SNR-Based Partial Relay Selection Scheme over Multiple Relay Network

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Department of Computer Engineering, Kyungil University,
Gyeongbuk, Korea
kshwang@kiu.ac.kr

Abstract. In this paper we propose a sub-optimal relay selection scheme over a multiple relay network where the relay node is selected if its link quality is above a certain threshold which is set to satisfy the required performance and the selected link is maintained unless its link quality does not fall below the threshold. From our derived statistics of the received output signal-to-noise ratio (SNR), we derive the end-to-end system performance in terms of the outage probability. In addition, we apply our proposed algorithm to the selection decode-and-forward protocol, and analyze its outage performances. We show from our numerical example that our proposed algorithm can provide adequate performance by setting the moderate threshold while its complexity is much lower than the one of an optimal relay selection scheme.

Keywords. Cooperative diversity, relay selection, performance analysis, opportunistic relaying and selection decode-and-forward

1 Introduction

Recently, the cooperative diversity systems with multiple relays, based on the distributed space-time coding (DSTC) have been presented in [1, 2] to provide the spatial diversity gain in the wireless networks. However, in order to apply the conventional DSTC schemes [1–3], all the operating relay nodes need to know the channel state information (CSI) of all the standing links among the relay nodes involved in the cooperation, which may be inappropriate for the low-power required systems such as sensor network and mm-wave WPAN systems. From a practical point of view, Bletsas, et. al. in [4] proposed the opportunistic relaying to reduce the complexity in which the best relay node among relay candidates is only used and proved that it can provide the same diversity-multiplexing gain tradeoff as obtained by more complex DSTC cooperative system [1]. However, the opportunistic relaying also needs to find the best relay nodes at every transmission time, which results in high complexity since the CSI of all participating links is required. For the low complexity relay selection, authors in [5] worked on multiple relay selection schemes for the signal-to-noise ratio (SNR)-optimal/suboptimal criteria and proved their diversity orders.

Amarasuriya, et. al. in [6] proposed the multiple relay selection scheme with the amplify-and-forward transmission where L c relays are sequentially selected out of L relays based on the output threshold at the destination node and analyze performance bounds over the independent, identically distributed (i.i.d.) Rayleigh fading channels.

In this paper, we propose the SNR-based partial relay selection algorithm, named "switch-and-examine relay selection" (SERS) under the DF transmission using the idea of the switching diversity in [7]. In our proposed SERS scheme, an arbitrary relay node is selected and keeps selected unless it does not fall below a certain target threshold, γ T . As we will show later on, we derive the statistics of the output signal-to-noise ratio (SNR) per hop over the independent, but non-identically distributed (i.ni.d) Rayleigh fading channels such as the cumulative distribution function (CDF), probability density function (PDF) in a closed-form expression. In addition, we discuss the outage performance of our proposed SERS under the selection decode-and-forward (SDF) transmission [8]. For probing of efficiency of SERS, we will show that our proposed SERS can achieve the same performance in terms of the end-to-end outage probability as the opportunistic relaying [4] based on the decode-and-forward (DF) transmission while it has much lowered complexity with low power consumption because it does not always need to feedback the CSI or work the channel estimations at each participating relay node.

2 System Description

2.1 System Model

In this paper we consider a DF cooperative diversity system where one source node, one destination node, and *L* relay nodes are utilized in a network. Consider half-duplex dual-hop communication systems from only one active relay by the proposed scheme. We denote the channel gains as source-destination, $a_{s,d}$, source-relay *i*, a_s, *i*, and relay *i*-destination, $a_{i,d}$, respectively. Let $\gamma_{n,m}$ be an instantaneous output SNR for each link between the node n and m which is given as $\gamma_{n,m} = |a_{n,m}|^2 / N_0$. N_0 is a noise variance at each node. When each channel undergoes the circularly symmetric complex Gaussian fading environment, an $\gamma_{n,m}$ is exponentially distributed with parameter $1/\bar{\gamma}_{n,m}$ (i.e. $\bar{\gamma}_{n,m}$ = E[$\lambda_{n,m}$]) where E($\cdot$) is the expectation operator. Generally, we consider the independent and non-identically distributed (i.ni.d.) channels for each hop, and if the assumption of the independent and identically distributed (i.i.d.) channels is given, the average SNRs for source-destination, source-relay and relay-destination links are represented as $\bar{\gamma}_{s,d}$ = E[$\gamma_{s,d}$], $\bar{\gamma}_{s,d}$ = E[$\gamma_{s,d}$] and $\bar{\gamma}_{r,d}$ = E[$\gamma_{i,d}$], respectively. Conveniently, we denote the instantaneous output SNRs for the source-relay and the relay-destination links as Γ_1 and Γ_2, respectively.

2.2 Mode of Operation of Proposed Algorithm

During the guard periods, the source node broadcasts its pilot sequence to all relay nodes via the RTS packet, and the destination node also sends its pilot sequence to all relay nodes via the CTS packet [4]. After transmitting RTS and CTS packets, the first relay candidate[1] starts to estimate its channels. If channels of the dual-hop for the first relay are above the predetermined target threshold, the first relay candidate informs it to the source node and the remainders of relay candidates by using an acknowledgement (ACK) signal. In this situation, the remainders of possible relay nodes need not to work such as channel estimations, decoding processes and retransmissions. More specifically, we first estimate the output SNR, $\gamma_{s,1}$, between the source node and the first relay candidate. If $\gamma_{s,1}$ is acceptable (i.e. $\gamma_{s,1} \geq \gamma_T$), the relay node estimates the output SNR for the relay-destination link, $\gamma_{1,d}$. When $\gamma_{1,d}$ is higher than the target threshold (i.e. $\gamma_{1,d} \geq \gamma_T$), finally, the first relay candidate is chosen as an acceptable relay node (i.e. $\Gamma_1 = \gamma_{s,1}$ and $\Gamma_2 = \gamma_{1,d}$). If the first relay candidate is not available, it sends a negative acknowledgement (NACK) signal to the source node and the remainders of relay candidates, and then the second candidate starts the channel estimations and compares them with the target threshold. Of course, when the source-relay link of the first relay candidate is unacceptable (i.e. $\gamma_{s,1} < \gamma_T$), no relay operation is performed, that is, the output SNR between the relay and destination need not be estimated. After comparison, the second relay sends its decision to others like the first one. This procedure continues up to $(L-1)$th relay candidate to find an adequate relay node. In case that $(L-1)$th relay candidate still fails to satisfy the target threshold, Lth relay candidate is used for a cooperation without comparing to the target threshold.

3 CDF and PDF

3.1 CDF and PDF

From the mode of operation, we can write the CDF of the output SNR for the source-relay link, Γ_1, in (1).

$$P_{\Gamma_1}(x) = \begin{cases} \Pr[\gamma_T \leq \gamma_{s,l} < x \,\&\, \gamma_T < \gamma_{1,d}] \\ \quad + \sum_{j=2}^{L-1} \Pr[\max\{\min\{\gamma_{s,1}, \gamma_{1,d}\}, \ldots, \min\{\gamma_{s,j-1}, \gamma_{j-1,d}\}\} < \gamma_T \\ \&\gamma_T \leq \gamma_{s,j} < x \,\&\, \gamma_T < \gamma_{j,d}] \\ \quad + \Pr[\max\{\min\{\gamma_{s,1}, \gamma_{t,d}\}, \ldots, \min\{\gamma_{s,L-1}, \gamma_{L-1,d}\}\} < \gamma_T \\ \&\gamma_{s,L} < x], & x \geq \gamma_T, \\ \quad \Pr[\max\{\min\{\gamma_{s,1}, \gamma_{1,d}\}, \ldots, \min\{\gamma_{s,L-1}, \gamma_{L-1,d}\}\} < \gamma_T \\ \&\gamma_{s,L} < x], & x < \gamma_T. \end{cases} \tag{1}$$

[1] In our proposed scheme, we presume that there is the predetermined order to probe relays.

Using the i.ni.d. assumption over relay paths, the CDF of Γ_1, $P_{\Gamma_1}(x)$, can be evaluated in terms of the individual CDF of $\gamma_{n,m}$, $P_{\gamma_{n,m}}(\cdot)$ as

$$P_{\Gamma 1}(x)=\begin{cases} (P_{\gamma_{s,1}}(x)-P_{\gamma_{s,1}}(\gamma_T))(1-P_{\gamma_{1,d}}(\gamma_T)) \\ +\sum_{i=2}^{L-1}\prod_{j=1}^{i-1}(1-(1-P_{\gamma_{s,j}}(\gamma_T))(1-P_{\gamma_{j,d}}(\gamma_T))) \\ \times(P_{\gamma_{s,i}}(x)-P_{\gamma_{s,i}}(\gamma_T))(1-P_{\gamma_{i,d}}(\gamma_T)) \\ +\prod_{k=1}^{L-1}(1-(1-P_{\gamma_{s,k}}(\gamma_T))(1-P_{\gamma_{k,d}}(\gamma_T)))P_{\gamma_{s,L}}(x), & x\geq\gamma_T, \\ +\prod_{k=1}^{L-1}(1-(1-P_{\gamma_{s,k}}(\gamma_T))(1-P_{\gamma_{k,d}}(\gamma_T)))P_{\gamma_{s,L}}(x), & x<\gamma_T, \end{cases} \tag{2}$$

Note that the statistics of the output SNR for the relay-destination link, Γ_2, can be obtained in a similar way by replacing the $P_{\gamma_{s,l}}(\cdot)$ and $P_{\gamma_{l,d}}(\cdot)$ with $P_{\gamma_{l,d}}(\cdot)$ and $P_{\gamma_{s,l}}(\cdot)$ in (2), respectively[2]. In addition, we obtain the PDF of Γ_1, $p_{\Gamma_1}(x)$ differentiating $p_{\Gamma_1}(x)$ in (2) with respect to x as

$$p_{\Gamma_1}(x)=\begin{cases} (1-P_{\gamma_{1,d}}(\gamma_T))p_{\gamma_{s,1}}(x)+\sum_{i=2}^{L-1}\prod_{j=1}^{i-1}(1-(1-R_{\gamma_{s,j}}(\gamma_T)) \\ \times(1-P_{\gamma_{j,d}}(\gamma_T)))(1-P_{\gamma_{i,d}}(\gamma_T))p_{\gamma_{s,i}}(x) \\ +\prod_{k=1}^{L-1}(1-(1-P_{\gamma_{s,k}}(\gamma T))(1-P_{\gamma_{k,d}}(\gamma_T)))p_{\gamma_{s,L}}(x), & x\geq\gamma_T, \\ +\prod_{k=1}^{L-1}(1-(1-P_{\gamma_{s,k}}(\gamma_T))(1-P_{\gamma_{k,d}}(\gamma_T)))p_{\gamma_{s,L}}(x), & x<\gamma_T, \end{cases} \tag{3}$$

where $p_{\gamma_{n,m}}(\cdot)$ denotes the individual PDF of the output SNR between a node n and node m. For the i.ni.d. Rayleigh fading channels, the CDF and PDF of Γ_1 for SERS in (2) and (3) can be represented by exponential distributions, respectively, as

[2] The PDF and MGF of Γ_2 are also obtained in a similar way by $P_{\gamma_{n,m}}(\cdot)$ and $p_{\gamma_{n,m}}(\cdot)$ with $P_{\gamma_{m,n}}(\cdot)$ and $p_{\gamma_{m,n}}(\cdot)$, respectively.

$$P_{\Gamma_1}(x)=\begin{cases}(e^{-\gamma_T/\overline{\gamma}_{s,1}}-e^{-x/\overline{\gamma}_{s,1}})\,e^{-\gamma_T/\overline{\gamma}_{1,d}} & \\ +\sum_{i=2}^{L-1}\prod_{j=1}^{i-1}(1-e^{-\gamma_T/\overline{\gamma}_{b_j}})(e^{-\gamma_T/\overline{\gamma}_{s,i}}-e^{-x/\overline{\gamma}_{s,i}})e^{-\gamma_T/\overline{\gamma}_{i,d}} & \\ +\prod_{k=1}^{L-1}(1-e^{-\gamma_T/\overline{\gamma}_{b_k}})(1-e^{-x/\overline{\gamma}_{s,r}}), & x\geq\gamma_T, \\ \prod_{k=1}^{L-1}(1-e^{-\gamma_T/\overline{\gamma}_{b_k}})(1-e^{-x/\overline{\gamma}_{s,r}}), & x<\gamma_T,\end{cases} \tag{4}$$

and

$$p_{\Gamma_1}(x)=\begin{cases}\frac{1}{\overline{\gamma}_{s,1}}e^{-\left(\frac{\gamma_\Gamma}{\overline{\gamma}_{1,d}}+\frac{x}{\overline{\gamma}_{s,1}}\right)}\sum_{i=2}^{L-1}\prod_{j=1}^{i-1}(1-e^{-\overline{\gamma}_T/\overline{\gamma}_{bj}})\frac{1}{\overline{\gamma}_{s,i}}e^{-\left(\frac{\gamma_T}{\overline{\gamma}_{i,d}}+\frac{x}{\overline{\gamma}_{s,i}}\right)} & \\ +\prod_{k=1}^{L-1}(1-e^{-\gamma_T/\overline{\gamma}_{b_k}})\frac{1}{\overline{\gamma}_{s,L}}e^{-x/\overline{\gamma}_{s,L}}, & x\geq\gamma_T, \\ \prod_{k=1}^{L-1}(1-e^{-\gamma_T/\overline{\gamma}_{b_k}})\frac{1}{\overline{\gamma}_{s,L}}e-^{x/\overline{\gamma}_{s,L}}, & x<\gamma_T,\end{cases} \tag{5}$$

where $\overline{\gamma}_{b_j}=\overline{\gamma}_{s,j}\overline{\gamma}_{j,d}/(\overline{\gamma}_{s,j}+\overline{\gamma}_{j,d})$.

4 Outage Performance of the Proposed SERS

4.1 End-to-End Outage Performance of SERS

In the end-to-end dual-hop communication where there is no direct transmission, we can define the end-to-end outage event as the case of when either one of dual links connected in series falls below the outage threshold. Thus, the outage probability can be obtained as [9]

$$P_{out}^{ETE}(\gamma_{th})=1-(1-P_{\Gamma_1}(\gamma_{th}))(1-P_{\Gamma_2}(\gamma_{th})), \tag{6}$$

where $P_{\Gamma_i}(\cdot)$ is defined in (2), and γ_{th} is a, outage threshold which can be rep-resented as $\gamma_{th}=2^{2R}-1$ for R bps/Hz transmission.

4.2 Outage Performance of SERS based on SDF Relaying

The SDF protocol for cooperative systems [8] was introduced as an efficient relaying protocol. In SDF, the relay node operates when only the channel between the source and the relay can support the transmitted data rate, R, without error. In other words, the relay may fully decode the entire source codeword without error by a Cyclic Redundancy Check (CRC) and successfully decoded signals are retransmitted to the destination node. When the relay cannot decode, only the direct transmission is performed without a relay node. Based on SDF protocol, we can consider two outage scenarios 1) the relay is not being able to decode, then the source is repeating its transmission, 2) the relay is ability to decode and repeat the source information. Thus, we can write the mutual information of the proposed SERS based on SDF as where

$$I_{\gamma_{tot}} = \begin{cases} \frac{1}{2}\log(1+2\gamma_{s,d}), & \gamma_{s,d} < \gamma_{th}, \\ \frac{1}{2}\log(1+2\gamma_{s,d}+\Gamma_2), & \gamma_{s,d} \geq \gamma_{th}. \end{cases} \tag{7}$$

Using the CDF of Γ_1 in (4) and γ_{tot} in (12), the outage probability of the proposed SERS over the i.ni.d. Rayleigh fading channels can be given as

$$P_{out}^{SDF}(\gamma_{th}) = P_{\Gamma 1}(\gamma_{th})P_{\gamma_{s,d}}(\gamma_{th}/2) + (1-P_{\Gamma_1}(\gamma_{th}))P_{\gamma_{tot}}(\gamma_{th}). \tag{8}$$

The closed-form expression of $P_{\gamma\, tot}(\gamma_{th})$ in (8) is given in Appendix A.

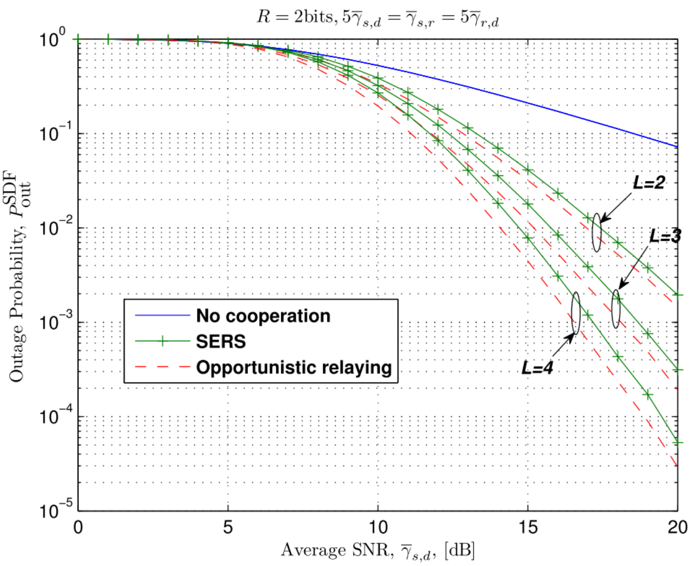

Fig. 1. Comparison of outage probability of the proposed SERS and the opportunistic relaying based on SDF protocol

5 Numerical Example

In Fig. 1, we apply our proposed SERS to SDF protocol. In this example, we set the outage threshold as 2 bps/Hz and use the optimal target threshold for our proposed SERS. Because our SERS does not maximize the total combined SNR at the destination, γ_{tot}, a little loss of outage performance is observed when comparing with the opportunistic relaying. However, the performance loss is only around 1 dB in most of SNR region of our interest whereas our proposed SERS requires a very low system complexity.

6 Conclusion

In this paper, we proposed a sub-optimal relay selection scheme, named SERS, in a dual-hop DF transmission to reduce the complexity and the power consumption at the relay nodes. Based on the derived statistics of the output SNR, we presented the outage performance of the proposed scheme. From our selected numerical examples, our proposed scheme can provide the commensurate performance gain with the optimal relay selection algorithm while it satisfies the required performance with lower complexity.

Appendix A. Statistics of Combined SNR at the Destination

Assuming the maximal ratio combining (MRC) at the destination node, the total combined SNR at the destination node can be written as

$$\gamma_{tot} = \gamma_{s,d} + \Gamma_2. \tag{9}$$

Since two random variables, $\gamma_{s,d}$ and Γ_2, are mutually independent, the PDF of γ_{tot} can be calculated as

$$p_{\gamma_{tot}} = \int_0^z p_{\gamma_{s,d}}(z-y)p_{\Gamma_2}(y)dy \tag{10}$$

By substituting (5) into (10) and doing some manipulations, the PDF of γ tot over the i.ni.d. Rayleigh fading channels can be given by

$$p_{\gamma_{tot}}(x) = \begin{cases} \frac{1}{\overline{\gamma}_{1,d} - \overline{\gamma}_{s,d}} e^{-\gamma_T/\overline{\gamma}_{b1}} (e^{-(x-\gamma_T)/\overline{\gamma}_{1,d}} - e^{-(x-\gamma_T)/\overline{\gamma}_{s,d}}) \\ + \sum_{i=2}^{L-1} \prod_{j=1}^{i-1} \frac{1}{\overline{\gamma}_{1,d} - \overline{\gamma}_{s,d}} e^{-\gamma_T/\overline{\gamma}_{bj}} (1 - e^{-\gamma_T/\overline{\gamma}_{bj}}) \\ \times (e^{-(x-\gamma_T)/\overline{\gamma}_{i,d}} - e^{-(x-\gamma_T)/\overline{\gamma}_{s,d}}) \\ + \prod_{k=1}^{L-1} (1 - e^{-\gamma_T/\overline{\gamma}_{bk}}) \frac{e^{-x/\overline{\gamma}_{s,d}} - e^{-x/\overline{\gamma}_{L,d}}}{\overline{\gamma}_{L,d} - \overline{\gamma}_{s,d}}, & x \geq \gamma_T, \\ \prod_{k=1}^{L-1} (1 - e^{-\gamma_T/\overline{\gamma}_{bk}}) \frac{e^{-x/\overline{\gamma}_{s,d}} - e^{-x/\overline{\gamma}_{L,d}}}{\overline{\gamma}_{L,d} - \overline{\gamma}_{s,d}}, & x < \gamma_T, \end{cases} \tag{11}$$

The CDF of γ_{tot} over the i.ni.d. Rayleigh fading channels can be obtained by integrating (11) with respect to x as follows

$$
P_{\gamma_{tot}}(x)=\begin{cases}
\dfrac{e^{-\gamma_T/\overline{\gamma}_{b_1}}}{\overline{\gamma}_{1,d}-\overline{\gamma}_{s,d}}\left(\overline{\gamma}_{1,d}(1-e^{-(x-\gamma_T)/\overline{\gamma}_{1,d}})-\overline{\gamma}_{s,d}(1-e^{-(x-\overline{\gamma}_T)/\overline{\gamma}_{s,d}})\right) \\
+\displaystyle\sum_{i=2}^{L-1}\prod_{j=1}^{i-1}\frac{1}{\overline{\gamma}_{1,d}-\overline{\gamma}_{s,d}}e^{-\gamma_T/\overline{\gamma}_{b_j}}(1-e^{-\gamma_T/\overline{\gamma}_{b_j}}) \\
\times\left(\overline{\gamma}_{i,d}(1-e^{-(x-\gamma_T)/\overline{\gamma}_{i,d}})-\overline{\gamma}_{s,d}(1-e^{-(x-\gamma_T)/\overline{\gamma}_{s,d}})\right) \\
+\displaystyle\prod_{k=1}^{L-1}(1-e^{-\gamma_T/\overline{\gamma}_{b_k}})\left(\frac{\overline{\gamma}_{L,d}(1-e^{-x/\overline{\gamma}_{L,d}})-\overline{\gamma}_{s,d}(1-e^{-x/\overline{\gamma}_{s,d}})}{\overline{\gamma}_{L,d}-\overline{\gamma}_{s,d}}\right), & x\ge\gamma_T, \\
\displaystyle\prod_{k=1}^{L-1}(1-e^{-\gamma_T/\overline{\gamma}_{b_k}})\left(\frac{\overline{\gamma}_{L,d}(1-e^{-x/\overline{\gamma}_{L,d}})-\overline{\gamma}_{s,d}(1-e^{-x/\overline{\gamma}_{s,d}})}{\overline{\gamma}_{L,d}-\overline{\gamma}_{s,d}}\right), & x<\gamma_T,
\end{cases} \tag{12}
$$

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