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PERFORMANCE ANALYSIS OF RELAY SELECTION SCHEMES WITH OUTDATED CSI

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ABSTRACT

This paper analyzes the effect of using outdated Channel State Information (CSI) for relay selection and signal amplification on the performance of Amplify and Forward (AF) relays in a Rayleigh fading environment,. Here two relay selection schemes are considered, namely single hop (Partial Relay Selection-PRS) and dual hop (Opportunistic Relay Selection -ORS). Relay selection typically assumes Perfect CSI; However Outdated CSI caused by time variation of channel or due to feedback delay cannot be ignored; hence relay selection depends on the correlation between the actual and the outdated channel, which deteriorates the system performance. The two reduced complexity Fixed Gain (FG) and Variable Gain (VG) AF relay selection systems are considered. For both these schemes the effects of the relay chosen and the correlation between the delayed and current channel information on the system performance such as outage probability, Bit Error Rate are analyzed. Simulation results imply that the performance of AF relay selection depends on the correlation between the actual and the outdated channel information. The analysis shows that when the correlation is low the single hop relay selection perform better than the dual hop relay selection, however as correlation increases the dual hop relay selection scheme shows a superior performance.

Keywords: relay selection, outdated channel state information, amplify and forward, signal amplification, rayleigh fading, outage probability.

1. INTRODUCTION

Cooperative communication [1] is an emerging technique that improves spatial diversity and coverage extension in wireless networks. A key component of cooperative communications is relaying in which a source takes help of user terminals in its coverage area to relay the source signal to the destination. There are three different relaying protocols namely (i) Decode and Forward Relay (ii) Compress and Forward relay (iii) Amplify and Forward relay. In Amplify-and-Forward (AF) protocols [3], [6], the form of the “overheard” signal does not require complex processing at the relays and only requires scaling and retransmission of the received signal, hence it is highly used protocol because of its simplicity and high performance. The development of wireless communication necessitates the case of having multiple relays to increase the performance and diversity gain. However, a system with multiple relays increases complexity and the power requirement and hence the overall implementation cost increases.

The inefficient utilization of the channel resources can be mitigated by relay selection. Previous relay selection schemes select a subset of relays[4], this leads to the inefficient utilization of channel resources, hence relay selection schemes which selects only a single best relay for retransmission of signal to the destination is implemented. The single relay selection schemes include (i) Single hop (Partial relay selection) (ii) Dual hop (Opportunistic relay selection). In this scheme a single best relay is selected, hence only two orthogonal channels (regardless of the number of relays) are required.

Relay node is selected based on instantaneous and partial knowledge of the channel [5]. Here the channel state information is assumed to be perfect and no feedback delay is considered. In ORS, a single relay based on the instantaneous global (two hop) CSI of the network is selected to assist the source (2). There have been several works in the literature dealing with the concept of relay selection (see, e.g., (6m1-26m1)) and the references therein). Most of these works deal with the case where perfect CSI is available for relay selection. The effect of outdated CSI on Opportunistic relay selection in Decode and Forward relay has been investigated [7]. The effect of various fading environment over relay selection schemes has been analyzed in the literature[9-11].The performance of the opportunistic relay selection scheme in dual-hop transmissions has been analyzed in the literature [12-13]. The outage probability is analyzed in [12], and the error performance of opportunistic relay selection with variable gain (VG) (also known as channel state information (CSI)-assisted) AF relaying under Rayleigh and Rician fading is analyzed in [9] and [10-11]. In [8], a new reduced complexity partial relay selection scheme using VG AF relays was introduced. Although the performance of this scheme is inferior to that of the opportunistic relay selection scheme, this simpler approach finds wide applicability especially in low complexity ad-hoc and sensor networks because such network nodes may not have resources to implement complex relay selection protocols. Among the works that have covered partial relay selection, in [8], the performance of VG AF relaying has been analyzed.

So far only few papers have investigated the impact of outdated CSI on the performance of single hop and dual hop relay selection. In a time varying communication systems outdated CSI is used for relay selection and signal amplification [14-22] due to feedback delay or scheduling delay..

In this paper we study the performance of the FG and VG Amplify and Forward relay selection systems in the presence of outdated Channel information due to feedback delay. The Fixed Gain AF relays using PRS retransmit the signal using a constant amplification factor; hence the current channel estimation is not required at the relay. The Variable Gain AF protocol using PRS considers the effect of outdated channel information for both relay selection and signal amplification. Next the two Variable Gain AF protocol based on ORS systems, where selection is based on the bottleneck SNR (i.e., minimum of 'source-relay', 'relay-destination' link SNRs) of the path are also analyzed. The VG AF protocol that uses outdated CSI for both relay selection and signal amplification, and the VG AF protocol presented in [20] are considered. In all four cases of study, we analyze the system performance in terms of its outage probability and BER.

The rest of the paper is organized as follows. In section II the system model of both relay selection schemes are introduced and the statistical expression for the outage probability and BER for all the case is discussed. The performance results for the system under consideration and related discussion are given in Section III. Finally Section IV concludes the paper.

2. THE STATISTICAL ANALYSIS

a) System model

Consider a cooperative relaying setup where dual hop Amplify and Forward relay system with a single source S, single destination D and L relays are present as depicted in Fig.1, in addition no direct link between S-D link is assumed due to the effect of high shadowing between them; so S can communicate with D only through the relay terminals. The fading in all S-R_i and R_i-D paths is assumed to be independent and identically distributed according to the Rayleigh distribution i.e., the channel gains are complex Gaussian random variables with zero mean and unit variance. All the nodes are half duplex and thus cannot receive and transmit simultaneously.

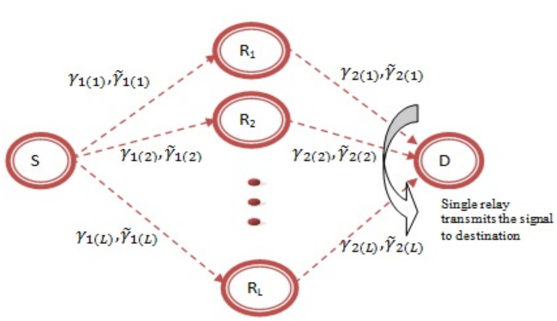

Figure-1. System model.

b) Single hop relay selection

In single hop relay selection the source continuously monitors the quality of its connectivity with all the relays through the transmission of local feedback. With this partial information of S-R or R-D channel the relay selection follows the best link between source and relay or the relay to destination. We assume that this feedback link has a time delay of T_d. Based on the outdated CSI; S selects a single relay, with the K^{th} worst S-R_i link. After that the communication takes place in two timeslots. During the first timeslot, S transmits its signal with an average power normalized to unity to the selected relay. In the second time slot, the relay amplifies the received signal and the output is transmitted to D. However in some cases the data transmission between S and D may not be scheduled immediately after the relay selection. Denoting the outdated channel between S-R_i as, the relationship between the outdated channel and the present channel is given by

$$h_{SR_k} = \mathbb{C}_1 g_{SR_k} + \sqrt{1-\mathbb{C}_1^2}\, w_{SR_k} \quad (1)$$

$$h_{R_kD} = \mathbb{C}_2 g_{R_kD} + \sqrt{1-\mathbb{C}_2^2}\, w_{R_kD} \quad (2)$$

Where, h_{SR_k} and h_{R_kD} is the channel between source to relay and relay to destination at the current time instant, $\mathbb{C}$ denotes the correlation coefficient between outdated and the current channel , and $w_{SR_k} and\ w_{R_kD}$ are complex Gaussian RV having the same variance as RV of $h_{SR_k} and h_{R_kD}$ respectively.

Let P_S denotes the transmission power at S, x is the modulated signal and n_{R_k} is the AWGN noise which satisfies $E\left(|n_{R_k}|^2\right) = \sigma_R^2$. Then the received signal at the relay is given by

$$y_{R_k} = \sqrt{P_s}\, h_{SR_k} x + n_{R_k} \quad (3)$$

The relay then multiplies the received signal with gain G and the output is transmitted to D. The received signal at D is given by

$$y_D = h_{R_kD} G y_{R_k} + n_D \quad (4)$$

Where n_D is the AWGN, which satisfies $E(|n_D|^2) = \sigma_D^2$.

Let $\tilde{\gamma}_{1(k)} = |h_{SR_k}|^2 \varphi_1\ and\ \tilde{\gamma}_{2(k)} = |h_{R_kD}|^2 \varphi_2$,

Where $\varphi_1 = \frac{P_s}{\sigma_R^2}, \varphi_2 = \frac{P_r}{\sigma_D^2}$ and P_r is the transmit power of relay. Consider $\gamma_{1(k)} = |g_{SR_k}|^2 \varphi_1, \gamma_{2(k)} = |g_{R_kD}|^2 \varphi_2$; $\tilde{\gamma}_{1(k)}\ and\ \tilde{\gamma}_{2(k)}$ are the delayed version of $\gamma_{1(k)}\ and\ \gamma_{2(k)}$. Thus the selection of the best relay is not based on the current channel; hence the channel with maximum $\gamma_{1(k)}$ is selected for the communication, if $\gamma_{1(1)} \leq \gamma_{1(2)} \leq \dots \leq \gamma_{1(L)}$ is the order obtained by arranging in increasing order of magnitude then the relay selected is given by [5]

$$k = arg\ max_k(\gamma_{1(k)}) \quad (5)$$

B.1 Fixed fain relaying

The FG AF protocol must consider the scheduling delay. Thus CSI used for relay selection differs substantially from actual CSI in both VG and FG AF relaying. The amplification factor in FG AF is chosen as

$$G = \sqrt{\frac{P_r}{P_s E\left(|h_{SR_k}|^2\right)+\sigma_R^2}} \quad (6)$$

The end to end SNR for this fixed gain relaying is given by

$$\gamma_{eq1} = \frac{\gamma_{1(k)}\gamma_{2(k)}}{C+\gamma_{2(k)}} \quad (7)$$

Where $C = \frac{P_r}{G^2\sigma_R^2}$. For the statistical analysis of single hop relay selection, the PDF of $\gamma_{1(k)}$ is to be determined and is given by

$$f_{\gamma_{1(k)}}(x) = k\binom{L}{k}\sum_{m=0}^{k-1}\frac{(-1)^m}{\varphi_1}\binom{k-1}{m} * \frac{1}{(L-k+m)(1-C)+1}e^{-\frac{(L-k+m+1)x}{((L-k+m)(1-C)+1)\varphi_1}} \quad (8)$$

Outage probability

The outage probability is the important quality of service (QOS) measure and is defined as the probability that a target data rate cannot be supported by the system, i.e., the overall end to end SNR is lower than the threshold value γ_T. The outage probability of the FG AF relaying protocol is given by $F_{\gamma_{eq1}}(\gamma_T) = Pr(\gamma_{eq1} < \gamma_T)$

$$F_{\gamma_{eq1}}(\gamma_T) = 1 - 2k\binom{L}{k}\sum_{m=0}^{k-1}\frac{(-1)^m\binom{k-1}{m}}{((L-k+m)(1-C)+1)} * e^{-\frac{(L-k+m+1)\gamma_T}{((L-k+m)(1-C)+1)\varphi_1}}\sqrt{\frac{((L-k+m)(1-C)+1)C\gamma_T}{(L-k+m+1)\varphi_1\varphi_2}} * K_1\left(2\sqrt{\frac{(L-k+m+1)C\gamma_T}{((L-k+m)(1-C)+1)\varphi_1\varphi_2}}\right) \quad (9)$$

Where $K_i(v)$ denotes the i^{th} order modified Bessel function of second kind. The above equation gives the exact outage probability for all SNR values but influence of network parameters such as L, C SNR imbalance on the systems outage performance equation is not explicit in that equation. To obtain useful insights about the diversity order and coding gain high SNR approximation is used.

The outage probability with large φ_1 and φ_2 (high SNR approximation) with ratio $\mu = \frac{\varphi_2}{\varphi_1}$ is given by

$$F_{\gamma_{eq1}}(\gamma_T) \approx \frac{\gamma_T}{\varphi_1}\sum_{m=0}^{k-1}\frac{(-1)^m k\binom{L}{k}\binom{k-1}{m}}{(L-k+m)(1-C)+1} * \left(\frac{\Lambda}{\mu}ln\left(\frac{((L-k+m)(1-C)+1)\varphi_1}{(L-k+m+1)}\right)+\Omega\right) \quad (10)$$

With $\Omega = e^{-\Lambda} + \Lambda(1-\gamma+Ei(-\Lambda)-\ln(\Lambda))$

$\Lambda = k\binom{L}{k}\sum_{m=0}^{k-1}(-1)^m\binom{k-1}{m}\frac{((L-k+m)(1-C)+1)}{(L-k+m+1)^2}$,

$\gamma = 0.57721$ is the Euler-Mascheroni constant and Ei(x) denotes the exponential integral function. The first order approximation for the special case of correlation with $C = 0,1$ is given by

$$F_{\gamma_{eq1}}(\gamma T) \approx \begin{cases} \frac{\gamma T}{\varphi_1}\left(\frac{\Lambda}{\mu}ln(\varphi_1)+1.01004771..\right) & C = 0 \\ \sum_{m=0}^{k-1}\frac{k\binom{L}{k}\gamma T(-1)^m\binom{k-1}{m}ln\left(\frac{\varphi_1}{L-k+m+1}\right)}{\varphi_1} & C = 1 \end{cases} \quad (11)$$

Average bit error rate

With the expression for system outage probability in low to high SNR regime, the general bit error rate is given by

$$P_b = \alpha\, E\left[Q\left(\sqrt{\beta\gamma_{eq1}}\right)\right] = \frac{\alpha}{\sqrt{2\pi}}\int_0^\infty F_{\gamma_{eq1}}\left(\frac{t^2}{\beta}\right)e^{-\frac{t^2}{2}}dt \quad (12)$$

Where $\alpha, \beta > 0$, are constants depending on the modulation schemes, here $\alpha = \beta = 1$ (QPSK modulation) is considered. On substituting the value of $F_{\gamma_{eq1}}$ in Equation (12) the BER for FG AF protocol is given as follows,

$$P_b = \frac{\alpha}{2} - \frac{\alpha\sqrt{\beta\varphi_1}kC}{2\varphi_2}\sum_{m=0}^{k-1}\frac{\binom{L}{k}(-1)^m\binom{k-1}{m}}{((L-k+m)(1-C)+1)} * \frac{e^{\zeta_3}(K_1(\zeta_3)-K_0(\zeta_3))}{\left(\frac{(L-k+m+1)}{((L-k+m)(1-C)+1)}+\beta\varphi_1\right)^{\frac{3}{2}}} \quad (13)$$

Where

$$\zeta_3 = \frac{C(L-k+m+1)}{\varphi_2(2(L-k+m+1)+\beta\varphi_1((L-k+m)(1-C)+1))} \quad (14)$$

B.2 Variable gain relaying

In variable gain single hop relay selection systems, each relay makes one channel measurement from S-R, based on which the relay is selected at the source and

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the selected relay uses the outdated channel information for computing the amplification factor. The VG AF protocol amplification factor is given by

$$G = \sqrt{\frac{P_r}{P_s\left|g_{SR_{\hat{k}}}\right|^2 + \sigma_R^2}} \tag{15}$$

This VG scheme has a reduced implementation compared to other VG scheme where both estimation of $h_{SR_{\hat{k}}}$ and $g_{SR_{\hat{k}}}$ are needed. From (16) and (4) the end to end SNR for Variable Gain can be given by

$$\gamma_{eq2} = \frac{\gamma_{1(k)}\hat{\gamma}_{2(k)}}{\gamma_{1(k)} + \hat{\gamma}_{2(k)} + 1} \tag{16}$$

Outage probability

The outage probability of the VG AF relaying protocol is given as

$$F_{\gamma_{eq2}}(\gamma_T) = Pr(\gamma_{eq2} < \gamma_T) \tag{17}$$

$$F_{\gamma_{eq2}}(\gamma_T) \geq 1 - \sum_{p=0}^{\infty}\sum_{m=0}^{k-1}\sum_{n=0}^{p} \frac{\binom{L}{k}(-1)^m\binom{k-1}{m}\binom{p}{n}k\mathbb{C}^p}{(1-\mathbb{C})^{p-n-1}\varphi_1^{p-n}\varphi_2^{n+1}p!} * \frac{\gamma_T^{p+1}(p+n+1)!}{((L-k+m)(1-\mathbb{C})+1)^{p+n+2}} e^{-\frac{\gamma_T}{\varphi_1(1-\mathbb{C})}}$$
$$* \, \mathcal{U}\left(p+n+2, n+2; \frac{\gamma_T}{\varphi_{2((L-k+m)(1-\mathbb{C})+1)}}\right) \tag{18}$$

Where $\mathcal{U}(a, b; z)$ is the confluent hyper geometric function of second kind. High SNR approximations are given as follows

$$F_{\gamma_{eq2}}(\gamma_T) \approx k\binom{L}{k}\sum_{m=0}^{k-1}(-1)^m\binom{k-1}{m}\left(\frac{p_1+p_2}{L-k+m+1} + \frac{ln(\varphi_1/p_1)}{\mu\omega^2(1-\mathbb{C})}\right)\left(\frac{\gamma_T}{\varphi_1}\right) \tag{19}$$

Where $\omega = \frac{((L-k+m)(1-\mathbb{C})+1)}{(1-\mathbb{C})}$,

$p_1 = \frac{L-k+m+1}{((L-k+m)(1-\mathbb{C})+1)}$ and

$p_2 = \frac{\mathbb{C}}{\mu((L-k+m)(1-\mathbb{C})+1)^2}$

Average bit error rate

Using (12) the average BER for the VG AF protocol is given as follows,

$$P_b \geq \frac{\alpha}{2} - \frac{\alpha k}{\sqrt{8\pi}}\sum_{p=0}^{\infty}\sum_{m=0}^{k-1}\sum_{n=0}^{p}\frac{\binom{L}{k}(-1)^m\binom{k-1}{m}\binom{p}{n}}{(1-\mathbb{C})^{p-n-1}\varphi_1^{p-n}\varphi_2^{\frac{n}{2}}p!} * \frac{(p+n+1)!\rho^p\beta^{\frac{n}{2}-p}\Gamma\left(p-n+\frac{1}{2}\right)\zeta_2^{\frac{n}{2}+1}}{((L-k+m)(1-\mathbb{C})+1)^{p+1+\frac{n}{2}}\left(\zeta_1+\frac{\zeta_2}{2}\right)^{p+\frac{3}{2}}}$$
$$* \frac{\Gamma\left(p+\frac{3}{2}\right)}{\Gamma\left(2p+\frac{5}{2}\right)} {}_2F_1\left(p+\frac{3}{2}, p+n+2, 2p+\frac{5}{2}; \frac{\zeta_1-\frac{\zeta_2}{2}}{\zeta_1+\frac{\zeta_2}{2}}\right) \tag{20}$$

Where $\zeta_1 = \frac{1}{\beta\varphi_1(1-\mathbb{C})} - \frac{1}{2\varphi_2((L-k+m)(1-\mathbb{C})+1)\beta} + \frac{1}{2}$

$\zeta_2 = \frac{1}{\beta\varphi_2((L-k+m)(1-\mathbb{C})+1)}$

Following the similar approach in FG AF the average BER for VG AF relaying at high SNR regime can be obtained as below,

$$P_b^{\infty} \approx \frac{\alpha k\binom{L}{k}}{2\beta\varphi_1}\sum_{m=0}^{k-1}(-1)^m\binom{k-1}{m} * \left(\frac{p_1+p_2}{L-k+m+1} + \frac{ln(\varphi_1/p_1)}{\mu\omega^2(1-\mathbb{C})}\right) \tag{21}$$

Dual hop relay selection

The dual hop relay selection method or (Opportunistic Relay selection) refers to the case where the decision on the selected relay is determined by both S-R and R-D links. At the first phase of transmission the signal from source is sent to all relays and in the second phase of transmission a single relay with highest value of

$$\hat{\gamma}_i = min(\gamma_{1(i)}, \gamma_{2(i)}) \tag{22}$$

is selected for retransmitting the source signal.

C.1 Variable gain I

In this scheme it is assumed that relay is selected and amplification factor is found using the outdated channel state information, but the channel states may have changed at the time of actual communication. Though the selection of relay is made using $\hat{\gamma}_{1(i)}, \hat{\gamma}_{2(i)}$, the actual SNR at the time of communication is $\gamma_{1(i)}, \gamma_{2(i)}$. The amplification factor in this scheme is given by (15) and the end to end SNR is given by (16).

Outage probability

The outage probability for this VG I scheme is given by

$$F_{\gamma_{eq3}}(\gamma_T) \approx 1 - Pr\left(\frac{\gamma_{1(k)}\gamma_{2(k)}}{\gamma_{1(k)}+\gamma_{2(k)}} > \gamma_T\right) \tag{23}$$

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$$F_{\gamma_{eq2}}(\gamma_T) \approx 1 - \frac{k^2\binom{L}{k}^2}{(1-\mathcal{C}_1)\varphi_1^2}\sum_{m=0}^{k-1} p_m \sum_{n=0}^{k-1} p'_n \sum_{i=1}^{2} q_{m,i} * \sum_{j=1}^{2} q'_{n,j}\int_0^\infty \frac{e^{-\frac{x+\gamma T}{(1-\mathcal{C}_1)\varphi_1}}\left(1-\frac{\mathcal{C}_1}{(1-\mathcal{C}_1)\left(r'_{n,j}+\frac{r_{m,i}\gamma T}{x}\right)}\right)}{\left(r'_{n,j}+\frac{r_{m,i}\gamma T}{x}\right)}dx \quad (24)$$

on approximating the above expression for high values of SNR, the first order approximation for this scheme is given by,

$$F_{\gamma_{eq2}}(\gamma_T) \approx 1 - k^2\binom{L}{k}^2 \sum_{m=0}^{k-1} p_m \sum_{n=0}^{k-1} p'_n \sum_{i=1}^{2} q_{m,i} * \sum_{j=1}^{2} q'_{n,j} e^{-\frac{\gamma T}{(1-\mathcal{C}_1)\varphi_1}\left(\frac{\mathcal{C}_1(r_{m,i}-r'_{n,j})}{(1-\mathcal{C}_1){r'_{n,j}}^2}+1\right)} * \left(\frac{1}{r'_{n,j}\left(1-\frac{\mathcal{C}_1}{(1-\mathcal{C}_1)r'_{n,j}}\right)} + \frac{\gamma_T r_{m,i}}{(1-\mathcal{C}_1)\varphi_1 {r'_{n,j}}^2} * ln\left(\frac{1}{(1-\mathcal{C}_1)\varphi_1} - \frac{\mathcal{C}_1}{(1-\mathcal{C}_1)^2\varphi_1 r'_{n,j}}\right)\right) \quad (25)$$

Where

$$p_m = \frac{(-1)^m\binom{k-1}{m}}{\left(1+\frac{\varphi_1}{\varphi}(L-k+m)\right)},$$

$$q_{m,i} = \begin{cases} 1 & i = 1 \\ \frac{(L-k+m)\varphi_1}{(L-k+m+1)\varphi_2} & i = 2 \end{cases}$$

$$r_{m,i} = \begin{cases} \frac{\varphi_1}{\varphi_2} & i = 1 \\ \frac{(L-k+m+1)\varphi_1}{\mathcal{C}_2\varphi+(1-\mathcal{C}_2)(L-k+m+1)\varphi_2} & i = 2 \end{cases}$$

$$p'_n = \frac{(-1)^n\binom{k-1}{n}}{\left(1+\frac{\varphi_2}{\varphi}(L-k+n)\right)}$$

$$q'_{n,j} = \begin{cases} 1 & j = 1 \\ \frac{\varphi_2(L-k+n)}{\varphi} & j = 2 \end{cases}$$

$$r'_{n,j} = \begin{cases} \frac{1}{(1-\mathcal{C}_1)} & j = 1 \\ \left(\frac{(L-k+m+1)\varphi_1}{\varphi} + \frac{\mathcal{C}_1}{(1-\mathcal{C}_1)}\right) & j = 2 \end{cases}$$

Average bit error rate

The average BER can be obtained by substituting (25) in to (12) and after the simplifications the BER can be expressed as

$$P_b \approx \frac{\propto}{2} - \frac{\propto k^2}{2}\binom{L}{k}^2 \sum_{m=0}^{k-1} p_m \sum_{n=0}^{k-1} p'_n \sum_{i=1}^{2} q_{m,i} \sum_{j=1}^{2} q'_{n,j}$$

$$\sqrt{\frac{\beta}{\beta+\frac{2}{(1-\mathcal{C}_1)\varphi_1}\left(\frac{\mathcal{C}_1(r_{m,i}-r'_{n,j})}{(1-\mathcal{C}_1){r'_{n,j}}^2}+1\right)}} * \left(\frac{(1-\mathcal{C}_1)}{r'_{n,j}(1-\mathcal{C}_1)-\mathcal{C}_1} - \frac{r_{m,i}\, ln\left(\frac{1}{(1-\mathcal{C}_1)\varphi_1} - \frac{\mathcal{C}_1}{(1-\mathcal{C}_1)^2\varphi_1 r'_{n,j}}\right)}{{r'_{n,j}}^2\beta(1-\mathcal{C}_1)\varphi_1 + 2\left(\frac{\mathcal{C}_1(r_{m,i}-r'_{n,j})}{(1-\mathcal{C}_1)}+{r'_{n,j}}^2\right)}\right) \quad (26)$$

C.2 Variable gain relaying II

In VG I scheme it is assumed that the relay selection at S is performed using the outdated channel state information due to feedback delay from the relays. In Variable Gain II relaying scheme it is assumed that the selected relay has the present CSI of S-R link through channel estimation, and will select the gain factor accordingly. This assumption leads to the analysis of having perfect CSI at the relays for calculating the gain factor. The Gain factor in VG II system is given by

$$G = \sqrt{\frac{P_r}{P_s|h_{SR_k}|^2+\sigma_R^2}} \quad (27)$$

and the end to end SNR is given by

$$\gamma_{eq4} = \frac{\gamma_{1(k)}\gamma_{2(k)}}{\gamma_{1(k)}+\gamma_{2(k)}+1}.$$

Outage probability

The outage probability of VG II system is given by,

$$F_{\gamma_{eq4}}(\gamma_T) = Pr(\gamma_{eq4} < \gamma_T)$$

$$= 1 - \frac{2k^2}{\varphi_1}\binom{L}{k}^2 \sum_{m=0}^{k-1} p_m \sum_{n=0}^{k-1} p_{1n} \sum_{i=1}^{2} q_{m,i} \sum_{j=1}^{2} q_{n,1j} * e^{-(r_{m,i}+r_{n,1j})\frac{\gamma_T}{\varphi_1}}\sqrt{\frac{r_{m,i}(\gamma_T+{\gamma_T}^2)}{r_{n,1j}}} * K_1\left(\frac{2}{\varphi_1}\sqrt{r_{m,i}r_{n,1j}(\gamma_T+{\gamma_T}^2)}\right) \quad (28)$$

Simple high SNR approximation is expressed as

$$F_{\gamma_{eq4}}(\gamma_T) \approx \frac{\gamma_T k^2}{\varphi_1}\binom{L}{k}^2 \sum_{m=0}^{k-1} p_m \sum_{n=0}^{k-1} p_{1n} \sum_{i=1}^{2} q_{m,i}$$

$$\sum_{j=1}^{2} q_{n,1j}\left(1+\frac{r_{m,i}}{r_{n,1j}}\right) \quad (29)$$

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Where $p_{1m} = \frac{(-1)^m \binom{k-1}{m}}{\left(1+\frac{\varphi_2}{\bar{\varphi}}(L-k+m)\right)}$,

$$q_{n1j} = \begin{cases} 1 & j = 1 \\ \dfrac{(L-k+n)\varphi_2}{\mathbb{C}_1\bar{\varphi} + (1-\mathbb{C}_1)(L-k+n+1)\varphi_1} & j = 2 \end{cases}$$

$$r_{n1j} = \begin{cases} 1 & j = 1 \\ \dfrac{(L-k+n+1)\varphi_1}{\mathbb{C}_1\bar{\varphi} + (1-\mathbb{C}_1)(L-k+n+1)\varphi_1} & j = 2 \end{cases}$$

Average bit error rate

The average BER for this case is given by

$$P_b \approx \frac{\alpha k^2}{2\beta\varphi_1}\binom{L}{k}^2 \sum_{m=0}^{k-1} p_m \sum_{n=0}^{k-1} p_{1n} \sum_{t=1}^{2} q_{mt} \sum_{j=1}^{2} q_{n1j}\left(1+\frac{r_{mt}}{r_{n1j}}\right) \quad (30)$$

3. SIMULATION RESULTS

a) Single hop relay selection

In this section the performance of FG and VG system discussed in section II under single hop relay selection is analyzed. The number of relays throughout the analysis is fixed with L=5. The VG AF and FG AF relaying discussed under single hop system is labeled as FG PRS and VG PRS respectively.

Figure-2 shows the outage performance analysis of FG and VG relaying schemes against φ_1 (in dB) with (μ=1, $\mathbb{C}$=0.8). The performance of both best relay (k=5) and worst relay (k=1) selection schemes are analyzed. The analysis shows that for the best relay the VG PRS relaying schemes performs better than the FG PRS scheme. But in the case of worst relay selection the VG PRS schemes performs better than FG PRS at low SNR but at high SNR the VG PRS scheme becomes worse.

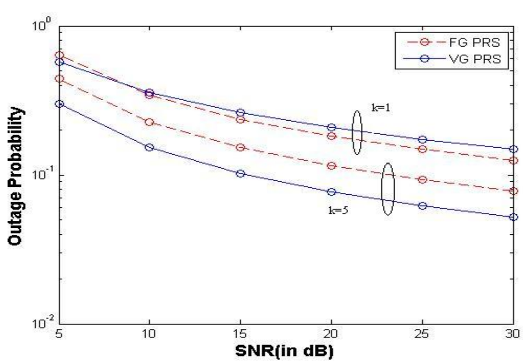

Figure-2. Outage probability vs. SNR (φ_1) for single hop relay selection.

Figure-3 shows the effect of correlation between the actual and delayed channel on the outage probability. For the best relay selection the increase in the value of correlation ($\mathbb{C}$) improves the performance for all the system. The VG PRS system outperforms FG PRS system when the two channels are well correlated i.e., for higher values of $\mathbb{C}$. In worst relay selection the FG PRS system performs better at lower values of $\mathbb{C}$. The performance of FG PRS system degrades as $\mathbb{C}$ increases in contrast to that the performance of VG PRS system increases at high level of $\mathbb{C}$, this is because of incorrectly selecting the amplification factor for the selected relay. The gap between the best and worst relay selection system vanishes as $\mathbb{C} = 0$.

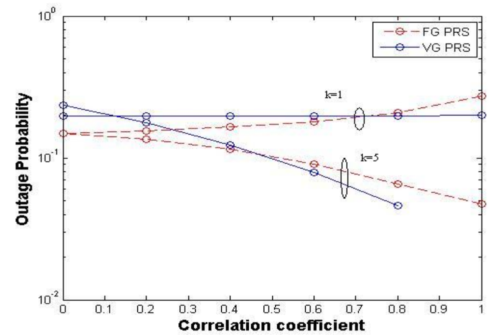

Figure-3. Outage probability vs. correlation coefficient ($\mathbb{C}$) for single hop relay selection.

Figure-4 presents the error rate performance of the two systems with QPSK modulation. The performance is measured for low correlated channels with $\mathbb{C}$=0.1 and for highly correlated channels with $\mathbb{C}$=0.8. The performance results shows that for high value of correlation between the outdated and the actual channel the VG PRS scheme performs better than FG PRS scheme. If the correlation is low the FG PRS system performs better at high SNR. Hence FG PRS scheme is better when the actual and outdated link is less correlated but when the correlation is high the VG PRS systems performs better.

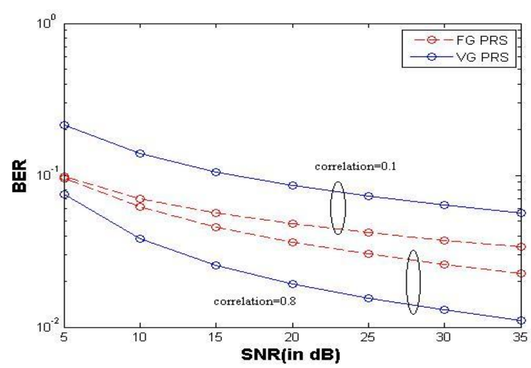

Figure-4. Average BER vs. SNR (φ_1) for single hop relay selection.

b) Dual hop relay selection

In this section the performance of VG I and VG II system discussed in section II under dual hop relay selection is analyzed. The number of relays is throughout the analysis is fixed constant with L=5. The VG I and VG II relaying discussed under dual hop system is labeled as VGI and VGII respectively.

Figure-5 shows the outage performance analysis of VG I and VG II relaying schemes against φ_1(in dB) where (μ=1, $\mathbb{C}_1 = 0.8, \mathbb{C}_2 = 0.7$). The performance of both best relay (k=5) and worst relay (k=1) selection schemes are analyzed. The analysis shows that the relay with perfect channel state information i.e., where the instantaneous CSI is available (VG II) relaying schemes performs better in all the cases. But in the case of worst relay selection the VG I schemes performs better than VG II at low SNR.

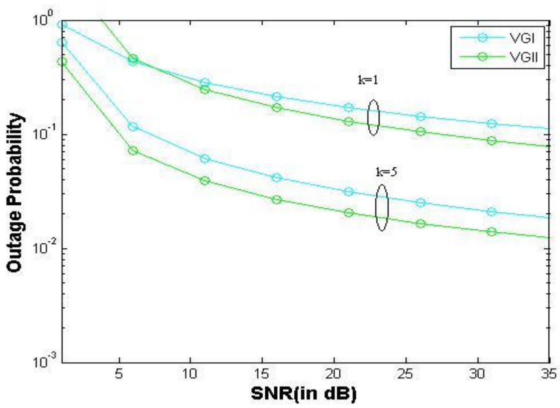

Figure-5. Outage probability vs. SNR ($\varphi_1 = \varphi_2$) for dual hop relay selection.

Figure-6 shows the dependency of the outage performance of the two systems with the correlation between the actual and outdated channel for both the best and worst relay selection. The performance of both systems increases as the value of $\mathbb{C}_1$ *and* $\mathbb{C}_2$ increases for best relay selection scheme.

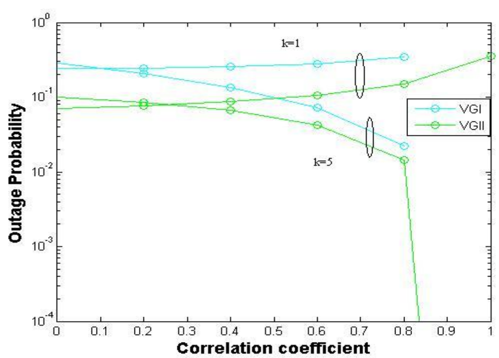

Figure-6. Outage probability vs. correlation coefficient ($\mathbb{C}_1 = \mathbb{C}_2$) for dual hop relay selection.

The performance of VG II system degrades as $\mathbb{C}$ increases in contrast to that the performance of VG I system increases as $\mathbb{C}$ increase, this is because of incorrectly selecting the amplification factor for the selected relay. The gap between the best and worst relay selection system vanishes as $\mathbb{C} = 0$.

Figure-7 presents the error rate performance of the two systems with QPSK modulation for which ($\alpha = \beta = 1$). The performance is measured for low correlated channels with $\mathbb{C}_1 = 0.1, \mathbb{C}_2 = 0.2$ and for highly correlated channels with $\mathbb{C}_1 = 0.8, \mathbb{C}_2 = 0.7$. The best relay selection scheme is alone considered with $\varphi_1 = \varphi_2$. The performance results shows that the average BER for VG I system is high in both cases, and the performance gap between the two system is decreased for highly correlated channel. The outdated CSI also affects the diversity gain, with perfect CSI the diversity gain is equal to the number of relays. However with outdated CSI the diversity gain is independent of the number of relays.

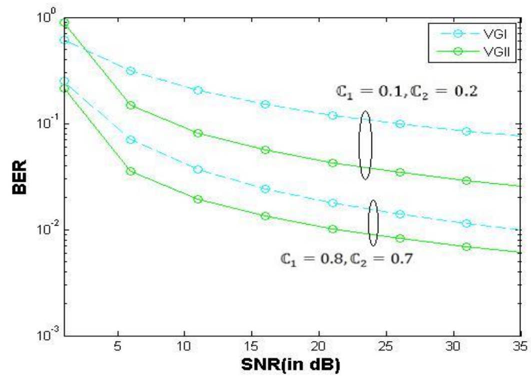

Figure-7. Average BER vs. SNR($\varphi_1 = \varphi_2$) for dual hop relay selection.

Comparing the variation of outage performance of PRS and ORS scheme due to change in $\mathbb{C}$ shows that ORS scheme shows higher variation with changing $\mathbb{C}$ than the PRS scheme. The FG PRS system outperforms VG I in ORS scheme, but it is worse than the VG II system in which the instantaneous CSI is assumed to be available.

4. CONCLUSIONS

The impact of outdated CSI due to feedback delay and scheduling delay on single hop and dual hop relay selection with Fixed gain & Variable gain Amplify and Forward relays was analyzed. In the variable gain AF relaying scheme the outdated CSI is used for both relay selection and signal amplification. By using simulation results for all the cases it was observed that the performance of FG PRS scheme is better when correlation between the current and the delay channel is low however the VG PRS scheme outperforms at high value of correlation i.e. when the best relay is selected the FG PRS scheme performs better than the VG PRS scheme at low

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correlation values however this case reverses as correlation is increased. In the case of ORS scheme the VG II scheme outperforms in high as well as low value of correlation because of the presence of actual CSI for computing the gain factor. The analysis shows that when the correlation is low the single hop relay selection perform better than the dual hop relay selection, however as correlation increases the dual hop relay selection scheme shows a superior performance.

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