A Spatial Incremental Relaying-Based User Transparent ARQ Protocol

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***Abstract*—In this paper, we propose an incremental decode-and-forward (DF) relaying scheme; in our proposed scheme, we make use of the free spatial dimensions over which the relay node will forward the source node data. The relay node will help in providing an automatic repeat request (ARQ) service for the source node that is completely transparent to the source node. The proposed ARQ service will not require any additional complexity at the source node transmitter and will not incur any rate loss. We provide a complete analysis for the symbol error rate (SER) of our proposed scheme. In addition, we derive SER upper-bounds to calculate the diversity order achieved by our scheme. Numerical simulations are conducted that support our derived SER expressions as well as the calculated diversity orders. The results show the significant performance gains of our proposed scheme, in terms of the system SER and the diversity order, compared to the system where no relay is deployed.**

I. Introduction

Enhancing the performance of digital communication systems has become a continuous demand. Many solutions have been proposed to achieve this requirement. One of the solutions is to support the *automatic repeat request* (ARQ) [1], [2], which is an error control mechanism that proved to be very effective in increasing the reliability of data transmission. The main idea of ARQ is to enable the destination to send a request to the transmitter to resend the data if the data was not correctly received; this will definitely decrease the error rate. However, supporting ARQ requires some added complexity to the transmitter to build the logic and the processing around the ARQ retransmissions.

Another solution for enhancing the system performance is to support the use of diversity achieving schemes to overcome the fading nature of the wireless channels. Size limitations of the small mobile units can limit the use of multiple antennas at the mobile unit and this has led to the use of relaying schemes to achieve diversity. Relay nodes can be used to assist the transmission of the source node data benefiting from the broadcast nature of the wireless channels. The two basic schemes of relaying are the *amplify-and-forward* (AF) scheme, in which the relay amplifies the received source signal and retransmits to the destination, and the *decode-and-forward (DF)* scheme, in which the relay decodes the data first before retransmitting it to the destination. Other relaying schemes abound and among them is the *Incremental relaying* scheme [3].

Incremental relaying scheme was first introduced in [3] as an adaptive relaying protocol based upon limited feedback from the destination terminal. In incremental relaying, the relay only assists the transmission under bad channel conditions, which will result in saving the valuable channel resources.

The performance of relay networks has been extensively studied in literature. In [4], closed-form expressions for the outage capacity for transmit diversity, incremental decode-and-forward, decode-and-forward, and selective decode-and-forward were derived; in addition, it was proved that in certain cases, the relaying protocols can do better than transmit diversity. In [5], an incremental relaying scheme in conjunction with selection decode-and-forward was proposed. The outage probability and the bit error rate expressions were derived, which show that the proposed scheme offers a good trade-off between performance and channel resources usage. In [6], a relaying scheme was proposed along with the derivation of closed form expressions for the scheme outage probability; the proposed relaying scheme combines the incremental decode-and-forward with the selective hybrid decode-amplify-forward (HDAF) relaying strategies. The authors proved the superiority of their proposed scheme over the conventional incremental DF relaying scheme. In [7], an incremental relaying protocol is proposed where the relays cooperate to send an Alamouti coded versions of their signals. In [8], outage probability analysis for the incremental DF protocol was carried out for the case of non-identical, independent Rayleigh fading channels.

In this paper, we propose a decode-and-forward based incremental relaying scheme. In our proposed scheme, the relay will help in forwarding the source node data in the free spatial dimensions in case of receiving a negative acknowledgement (NACK) from the receiving node. In our model, the destination is assumed to be equipped with multiple receiving antennas and this will allow it to receive the relay node transmissions in the available free spatial dimensions not occupied by the source node transmissions. The proposed scheme allows for supporting ARQ service that is completely transparent to the source node with no rate loss. So if the transmitters of a legacy system are not supporting ARQ retransmissions, our proposed scheme can provide the system with ARQ support by adding multiple receive antennas at the destination and by adding relay node(s) in the network; the legacy system transmitters will not be modified and the ARQ support will be completely transparent for them. Also, the proposed scheme incurs no rate loss for the retransmitted packets since they are sent in the free

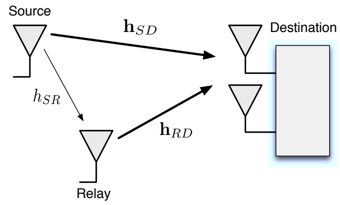

Fig. 1. System model.

spatial dimensions.

Another advantage of the proposed scheme is that it can simplify the design of the source node transmitter since the ARQ support, with all of the required logic and processing, will be carried out at the relay node (note that the same relay node can serve many source nodes); this can reduce the cost of the source node while still supporting ARQ retransmissions. Our contribution in this paper can be stated as follows:

- propose an incremental relaying scheme that makes use of the free spatial dimensions to support ARQ in the system that is completely transparent to the source node;
- derive a closed form expression for the symbol error rate (SER) of the proposed scheme; provide diversity order analysis for our proposed scheme.

Notations: Throughout the paper we refer to vectors with bold lower-case letters, e.g., $\mathbf{x}$. Matrices are referred to with bold upper-case letters, e.g., $\mathbf{A}$. $\mathbf{A}^{\mathcal{H}}$ denotes the Hermitian transpose of a matrix $\mathbf{A}$. $\mathbb{C}$ is used to denote the field of complex numbers.

II. System Model

We consider a system with a single-antenna source, a two-antenna destination and a single-antenna relay node; extension to the case of having $N_r > 2$ receive antennas at the destination node follows directly from the analysis presented in the paper. The system model is shown in Fig. 1.

In our model, we assume that the time is slotted. At each new time slot the source node will be transmitting a new data symbol. As we have mentioned above, the proposed scheme will be completely transparent to the source node. The source node will not be aware of whether ARQ is supported or not. The system has two modes of operation depending on the state of the relay node; in the first mode, the relay node will not be transmitting any data to the destination node. The source transmits its data to both the destination node and the relay node. The destination node decodes the transmitted data and sends a feedback packet to the relay node. This packet is either an acknowledgement (ACK) in case of correct reception or a negative acknowledgement (NACK) in case of erroneous reception of the source data. This is based on the assumption that the destination is provided with a perfect *cyclic redundancy check* (CRC) code. Meanwhile, the relay node decodes the transmitted source data and waits to hear the destination feedback packet. If an ACK is received the relay will drop the source data and the system will remain in the first mode in the next time slot. However, if the relay has received a NACK from the destination node the system will move to the second mode of operation.

In the second mode, the relay will transmit its decoded version of the source data, which was erroneously received at the destination node in the previous slot, and the source node will transmit its new data symbol. Since the destination is equipped with multiple antennas it will be able to separate the transmissions of the new source data and the relay ARQ transmission.

In our model, we assume a single retransmission attempt from the relay node. We also make the practical assumption of having a half-duplex relay node(s), i.e., the relay node cannot be transmitting and receiving at the same time. Based on that constraint, the source data transmitted while the system is in the second mode of operation will not be decoded at the relay node. So if the system was in the second mode of operation in a given time slot it must move to the first mode in the next time slot[1]. Next, we will present the signal model for the system two modes of operation.

In the first mode, the source transmits a symbol $x \in \mathbb{C}$. The symbol x is carved from an M-ary constellation such as QPSK, 16-QAM or 64-QAM. The transmitted symbol x follows a unit average transmit power constraint, i.e., $E\{\|\mathbf{x}\|^2\} \leq 1$. The received signals at the destination node, $\mathbf{y}_{SD}$, and at the relay node, y_{SR}, are given, respectively, by

$$\begin{aligned} \mathbf{y}_{SD} &= \mathbf{h}_{SD}x + \mathbf{n}_{SD}, \\ y_{SR} &= h_{SR}x + n_{SR}, \end{aligned} \tag{1}$$

where $\mathbf{h}_{SD}$ is a 2×1 vector containing the channel coefficients between the source and the destination nodes. h_{SR} is the channel coefficient between the source and the relay nodes. All of the channel coefficients are modeled as independent, zero-mean complex Gaussian random variables with unit variance, i.e., a flat-fading Rayleigh channel model is assumed. The 2×1 vector $\mathbf{n}_{SD}$ contains the noise terms for the source-destination link; the components of $\mathbf{n}_{SD}$ are modeled as zero mean complex Gaussian random variables, with a variance of σ^2_{SD} per component, and are assumed to be independent of each other. n_{SR} denotes the noise term for the source-relay link and is modeled as zero mean complex Gaussian random variable with a variance of σ^2_{SR}. Also, we assume that the channels change independently from one time slot to the next. Therefore, the signal to noise ratio (SNR) will be $\frac{1}{\sigma^2_{SD}}$ for the source-destination link and $\frac{1}{\sigma^2_{SR}}$ for the source-relay link. This model will allow us to consider different qualities for the source-relay and the source-destination links by setting the parameters σ^2_{SR} and σ^2_{SD}.

In the first mode, the source-destination link is a 1×2 channel and the destination combines the two received copies of the source symbol by using a *maximal ratio combiner*

[1]We assume a zero delay feedback channel but this assumption does not affect the analysis presented in the paper which applies to any system with a fixed feedback delay.

(MRC). The output of the destination MRC, y_1, is given by

$$y_1 = \frac{\mathbf{h}_{SD}^{\mathcal{H}} \mathbf{y}_{SD}}{\|\mathbf{h}_{SD}\|^2}. \quad (2)$$

After decoding, the destination will send a feedback packet to the relay node. If the destination was able to decode the source data correctly it will send an ACK packet; the relay will drop the source node data from the previous slot and will listen to the source node transmission in the next slot, i.e., the system remains in its first mode of operation. However, if the destination was not able to decode the source data, it will send a NACK packet to the relay node. The relay will send another copy of the undelivered source data to the destination in the next time slot; the source node transmitter will not decode the feedback packets from the destination node and will not respond to any NACK from the destination. Therefore, our proposed system supports ARQ in a way that is transparent to the source node. This relay transmission will move the system to the second mode of operation in the next time slot.

In the second mode, both the source and the relay nodes will be transmitting to the destination node; the source node will transmit a new data symbol and the relay node will transmit its decoded version of the undelivered source symbol from the previous slot. The received signal at the destination node is given by

$$\mathbf{y}_{SR-D} = [\mathbf{h}_{SD}\mathbf{h}_{RD}] \begin{bmatrix} x_n \\ \hat{x} \end{bmatrix} + \mathbf{n}, \quad (3)$$

where x_n is the new source symbol and $\hat{x}$ is the decoded source symbol at the relay node from the undelivered source data. The 2×1 vector $\mathbf{n}$ represents the additive white Gaussian noise (AWGN) at the destination node. The components of $\mathbf{n}$ are assumed to be independent and are modeled as zero mean complex Gaussian random variables with a variance of σ^2 per component, where $\sigma^2 = \sigma_{SD}^2$. The destination detects these symbols by using a *minimum mean square error* (MMSE) detector. The MMSE equalized signal is given by

$$\mathbf{y}_2 = \left(\mathbf{H}^{\mathcal{H}}\mathbf{H} + \sigma^2\mathbf{I}\right)^{-1} \mathbf{H}^{\mathcal{H}}\mathbf{y}_{SR-D}, \quad (4)$$

where $\mathbf{H} = [\mathbf{h}_{SD}\ \mathbf{h}_{RD}]$ and $\mathbf{I}$ is the 2×2 identity matrix. As mentioned above, the relay will not be able to assist the transmission of the source data symbol transmitted while the system is in the second mode of operation. After retransmitting the undelivered data symbol the system will return to its first mode of operation.

III. Symbol Error Rate and Diversity Order Analysis for the Proposed Scheme

In this section, we study the symbol error rate (SER) as well as the diversity order for the proposed relaying scheme. For comparison purposes we derive the expressions for the SER and the diversity order for the system with no relaying.

A. Symbol Error Rate Analysis

In error probability analysis, closed form expressions for the average symbol error rate are derived for both the no relaying and the proposed incremental relaying schemes.

1) No-Relaying Scheme Symbol Error Rate: In this case, we have only the direct link between the source and the destination nodes. A closed form expression for the symbol error rate, $P_s(E)$, for the multichannel MRC reception of square M-QAM constellation was derived in [9] and is given by

$$\begin{aligned} P_s(E) =& \frac{4}{\pi}\Bigg[\left(1-\frac{1}{\sqrt{M}}\right)\int_0^{\frac{\pi}{2}}\prod_{l=1}^{Lr} I\left(\bar{\gamma}_l, g_{QAM}, \Theta\right) d\Theta \\ &- \left(1-\frac{1}{\sqrt{M}}\right)^2\int_0^{\frac{\pi}{4}}\prod_{l=1}^{Lr} I\left(\bar{\gamma}_l, g_{QAM}, \Theta\right) d\Theta\Bigg], \end{aligned} \quad (5)$$

where $I(\gamma, g_{QAM}, \Theta) = \left(1+\frac{g_{QAM}\gamma}{\sin^2\Theta}\right)^{-1}$, $g_{QAM} = \frac{3}{2(M-1)}$, $\bar{\gamma}_l$ is the average SNR of the l-th channel, M is the constellation size, and L_r is the number of signal copies (channels) received at the destination. In our case, $L_r = 2$ and $\bar{\gamma}_l = \frac{1}{\sigma_{SD}^2}$.

2) Spatial Incremental Relaying Scheme Symbol Error Rate: The symbol error rate, P_S, of our proposed scheme can be expressed as

$$P_S = P_1P_2 + P_3P_4, \quad (6)$$

where P_1 is the probability of symbol error given that in the first transmission of the symbol the relay was not transmitting, P_2 is the probability that the relay is not transmitting in a given time slot, P_3 is the probability of symbol error given that in the first transmission of the symbol the relay was transmitting, and P_4 is the probability that the relay is transmitting in a given time slot. Next, we will drive expressions for the different terms in (6).

First, we derive the expression for P_1. If the source transmits the symbol when the relay was not transmitting then the destination was not able to correctly receive the source symbol. This means that the destination was not able to get the symbol from the direct link as well as from the retransmitted relay symbol. So for the source symbol to be lost in this case, the direct source-destination link must result in a decoding error and the retransmitted relay node symbol must be decoded in error as well.

Let Pe_{SD} denote the probability of error between the source and the destination direct link, Pe_{SR} denote the probability of error between the source and the relay and $\tilde{P}e_{RD}$ denote the probability of error between the relay and destination when both the relay and the source are transmitting. Therefore, P_1 can be written as[2]

$$\begin{aligned} P_1 =& \Pr\{\text{direct source-destination link resulted in a decoding error}\} \\ &\times \Pr\{\text{relay-destination link resulted in a decoding error}\} \\ =& Pe_{SD}[Pe_{SR} + (1-Pe_{SR})\,\tilde{P}e_{RD}]. \end{aligned} \quad (7)$$

The value of Pe_{SD} can be calculated from (5) by substituting $L_r = 2$ and $\bar{\gamma}_l = \frac{1}{\sigma_{SD}^2}$. Moreover, the value of Pe_{SR} can be calculated from (5) by substituting $L_r = 1$ and $\bar{\gamma}_l = \frac{1}{\sigma_{SR}^2}$

[2]We assume error propagation from the relay node to the destination node; so if the relay has erroneously decoded a source symbol and it was asked by the destination to retransmit that symbol this will result in a symbol error at the destination as well.

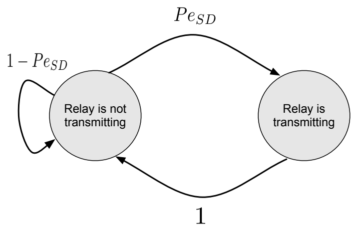

Fig. 2. The Markov chain model of the relay state.

The value of $\tilde{P}e_{RD}$ can be calculated from the SER expressions for the MMSE detector. Tight closed form approximations for the SER of the MMSE detector were derived in [10]. The MMSE detector SER can be tightly approximated as

$$P_{N_r\times N_t}(e) = \left(1-\frac{1}{\sqrt{M}}\right)\left[\frac{1}{3}M_{N_r\times N_t}\left(\frac{3}{2(M-1)}\right) + \frac{2}{3}M_{N_r\times N_t}\left(\frac{2}{M-1}\right)\right], \quad (8)$$

where N_r is the number of receive antennas, N_t is the number of transmit antennas, M is the constellation size, and $M_{N_r\times N_t}$ is the moment generating function of the signal to interference and noise ratio (SINR). $M_{N_r\times N_t}$ for the case of $N_r = N_t = 2$ is given by [10]

$$M_{2\times 2}(m) = s\left[\frac{1-m}{s+m} + me^{s+m}E_i(s+m)\right], \quad (9)$$

where $s = \frac{N_t}{\bar{\gamma}}$, and $E_i(.)$ is the exponential integral function defined as

$$E_i(x) = \int_x^\infty \frac{e^{-t}}{t}dt, \quad \text{for } x > 0. \quad (10)$$

Now we move to calculating the values of P_2 and P_4, which represent the probability that the relay was not transmitting and the probability that relay was transmitting in any time slot, respectively. The relay state can be modeled as a two-state Markov chain as shown in Fig 2. The transition matrix for this Markov chain is given by

$$\mathbf{P} = \begin{bmatrix} 1-Pe_{SD} & Pe_{SD} \\ 1 & 0 \end{bmatrix}. \quad (11)$$

Note that the transition from the "relay is not transmitting" state to the "relay is transmitting" state occurs with probability that equals the probability of error for the direct 2×1 channel between the source and destination nodes. The transition from the "relay is transmitting" state to the "relay is not transmitting" state occurs with probability 1 due to the half-duplex operation of the relay node as described before.

The steady state distribution for this two-state Markov chain can be calculated as

$$\begin{bmatrix} P_2 & P_4 \end{bmatrix} \times \begin{bmatrix} 1-Pe_{SD} & Pe_{SD} \\ 1 & 0 \end{bmatrix} = \begin{bmatrix} P_2 & P_4 \end{bmatrix}, \quad (12)$$

where $P_4 = 1 - P_2$. From (12), it can be easily proved that the values of P_2 and P_4 are given by

$$P_2 = \frac{1}{1+Pe_{SD}} \text{ and } P_4 = \frac{Pe_{SD}}{1+Pe_{SD}}. \quad (13)$$

Finally, we need to calculate the value of P_3, which is the probability of source symbol error when the source symbol is transmitted while the relay is transmitting. This is the same case as the one considered when calculating the value of $\tilde{P}e_{RD}$. Therefore, P_3 can also be calculated from (8).

B. Diversity Order Analysis

In this section, we calculate the diversity order achieved by our proposed incremental relaying scheme. The diversity order for any system, d, is defined as

$$d = \lim_{SNR\to\infty} -\frac{\log SER}{\log SNR},$$

where SER is the system symbol error rate and SNR is the average system SNR. We will begin with the analysis for the no relaying scheme and then we derive the diversity order for our proposed scheme.

1) No-Relaying Scheme Diversity Analysis: In this case, the probability of symbol error is given by (5) by setting $L_r = 2$. The value of $I(\gamma, g_{QAM}, \Theta)$ can be upper bounded by $\left(\frac{g_{QAM}\gamma}{\sin^2\Theta}\right)^{-1}$. Therefore, the symbol error probability upper-bound, $\overline{P_s(E)}$, can be given as

$$\overline{P_s(E)} = \frac{4}{g_{QAM}^2\pi}\left(1-\frac{1}{\sqrt{M}}\right)\bar{\gamma}_{SD}^{-2}\left[\int_0^{\frac{\pi}{2}}\sin^4\Theta d\Theta - \left(1-\frac{1}{\sqrt{M}}\right)\int_0^{\frac{\pi}{4}}\sin^4\Theta d\Theta\right]. \quad (14)$$

After evaluating the above integrals, the upper bound can be found to be

$$\overline{P_s(E)} = \frac{4}{g_{QAM}^2\pi}\left(1-\frac{1}{\sqrt{M}}\right)\left[\frac{3\pi}{16} - 0.0445\left(1-\frac{1}{\sqrt{M}}\right)\right]\bar{\gamma}_{SD}^{-2}, \quad (15)$$

which achieves a diversity order of two.

2) Relaying Scheme Diversity Analysis: In this case, the symbol error probability can be calculated from (6)-(13). The upper bound for Pe_{SD} is given by (15). Following the same approach presented in the previous section we can get the upper bound for Pe_{SR} as

$$\overline{Pe_{SR}} = \frac{4}{g_{QAM}\pi}\left(1-\frac{1}{\sqrt{M}}\right)\left[\frac{\pi}{4} - 0.1426\left(1-\frac{1}{\sqrt{M}}\right)\right]\bar{\gamma}_{SR}^{-1}. \quad (16)$$

It can be noticed that $\overline{Pe_{SR}}$ scales as $\bar{\gamma}_{SR}^{-1}$ at high SNRs.

To finish our diversity order analysis we need to calculate the diversity order for (8), which is the diversity order for both $\tilde{P}e_{SD}$ and $\tilde{P}e_{RD}$. At high values of SNR the value of $s = \frac{N_t}{\bar{\gamma}}$ will be very small. The value of the moment generating function at high SNR can be approximated as [10]

$$\overline{M_{2\times 2}(m)} \simeq \frac{N_t}{\gamma}\left[\frac{1-m}{m}\right]. \quad (17)$$

Therefore, the expression in (8) can be approximated at high SNR as

$$P_{N_r\times N_t}(e) \simeq \left(1-\frac{1}{\sqrt{M}}\right)\left[\frac{1}{3}\left(\frac{1-m_1}{m_1}\right) + \frac{2}{3}\left(\frac{1-m_2}{m_2}\right)\right]\frac{N_t}{\bar{\gamma}}, \quad (18)$$

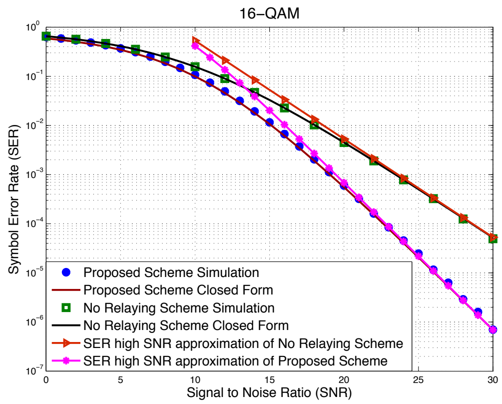

Fig. 3. The symbol error rate (SER) for the 16-QAM constellation.

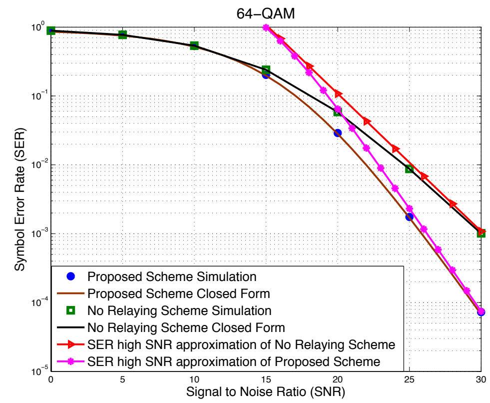

Fig. 4. The symbol error rate (SER) for the 64-QAM constellation.

where $m_1 = \frac{3}{2(M-1)}$ and $m_2 = \frac{2}{(M-1)}$. It is clear that this approximated expression scales as $\bar{\gamma}^{-1}$ at high SNR, which corresponds to a diversity of order 1.

By combining the results obtained in (14) - (18), it can be easily proved that our proposed scheme achieves a diversity order of three compared to two for the the no relaying scheme.

IV. Numerical Results

In this section, we present some simulation results for our proposed incremental relaying scheme to check the validity of the derived closed form SER expressions. Our system performance will be compared to the conventional 1×2 system. In our simulations, we assume that σ_{SR}^2 is higher than σ_{SD}^2 by 5 dB (which means that the SNR of the link between the source and the relay is better than that of the link between the source and the destination by 5 dB).

Fig. 3 shows the symbol error rate for the 16-QAM constellation. We compare the system simulation results with the derived closed form expressions given in (6). In this case, we have $M = 16$ and $g_{QAM} = \frac{1}{10}$. We also plot the high SNR SER approximation derived above. Our simulation results prove the tightness of the derived SER expressions. We can see that the proposed scheme achieves a diversity of order three as compared to a diversity order of two for the conventional, no relaying scheme.

Fig. 4 shows the symbol error rate for the 64-QAM constellation. Similar to the 16-QAM case, we compare the system simulation results with the derived closed form expressions given in (6). In this case, we have $M = 64$ and $g_{QAM} = \frac{1}{42}$. We also plot the high SNR SER approximation derived above. Again, our simulation results prove the tightness of the derived SER expressions. We can see that the proposed scheme achieves a diversity of order three as compared to a diversity order of two for the conventional, no relaying scheme.

V. Conclusion

In this paper, a spatial incremental relaying scheme was proposed which can provide a transparent ARQ support. Relay node(s) will help the source node(s) using the free spatial dimensions over which it can retransmit the undelivered source symbols. The proposed scheme can provide an ARQ support for legacy systems without the need for modifying the source node transmitter and this can reduce the design complexity and cost of the source node transmitter. We have derived closed form expression for the SER of our proposed scheme; we have also derived high SNR SER approximation for our proposed scheme to calculate the diversity gain compared to the conventional, no relaying scheme. Our results indicate that the proposed scheme can achieve higher diversity orders as well as better SER performance compared to the no relaying scheme.

References

[1] Shu Lin, D Costello, and M Miller, "Automatic-repeat-request error-control schemes," *IEEE Communications Magazine*, vol. 22, no. 12, pp. 5–17, 1984.

[2] G Caire and D Tuninetti, "The throughput of hybrid-arq protocols for the gaussian collision channel," *IEEE Transactions on Information Theory*, vol. 47, no. 5, pp. 1971–1988, 2000.

[3] J N Laneman, D N C Tse, and G W Wornell, "Cooperative diversity in wireless networks: Efficient protocols and outage behavior," *IEEE Transactions on Information Theory*, vol. 50, no. 12, pp. 3062–3080, 2004.

[4] H Jondral F.K. Renk, T Jaekel and A Goldsmith, "Do decode-and-forward relaying protocols beat transmit diversity?," *2010 European Wireless Conference (EW)*, vol. 47, pp. 294 – 300, 2010.

[5] Vo Nguyen Quoc Bao and Hyung Yun Kong, "Performance analysis of incremental selection decode-and-forward relaying over rayleigh fading channels," *IEEE International Conference on Communications Workshop.*, pp. 1–5, 2009.

[6] Juan Cui Jianlan Jia, Zhiquan Bai and Kyungsup Kwak, "Performance analysis of hybrid daf based incremental relaying cooperative system," *2012 IEEE 23rd International Symposium on Personal, Indoor and Mobile Radio Communications - (PIMRC)*, pp. 1824 – 1828, 2012.

[7] Ons Mabrouk and Hatem Boujemaa, "Incremental decode and forward relaying using distributed space time coding," *2012 5th International Symposium on Communications Control and Signal Processing (ISCCSP)*, pp. 1–5, 2012.

[8] S.S. Ikki and M.H. Ahmed, "Performance analysis of decode-and-forward incremental relaying cooperative-diversity networks over rayleigh fading channels," in *Vehicular Technology Conference, 2009. VTC Spring 2009. IEEE 69th*, april 2009, pp. 1 –6.

[9] M.K. Simon and M. Alouini, "A unified approach to the performance analysis of digital communication over generalized fading channels," *Proceedings of the IEEE*, vol. 86, pp. 1860 – 1877, 1998.

[10] Namshik Kim, Yusung Lee, and H Park, "Performance analysis of mimo system with linear mmse receiver," *IEEE Transactions on Wireless Communications*, vol. 7, no. 11, pp. 4474–4478, 2008.