This full text paper was peer reviewed at the direction of IEEE Communications Society subject matter experts for publication in the WCNC 2008 proceedings.

Performance Analysis of Incremental Relaying Cooperative Diversity Networks over Rayleigh Fading Channels

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***Abstract*— Cooperative diversity networks have recently been proposed as a way to form virtual antenna arrays without using collocated multiple antennas. Cooperative diversity networks use the neighbor nodes to assist the source by sending the source information to the destination for achieving spatial diversity. Regular cooperative diversity networks make an inefficient use of the channel resources because relays forward the source signal to the destination every time regardless of the channel conditions. Incremental relaying cooperative diversity has been proposed to save the channel resources by restricting the relaying process to the bad channel conditions only [1]. Incremental relaying cooperative relaying networks exploit limited feedback from the destination terminal, e.g., a single bit indicating the success or failure of the direct transmission. If the destination provides a negative acknowledgment via feedback; in this case only, the relay retransmits in an attempt to exploit spatial diversity by combining the signals that the destination receives from the source and the relay. In this paper, we study the end-to-end performance of incremental relaying cooperative diversity networks using amplify-and-forward relays over independent non-identical Rayleigh fading channels. Closed-form expressions for the bit error rate and the signal-to-noise ratio (SNR) outage probability are determined. Results show that the incremental relaying cooperative diversity can achieve the maximum possible diversity, compared with the regular cooperative diversity networks, with higher channel utilization.**

Keywords-Cooperative diversity networks, amplify-and-forward, Rayleigh fading channel, single relay networks, incremental relaying.

I. Introduction

Cooperative diversity networks technology is a promising solution for the high data-rate coverage required in future wireless communications systems. There are two main advantages of this technology; the low transmit RF power requirements, and the spatial diversity gain [1]-[6]. The basic idea is that in addition to the direct transmission from the transmitter to the receiver, there can be other nodes, which can be used to enhance the diversity by relaying the source signal to the destination.

Performance analysis of cooperating diversity networks has yielded many interesting results including signal-to-noise ratio (SNR) outage, information theoretic metrics, and average error probability expressions over Rayleigh-fading channels [7], [8]. More specifically, the authors in [1] have proposed a variety of low-complexity cooperative protocols using a single relay network. These protocols have been applied on different relaying modes as amplify-and-forward (i.e., non-regenerative relays) and decode-and-forward (i.e., regenerative relays). Also the capacity outage, using high-SNR approximations, has been analyzed. Furthermore, the authors in [11] have presented an overview of cooperative diversity networks and compared their performance with that of direct transmission and relaying networks (without diversity).

Although regular cooperative diversity networks can achieve spatial diversity gain, it wastes the channel resource because the relay forwards the signal every time regardless of the channel conditions. Since the relay and the source need to use orthogonal channels, additional resources will be used for relaying even if the relaying is not needed because the direct signal is good enough.

Incremental relaying cooperative diversity networks try to save the channel resources by restricting the relaying process to the necessary conditions [1]. This can be implementing by exploiting a limited feedback from the destination terminal, (e.g., a single bit indicating the success or failure of the direct transmission). If the source-destination SNR is sufficiently high, the feedback indicates success of the direct transmission, and the relay does nothing. If the source-destination SNR is not sufficiently high for successful direct transmission, the feedback requests that the relay amplify-and-forward what it received from the source. In the latter case, the destination combines the two signals using Maximum Ratio Combining (MRC) technique or any other combining technique [1].

Such a protocol makes more efficient use of the channel resources, because the relay will forward the signal only when it is necessary. To the best of the authors' knowledge, the error and SNR outage performance of this scheme has not been addressed in the literature yet.

In this paper, we present a completely analytical approach in obtaining closed-form expressions for the error rate and SNR outage probability of the incremental relaying cooperative networks equipped with amplify-and-forward relays over independent non-identical Rayleigh fading channels. The remainder of this paper is organized as follows. Section II discusses the system model. Performance analysis is given in

This work is supported by the National Sciences and Engineering Research Council of Canada (NSERC) through the NSERC Discovery grant program.

section III. Section IV includes the performance results. Finally, the conclusions are given in Section V.

II. THE SYSTEM AND CHANNEL MODEL

In Fig. 1, the information source (*S*) and the destination (*D*) communicate over a channel with a slow and frequency-flat Rayleigh fading coefficient *f*. A relay terminal participates by providing the destination with a second copy of the original signal (when it is necessary) through a two hop-link with Rayleigh fading coefficients *h* and *g*. We assume that all the additive white Gaussian noise (AWGN) terms in the three links (*S-D*, *S-R* and *R-D*) have equal variance N_0 and all the channels coefficients (*f*, *h*, *g*) are independent of each other. All terminals are equipped with a single antenna.

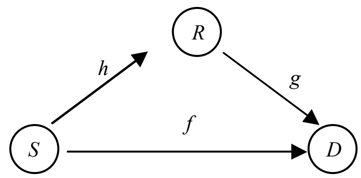

Fig.1. Illustration of a wireless cooperative diversity network.

Communication takes place in two phases due to the inability of the relay to transmit and receive simultaneously at the same frequency. In the first phase, the source sends its signal. Both the relay and the destination receive faded noisy versions of this signal. Based on the quality of the received signal at the destination, the destination decides whether the relay should send another copy of the source signal or not. For sufficient signal quality, the relay will not send another copy of the source signal and the source will send a new message in the second phase. For insufficient signal quality at the destination, the relay in the second phase will forward the received signal to the destination.

Mathematically speaking, the received signal from the source at the destination $(y_{S\to D}(t))$ and at the relay $(y_{S\to R}(t))$ can be written as

$$\begin{aligned} y_{S\to D}(t) &= f\sqrt{E_s}\,x(t) + n_1(t) \\ y_{S\to R}(t) &= h\sqrt{E_s}\,x(t) + n_2(t) \end{aligned}. \quad (1)$$

where E_s is the average energy of source symbol transmitted signal, $x(t)$ is a transmitted symbol signal with unit energy and $n_1(t)$ and $n_2(t)$ are the AWGN terms. In the second phase, if it is necessary, the relay amplifies the received signal $y_{S\to R}(t)$, generates a signal $x_r(t)$ and transmits it to the destination. The received signal at the destination from the relay is given by

$$y_{R\to D}(t) = g\sqrt{E_s}\,x_r(t) + n_3(t)\,. \quad (2)$$

where $n_3(t)$ is the AWGN term of the *R-D* link. In the amplify-and-forward scheme, the relayed signal ($x_r(t)$) is an amplified version of $(y_{S\to R}(t))$ and can be written as

$$x_r(t) = \beta\, y_{S\to R}(t)\,. \quad (3)$$

where β is the amplification gain given by

$$\beta = \frac{1}{\left(N_0 + E_s h^2\right)^{1/2}}\,. \quad (4)$$

In (4), we allow the amplifier gain to depend upon the fading coefficient *h*, which the relay can estimate with high accuracy. The choice of this gain aims to invert the fading effect of the first hop to limit the output energy from the relay to be E_s.

For the rest of this paper, we will focus on the case that the forwarding decision at the destination is made on the basis of the SNR forwarding threshold (γ_0), which defines the minimum SNR for which the destination can detect the signal successfully without the need of the relayed signal.

While a large value of γ_0 lowers the probability of error, it reduces the bandwidth efficiency because the relay will forward the signal more often but this, of course, will increase the diversity benefit. Note that for direct transmission only, γ_0 is equal to 0 and for regular cooperative diversity networks in which the relay always amplifies-and-forwards the source signal to destination, γ_0 is equal to ∞.

To capture the effect of the path-loss on the error performance we use the following model, which is widely accepted in the literature: $\mathrm{E}(h^2) \propto d_{S,R}^{-\alpha}$, $\mathrm{E}(g^2) \propto d_{R,D}^{-\alpha}$ and $\mathrm{E}(f^2) \propto d_{S,D}^{-\alpha}$ where $d_{i,j}$ is the distance between terminal *i* and *j*, α is the power exponent path, and E is the statistical average operator.

III. SYSTEM PERFORMANCE

A) Error Performance Analysis

The average error probability of the combined signal using the incremental relaying technique can be written as

$$P(e) = P(\gamma_f \le \gamma_0)\times P_{div}(e) + \left(1 - P(\gamma_f \le \gamma_0)\right)\times P_{direct}(e) \quad (5)$$

where $\gamma_f = E_s f^2 / N_0$ is the instantaneous SNR of $y_{S\to D}(t)$, $P_{div}(e)$ is the average probability that an error occurs in the combined diversity transmission from *S* and *R* to the *D*. The fading parameter *f* follows the Rayleigh distribution; therefore, γ_f follows the exponential distribution. Hence, it is straightforward to show that

$$P(\gamma_f \le \gamma_0) = 1 - \exp(-\gamma_0 / \bar{\gamma}_f)\,. \quad (6)$$

where $\bar{\gamma}_f = \mathrm{E}(f^2) E_s / N_0$ is the average SNR of $y_{S \to D}(t)$. $P_{direct}(e)$ is the probability of error at the destination given that the destination decides that the relay should not forward the signal. In this case the destination needs to rely only on the direct signal from the source. If the conditional error probability takes the form $a \times erfc(\sqrt{b\gamma_f})$, where $erfc(x) = (2/\sqrt{\pi})\int_x^\infty \exp(-x^2)dx$, and (a, b) are constants depending on the type of modulation, then the corresponding error probability can be written as

$$P_{direct}(e) = \int_0^\infty P_{direct}(e/\gamma) f_{\gamma_f}(\gamma|\gamma_f \geq \gamma_0) d\gamma \tag{7}$$

where $f_{\gamma_f}(\gamma|\gamma_f \geq \gamma_0)$ can be easily found to be as

$$f_{\gamma_f}(\gamma|\gamma_f > \gamma_0) = \begin{cases} 0 & \gamma < \gamma_0 \\ \dfrac{e^{\gamma_0/\bar{\gamma}_f}}{\bar{\gamma}_f} e^{-\gamma/\bar{\gamma}_f} & \gamma \geq \gamma_0 \end{cases} \tag{8}$$

Substituting (8) into (7) and solving the integration, the average error probability can be written in a closed-from as

$$P_{direct}(e) = a \times erfc(\sqrt{b\gamma_0}) - a \times e^{(\gamma_0/\bar{\gamma}_f)} \sqrt{\frac{b\bar{\gamma}_f}{1+b\bar{\gamma}_f}} erfc\left(\sqrt{\gamma_0(b+1/\bar{\gamma}_f)}\right) \tag{9}$$

Note that for $\gamma_0 = 0$, $a = 0.5$, and $b = 1$, we obtain the well known probability of error for BPSK transmission over Rayleigh fading channel [9].

In order to calculate $P_{div}(e)$ we need to know the equivalent SNR at the destination. By assuming that MRC technique is employed at *D*, the instantaneous output SNR is the sum of the instantaneous SNRs of the direct and the indirect (cascaded) links

$$\gamma_{equ} = \gamma_{s,r,d} + \gamma_f \tag{10}$$

where $\gamma_{s,r,d}$ is the SNR of the indirect (cascaded) link *S-R-D*, which is given by [12]

$$\gamma_{s,r,d} = \frac{\gamma_h \gamma_g}{\gamma_h + \gamma_g + 1} \tag{11}$$

By using the same approximation adopted in [14]-[15], the equivalent SNR can be approximated by its upper bound (γ_b) as

$$\gamma_{equ} \leq \gamma_b = \gamma_f + \min(\gamma_h, \gamma_g) \tag{12}$$

where $\min(x, y)$ is the minimum value of x and y. The approximate SNR value (γ_b) is analytically more tractable than the exact value (γ_{equ}); and as a result, this facilitates the derivation of the SNR statistics (CDF and PDF).

Since γ_h and γ_g are exponentially distributed, the PDF of $\min(\gamma_h, \gamma_g)$ is also exponential with a mean $\bar{\gamma} = \bar{\gamma}_h \bar{\gamma}_g / (\bar{\gamma}_h + \bar{\gamma}_g)$. The unconditional error rate ($P_{div}(e)$) can be computed for the two case $\bar{\gamma}_f \neq \bar{\gamma}$ and $\bar{\gamma}_f = \bar{\gamma}$ as follows. By defining a new variable $Y = \gamma_f + \min(\gamma_g, \gamma_h)$, then the average error probability $P_{div}(e)$ can be written as

A. $\bar{\gamma}_f \neq \bar{\gamma}$**:**

$$P_{div}(e) = a\int_0^\infty f_Y(y|\gamma_f \leq \gamma_0)\, erfc(\sqrt{by}) dy \tag{13}$$

where $f_Y(y|\gamma_f \leq \gamma_0)$ can be derived by using the same method in [13] as

$$f_Y(y|\gamma_f \leq \gamma_0) = \begin{cases} \dfrac{e^{-y/\bar{\gamma}} - e^{-y/\bar{\gamma}_f}}{(\bar{\gamma} - \bar{\gamma}_f)(1 - e^{-\gamma_0/\bar{\gamma}_f})} & y \leq \gamma_0 \\ \dfrac{1 - e^{-\gamma_0(1/\bar{\gamma}_f - 1/\bar{\gamma})}}{(\bar{\gamma} - \bar{\gamma}_f)(1 - e^{-\gamma_0/\bar{\gamma}_f})} e^{-y/\bar{\gamma}} & y > \gamma_0 \end{cases} \tag{14}$$

Then, $P_{div}(e)$ reduces to

$$\begin{aligned} P_{div}(e) = {} & \frac{a}{(\bar{\gamma} - \bar{\gamma}_f)(1 - e^{-\gamma_0/\bar{\gamma}_f})} \times \\ & \Bigg\{ \bar{\gamma}_f \sqrt{\frac{b\bar{\gamma}_f}{1+b\bar{\gamma}_f}} erf(\sqrt{\lambda}) - \bar{\gamma}\sqrt{\frac{b\bar{\gamma}}{1+b\bar{\gamma}}} erf(\sqrt{\zeta}) \\ & + e^{-\gamma_0(1/\bar{\gamma}_f + 1/\bar{\gamma})}\left(\bar{\gamma}_f e^{\gamma_0/\bar{\gamma}} - \bar{\gamma} e^{\gamma_0/\bar{\gamma}_f}\right) erfc(\sqrt{b\gamma_0}) - (\bar{\gamma}_f - \bar{\gamma}) \\ & + \left(1 - e^{-\gamma_0(1/\bar{\gamma}_f - 1/\bar{\gamma})}\right)\left[\bar{\gamma} e^{-\gamma_0/\bar{\gamma}} erfc(\sqrt{b\gamma_0}) - \sqrt{\frac{b\bar{\gamma}}{1+b\bar{\gamma}}} erfc(\sqrt{\zeta})\right] \Bigg\} \end{aligned} \tag{15}$$

where $\lambda = \gamma_0(1 + b\bar{\gamma}_f)/\bar{\gamma}_f$ and $\zeta = \gamma_0(1 + b\bar{\gamma})/\bar{\gamma}$

B. $\bar{\gamma}_f = \bar{\gamma}$**:** In this case $f_Y(y|\gamma_f \leq \gamma_0)$ can be written as

$$f_Y(y|\gamma_f \leq \gamma_0) = \begin{cases} \dfrac{y e^{-y/\bar{\gamma}_f}}{\bar{\gamma}_f^2 (1 - e^{-\gamma_0/\bar{\gamma}_f})} & y \leq \gamma_0 \\ \dfrac{\gamma_0 e^{-y/\bar{\gamma}_f}}{\bar{\gamma}_f^2 (1 - e^{-\gamma_0/\bar{\gamma}_f})} & y > \gamma_0 \end{cases} \tag{16}$$

Substituting (16) into (13) and doing the integral and some simplifications, $P_{div}(e)$ can be written as

$$
\begin{aligned}
P_{div}(e) = {} & \frac{a}{\left(1-e^{-\gamma_0/\bar{\gamma}}\right)} \times \\
& \left\{ 1 + \frac{0.5}{1+b\bar{\gamma}}\sqrt{\frac{4b\gamma_0}{\pi}}\, e^{-\gamma_0(1+b\bar{\gamma})} - \frac{\bar{\gamma}+\gamma_0}{\bar{\gamma}} e^{-\gamma_0/\bar{\gamma}} erfc\left(\sqrt{b\gamma_0}\right) \right. \\
& - \sqrt{\frac{b\bar{\gamma}}{1+b\bar{\gamma}}}\, erf\left(\sqrt{\lambda}\right) - \frac{0.5}{1+b\bar{\gamma}}\sqrt{\frac{b\bar{\gamma}}{1+b\bar{\gamma}}}\, erf\left(\sqrt{\lambda}\right) \\
& \left. + \frac{\gamma_0}{\bar{\gamma}} e^{-\gamma_0/\bar{\gamma}} erfc\left(\sqrt{b\gamma_0}\right) - \frac{\gamma_0}{\bar{\gamma}^2}\sqrt{\frac{b\bar{\gamma}}{1+b\bar{\gamma}}}\, erfc\left(\sqrt{\lambda}\right) \right\}
\end{aligned} \tag{17}
$$

By substituting (6), (9) and (15) or (17) into (5), we can have a closed-form expression for the error probability of the amplify-and-forward incremental relaying wireless cooperative diversity network over Rayleigh flat fading channels.

B) Outage Performance Analysis

In this subsection, we derive closed-form expressions for the SNR outage probability. In incremental relaying cooperative diversity networks, if the SNR of direct link at the destination is less than the threshold value γ_0, the destination will need assistance from the relay to send another copy of the source signal. In this case, the relay will send another copy of the signal but there is still a probability that the overall SNR at the destination is less than γ_0, and in this subsection we will determine this probability.

The SNR outage probability can be easily derived as

$$
\begin{aligned}
P(out) &= P(\gamma_{s,r,d} + \gamma_f \le \gamma_0 \mid \gamma_f \le \gamma_0) P(\gamma_f \le \gamma_0) \\
&= P(\gamma_{s,r,d} + \gamma_f \le \gamma_0) \\
&= P(\gamma_{equ} \le \gamma_0)
\end{aligned} \tag{18}
$$

By using the same approximation for γ_{equ} in (11) (i.e., using γ_b) and noting that γ_b follows the exponential distribution, then $P(out)$ can be derived and written in a closed form as

$$
P(out) = \begin{cases} 1 + \dfrac{\bar{\gamma}}{\bar{\gamma}_f - \bar{\gamma}}\exp(-\gamma_0/\bar{\gamma}) - \dfrac{\bar{\gamma}_f}{\bar{\gamma}_f - \bar{\gamma}}\exp(-\gamma_0/\bar{\gamma}_f) & \bar{\gamma}_f \ne \bar{\gamma} \\ 1 - \dfrac{\gamma_0 + \bar{\gamma}_f}{\bar{\gamma}_f}\exp(-\gamma_0/\bar{\gamma}_f) & \bar{\gamma}_f = \bar{\gamma} \end{cases} \tag{19}
$$

IV. NUMERICAL RESULTS

Asymmetric network geometry is examined where the relay is located across the straight line connecting the source and the destination. Direct path length *S-D* is normalized to be equal to 1. We also denote *d* as the distance between the source and the relay. In all presented results, the path-loss exponent α is assumed to be equal to 3 and the signal modulation is BPSK.

Fig. 2 shows the bit error rate (BER) for different values of γ_0 for the incremental relaying scheme. Fig. 2 demonstrates that the cooperation significantly improves the BER performance in comparison with the direct transmission. This is expected because the cooperation benefits from the diversity gain as well as from the path-loss reduction. Also, Fig. 2 shows that as γ_0 increases, the error performance improves because we will benefit more from the diversity. Fig. 2 shows also that at high SNR, the error performance for incremental relaying scheme tends to be parallel with direct transmission, which means that the system achieves virtual antenna array gain but not diversity gain. This is because at high SNR the destination will rarely need any assessment from the relay. Finally, we can conclude that the error probability for the incremental relaying lies between the direct link and the regular cooperative diversity scheme.

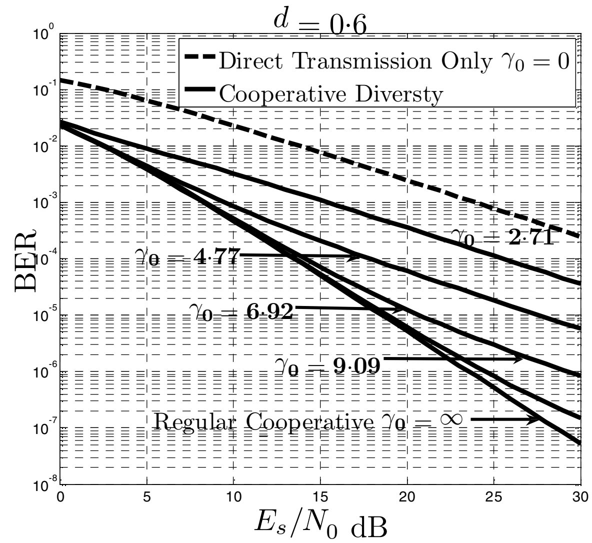

Fig. 2. Error probability performance for incremental relaying.

Fig. 3 shows the channel utilization of efficient bandwidth cooperative diversity network. We mean by the channel utilization the ratio of the useful frames transmitted by the source to the total number of the frames (transmitted by the source and the relay). Mathematically speaking, channel utilization *CU* can be defined by the ratio

$$
CU = \frac{N_{useful}}{N_{Total}} \tag{20}
$$

where N_{useful} is the number of useful frames and N_{Total} is the total number of frames. It is known that direct transmission has 100% channel utilization. Regular cooperative diversity network has 50% channel utilization since this system always needs to transmit the source signal in two phases. Obviously, the cannel utilization of the incremental relaying will lie between 50% and 100%. Fig. 3 shows when the SNR detection threshold (γ_0) increases the channel utilization decreases. Fig. 3 also shows that incremental relaying cooperative diversity network gives high channel utilization (very close to direct system) at medium and high SNR. For example incremental relaying scheme at 15 dB reaches 90% channel utilization and $P(e) = 10^{-4}$ for $\gamma_0 = 6.92$ while direct transmission has 100% channel utilization and $P(e) = 10^{-2}$.

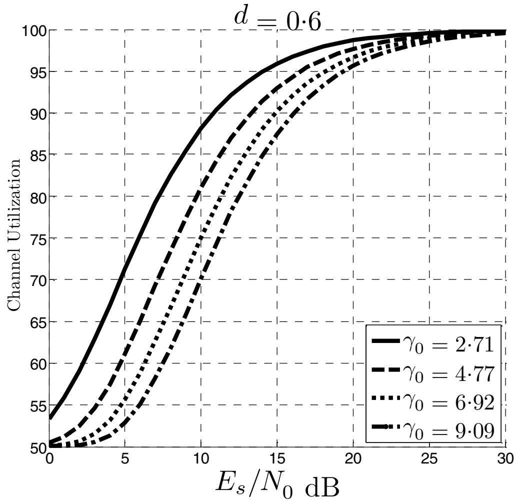

Fig. 3. Channel utilization for different values of γ_0.

Fig. 4 shows the outage probability performance defined in the previous section. Form Fig. 4, we can conclude that as γ_0 increases the outage probability increases. The reason is that as γ_0 increase the probability that the summation of the SNR of the combined signal is less than γ_0 will also increase.

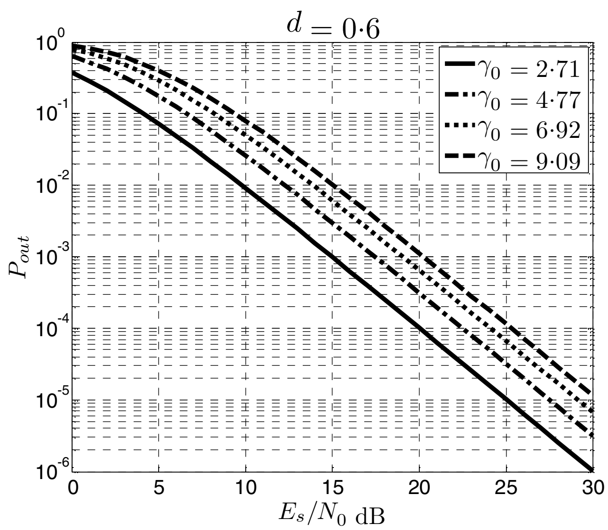

Fig. 4. Outage probability performance for incremental relaying.

V. CONCLUSIONS

Incremental relaying cooperative diversity network is an efficient technique that can be used to save the channel resources and use extra channel resources only when it is necessary. We have derived closed-form expressions for the error and outage probabilities.

Results show that incremental relaying technique can achieve significant spatial diversity with a high channel utilization compared with regular cooperative diversity. Also, results show that the channel utilization and error performance are highly dependent on the error threshold employed at the destination. Obviously, the value of this threshold depends on the application used at the destination. Furthermore, it can also be seen that incremental relying has high channel utilization comparable to that of the direct transmission particularly at medium and high SNR.

As a future work, this work can be extended to the decode-and-forward relaying scheme. Also, this work can be extended to more general fading channel models such as Nakagami-*m* and generalized Gamma fading channels.

REFERENCES

[1] J. N. Laneman, D. N. C. Tse, and G. W. Wornell, "Cooperative diversity in wireless networks efficient protocols and outage behaviour," *IEEE Trans. Inform. Theory*, vol. 50, no. 12, pp. 3062–3080, Dec. 2004.

[2] J. N. Laneman and G. W. Wornell, "Energy-efficient antenna sharing and relaying for wireless networks," *in Proc. IEEE Wireless Communications and Networking Conf.* (*WCNC*'00), Chicago, IL, Oct. pp. 7–12, 2000.

[3] A. Sendonaris, E. Erkrip, and B. Aazhang, "User cooperation diversity–Part I: System description," *IEEE Trans. Commun*., vol. 51, no. 11, pp. 1927–1938, Nov. 2003.

[4] ——, "User cooperation diversity–Part II: Implementation aspects and performance analysis," *IEEE Trans. Commun*., vol. 51, no. 11, pp. 1927–1938, Nov. 2003.

[5] T. A. Tsiftsis, G. K. Karagiannidis, S. A. Kotsopoulos, and F. N. Pavlidou, "BER analysis of collaborative dual-hop wireless transmissions," *Electron. Lett*., vol. 40, pp. 679–681, May 2004.

[6] R. Nabar, H. B¨olcskei, and F. W. Kneub¨uhler, "Fading relay channels: Performance limits and space-time signal design," *IEEE J. Select. Areas Commun.*, vol. 22, no. 6, pp. 1099–1109, Aug. 2004.

[7] J. Boyer, D. Falconer and H. Yanikomeroglu, "Multihop diversity in wireless relaying channels," *IEEE Trans. Commun.*vol. 52, pp 1820-1829, Oct 2004.

[8] J. Boyer, D. Falconer, and H. Yanikomeroglu, "A theoretical characterization of the multi-hop wireless communication channel with diversity," *in Proc. Global telecommunications conf.*, San Antonio, TX, pp. 841-845, Nov. 2001.

[9] M. K. Simon and M.-S. Alouini, Digital Communication over Fading Channels: A Unified Approach to Performance Analysis. NewYork: John Wiley and Sons, 2000.

[10] I. S. Gradshteyn and I. M. Ryzhik, Table of Integrals, Series and Products San Diego, CA: Academic Press, 5th edition, 1994.

[11] P. Herhold, E. Zimmermann, G. Fettweis, "A Simple Cooperative Extension to Wireless Relaying," Int. Zurich *Seminar on Communications*, Zurich, Switzerland, Feb. 2004.

[12] M. O. Hasna and Mohamed-Slim Alouini "End-to-end performance analysis of two hop relayed transmission over Rayleigh fading channels," *Proceeding of IEEE Vehicular technology conference VTC Fall* 2002, Vancouver, British Colombia, Canada, Sep. 2002.

[13] A. Papoulis and S.U. Pillai, Probability, Random Variables and Stochastic Process, Fourth ed., McGraw Hill, 2002.

[14] Bletsas, A., Khisti, A., Reed, D.P., and Lippman, A. 'A simple cooperative diversity method based on network path selection," *IEEE Journal on SelectedAareas in Commun.*, vol. 24, no. 3, March 2006.

[15] T. Wang, A. Cano, G. B. Giannakis, and N. Laneman, ``High-Performance Cooperative Demodulation with Decode-and-Forward Relays," *IEEE Trans. on Comm.*, in press.