t)\\&+a_{1d}[q]n_{21}(t)+a_{2d}[q]n_{12}^*(t)+n_2(t)\end{aligned} \tag{18}$$

Take complex conjugate both sides of Equation (18)

$$\begin{aligned}y_2^*(t)&=[a_{x2}^*[q]a_{_{2d}}[q^{-1}]]^*x_1(t)\\&+[a_{x1}[q^{-1}]a_{1d}[q^{-1}]]^*x_2^*(t)\\&+[a_{1d}[q]n_{21}(t)+a_{2d}[q]n_{12}^*(t)+n_2(t)]^*\end{aligned} \tag{19}$$

Let the following notations:

$$\begin{aligned}&A_1=a_{x1}[q^{-1}]a_{1d}[q^{-1}]\\&A_2=a_{x2}^*[q]a_{2d}[q^{-1}]\\&N_1(t)=a_{1d}[q^{-1}]n_{11}(t)-a_{2d}[q^{-1}]n_{22}^*(t)+n_1(t)\\&N_2(t)=a_{1d}[q]n_{21}(t)+a_{2d}[q]n_{12}^*(t)+n_2(t)\end{aligned}$$

The channel gains are modeled as independent zero-mean complex Gaussian random variables. Since the channels are fixed during the multiple access time frame, the time-dependent variable is neglected. The channel gains are incorporates the effects of noise and channel path loss. The additive white noise $N_i[t]$, $i\in[1,2,d]$ associated with the users' mobiles and the destination receiver, are modeled as independent circularly symmetric complex Gaussian random variables with zero-mean and variance N_0. The common SNR without fading is defined as $E[a_{ij}^2]E_b/N_0$ where E_b is the energy per bit.

The probability of the channel gain is given by [6]

$$p(a)=\begin{cases}\frac{a}{\sigma^2}\exp\left(\frac{-a^2}{2\sigma^2}\right), & \text{for} \quad a\geqslant 0\\ 0, & \text{otherwise}\end{cases} \tag{20}$$

The received sequence at the destination summarized as follows

$$\begin{bmatrix}y_1\left(t\right)\\y_2^*\left(t\right)\end{bmatrix}=\begin{bmatrix}A_1&-A_2\\A_2^*&A_1^*\end{bmatrix}\begin{bmatrix}x_1\left(t\right)\\x_2^*\left(t\right)\end{bmatrix}+\begin{bmatrix}N_1\left(t\right)\\N_2^*\left(t\right)\end{bmatrix}. \tag{21}$$

3 PROTOCOL CLASS

In cooperative diversity systems, the relaying protocol is a crucial component to achieve diversity. Each protocol has its own trade-offs among performance, complexity and data transmission rate. The relaying protocols in this paper are taken from [5] with some adaptations.

A. Fixed Protocols:

The time division scheme is used and the relay always forwards what it has received from the source in the preceding time slot. These protocols are classified as

- **Amplify-and-forward transmission:**

The relay transmits a scaled version of its received noisy signal. The first mobile user transmits its information as $x_1[n]$ for $n = 1, 2, \dots, N/3$ in the first time frame. During this frame interval, the relay processes $x_{12}[n]$, and relays the information by transmitting

$$x_{12}[n] = \beta y_{12}\left(n - \frac{2N}{3}\right) \tag{22}$$

$$x_{12}[n] = \beta\left[a_{12}x_1\left(n - \frac{2N}{3}\right) + z_2\left(n - \frac{2N}{3}\right)\right] \tag{23}$$

for $n = 2N/3 + 1, \dots, 2N/3$. The second mobile user transmits its information as $x_2[n]$ for $n = N/3 + 1, \dots, 2N/3$ in the second time frame. During this frame interval, the partner processes $y_{21}[n]$, and transmits the new signal for $n = 2N/3 + 1, \dots, 2N/3 + 2, \dots, N$ as

$$x_1[n] = \gamma y_{21}\left(n - \frac{2N}{3}\right) \tag{24}$$

$$x_1[n] = \gamma\left[a_{21}x_2\left(n - \frac{2N}{3}\right) + z_1\left(n - \frac{2N}{3}\right)\right] \tag{25}$$

Since the symmetric channel is assumed, then $|a_{12}| = |a_{21}|$. The amplifier gain depends on the fading coefficient of both users. To remain within its power constraint (with high probability), an amplifying relay must use gain [5]

$$\beta, \gamma \leqslant \sqrt{\frac{E_b}{|a_{12}|^2 E_b + N_0}} \tag{26}$$

- **Decode-and-forward transmission:**

In this protocol, the relay mobile fully decode the received codeword before detection the relay signal. In this scenario, 'decode' refers to coherent detection and 'forward' refers to transmission of repetition of decoded symbols from the relay mobiles. The first mobile user transmits its information as $x_1[n]$, $n = 1, \dots, N/3$. During this interval, the partner processes $y_{12}[n]$ by decoding an estimate $\hat{x}_1[n]$ of the first user transmitted signal. Under a repetition-coded scheme, the partner transmits the signal

$$x_2[n] = \hat{x}_1(n - \frac{2N}{3}) \tag{27}$$

The second mobile user transmits its information as $x_2[n]$, $n = N/3 + 1, \dots, 2N/3$. During this interval, the partner processes $x_{21}[n]$, by decoding an estimate $\hat{x}_2[n]$ of the second user transmitted signal. Under a repetition-coded scheme, the partner transmits the signal a

$$x_1[n] = \hat{x}_2(n - \frac{2N}{3}) \tag{28}$$

The relay fully decodes, re-encodes and retransmits the source message.

B. Selection Relaying:

In [5], selection relaying was proposed in which not all relay mobiles are allowed to transmit the relay signals. The permission to transmit the relay signals or not depends on the amplitudes of the fading gains between the source mobile and the relay mobile. If these values fall below a certain threshold, the relay mobile is not allowed to transmit the relay signal but instead transmit its own information signal. The destination knows whether the mobiles are transmitting the relay signals or not so that it can apply an optimal decoding scheme.

In this paper, the cyclic redundancy check (CRC) bits have been added at the source mobile before encoding. Then, at the relay mobile, the receiver performs CRC check after decoding to see if the whole frame has been received correctly. If the frame is received correctly, the relay mobile is allowed to perform re-encoding and forward the relay signal, otherwise it does nothing. In our case, we assume that both the CRC bits are neglected when evaluating the performance and the CRC check is perfect.

C. Incremental Relaying:

In [5], the incremental relaying was proposed which exploits a limited feedback from the destination. The feedback is in a form of a single bit to inform each relay whether it needs to transmit the relay signal. The feedback relies on the SNR between each user and the destination. If the SNR is sufficiently high, the feedback will notify the relay mobile not to transmit the relay signal.

In this paper, we employ CRC to detect error. CRC bits have been added at the source mobiles. Then, CRC check is performed at the destination to see whether the frame is received correctly from the direct transmissions. If the frame is received correctly from the direct transmission, the feedback from the destination will notify the corresponding relay mobiles not to transmit the relay signal. In the analysis, we assume that CRC check is perfect and CRC bits as well as feedback bits are neglected when evaluating the performance of the protocol.

4 SIMULATION RESULTS

We investigate the performance of two-user cooperative diversity in frequency selective Rayleigh fading channel. The average SNRs between each user and the destination are equal and the interuser channels are symmetric case. The channel state information is known at the user mobiles or at the destination.

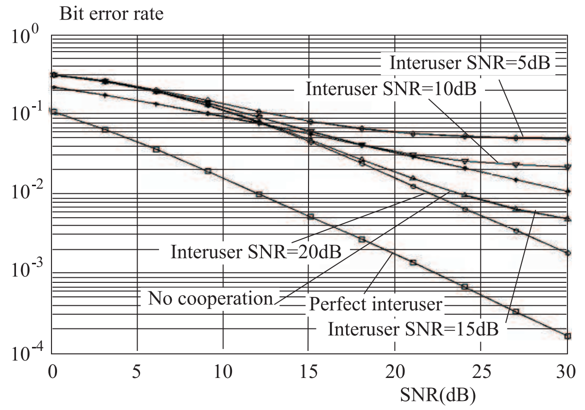

Fig. 4. Bit error rate of two-user cooperative diversity with amplify-and-forward relaying protocol in Frequency Selective Rayleigh Fading channel at various interuser SNRs.

As shown in Fig. 4, the amplify-and-forward relaying protocol achieves a performance gain over BPSK when the interuser SNRs are greater than 15 dB.

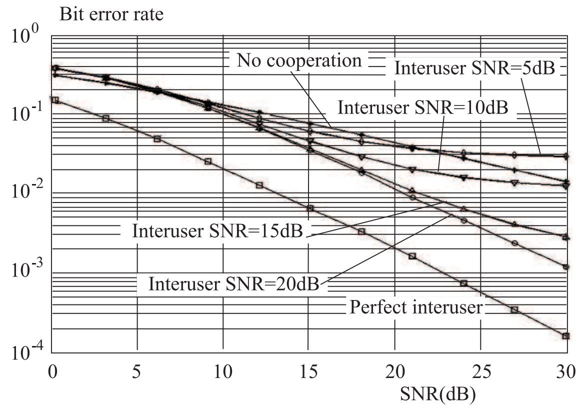

Fig. 5. Bit error rate of two-user cooperative diversity with decode-and-forward relaying protocol in Frequency Selective Rayleigh Fading channel at various interuser SNRs.

From Fig. 5, the decode-and-forward relaying protocol achieves a performance gain over BPSK when the interuser SNRs are greater than 10 dB. As the interuser SNRs increase, the protocol has some gains over BPSK cooperative transmission as long as the interuser SNRs are greater than the direct transmission SNRs.

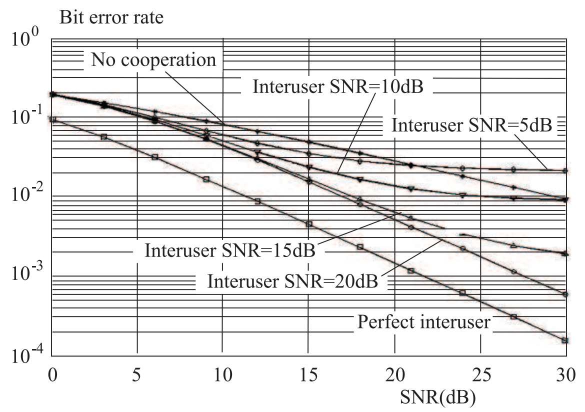

Fig. 6. Bit error rate of two-user cooperative diversity with selection relaying protocol in Frequency Selective Rayleigh Fadiing channel at various interuser SNRs.

The performance of the selection relaying protocol in Fig. 6 and the incremental relaying protocol in Fig. 7 show similar characteristics. At 10 dB interuser SNR both selection and incremental relaying achieve the performance gain about 5 dB over nocoperation BPSK but at high value of interuser SNRs incremental relaying is better. This is the result of limited feedback in the incremental relaying protocol from the destination yield a great improvement on the system performance.

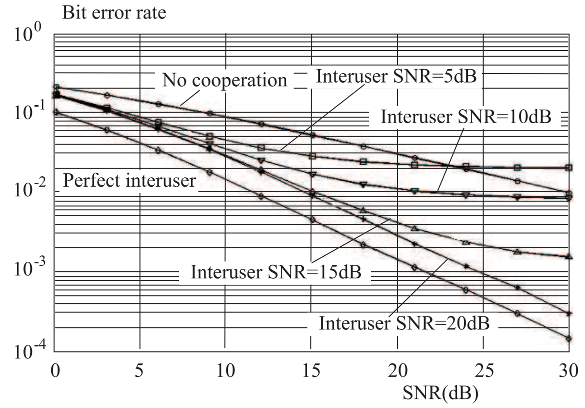

Fig. 7. Bit error rate of two-user cooperative diversity with incremental relaying protocol in Frequency Selective Rayleigh Fading channel at various interuser SNRs.

In order to make a comparison among amplify-and-forward, decode-and-forward, selection relaying protocol, and incremental relaying protocol, we should normalized the SNR. We define the normalized SNR as $SNR_{norm} = \frac{SNR}{2^R-1}$, where R is the transmission rate. In our case, we perform BPSK modulation, so R is equal to one. Fig. 8 represents the performance comparison of various relaying protocols. From this figure, both of selection and incremental relaying achieve full diversity while decode-and forward relaying protocol is better than direct transmission in the medium SNR range. The incremental relaying protocol gives the best bit error rate and close to the transmit diversity bound.

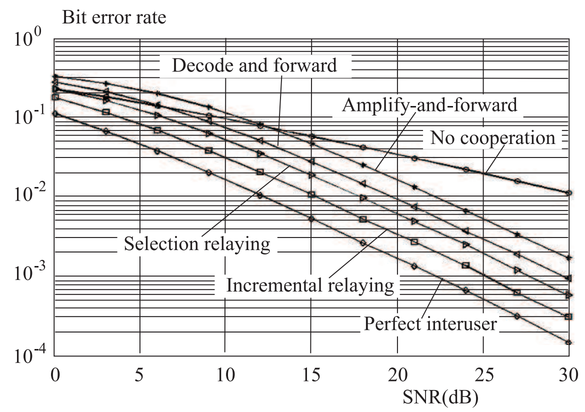

Fig. 8. Performance comparison of various relaying protocols, decode-and-forward, selection releaying, and incremental relaying at 20 dB interuser SNRs.

5 CONCLUSIONS

In this paper, the bit error rate of relaying protocol in the uplink frequency selective Rayleigh fading channel is proposed. The two-user cooperative diversity is transmitted the signal but not the same time. Therefore, the time division multiple access scheme is represented with half duplex mode. From all relaying protocols, the more interuser SNRs the better performance. Our proposed system achieves second-order diversity with appropriate relaying protocols at sufficiently high interuser SNRs. The results obtained shown that the incremental relaying protocol give the best performance since it exploits a limited feedback to allow only necessary relaying which results in an increase in the transmission rate.

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Chirawat Kotchasarn received the BEng degree in electronics engineering from King Mogkut Institute of Technology Ladkrabang in 1996 and Ms Eng degree in telecommunications engineering from King Mongkut University of Technology Thonburi in 1999, respectively. Currently, he is pursuing his doctoral degree in Telecommunications FoS, Asian Institute of Technology (AIT), Thailand.

Kazi M. Ahmed received the MSc Eng degree in electrical engineering from the Institute of Communications, Leningrad, USSR, and the PhD degree from the University of Newcastle, NSW, Australia, in 1978 and 1983, respectively. Currently, he is a Professor of telecommunications in the School of Engineeing and Technology, Asian Institute of Technology, Pathumthani, Thailand. His current research interests include digital signal processing, antenna array processing, tropospheric and ionospheric propagation studies for microwave, very high frequency-ultrahigh frequency (VHF-UHF) communications, and satellite communications.

R. M. A. Premanandana-Rajatheva received the BSc degree in electronic and telecommunication engineering (with first class honors) from the University of Moratuwa, Moratuwa, Sri Lanka, and the MSc and PhD degrees from the University of Manitoba, Winnipeg, MB, Canada, in 1987, 1991, and 1995, respectively. Currently, he is an Associate Professor of telecommunications in the School of Engineeing and Technology, Asian Institute of Technology, Pathumthani, Thailand. His research interests include mobile and wireless communications, coding and modulation techniques, space time processing for multiple input-multiple output (MIMO) systems, and communication theory.