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Performance Analysis of Wireless Cooperative Networks with Iterative Incremental Relay Selection

S. Poursajadi* and M. H. Madani

Electrical and Electronic Engineering University Complex (EEEUC), Malek-Ashtar University of Technology (MUT), Tehran , Iran

ABSTRACT: In this paper, an iterative incremental relay selection (IIRS) scheme is considered for wireless cooperative networks in order to increase the reliability of transmission. Different from the conventional incremental relay selection which incrementally selects the best relay for only one iteration; the IIRS scheme iteratively applies the incremental relaying and relay selection processes. To evaluate the performance of the proposed scheme, outage probability and average capacity of the system are investigated through analysis and simulation. This scheme provides $(I+1)$ diversity order in a system of I relays as the highest diversity order which can be provided by all participate (AP) cooperative scheme. Also, it is shown that the IIRS scheme combats with the spectral efficiency loss resulted from applying all of the relays. As the cost of the improvement, it is seen that the average required feedback bits to implement the IIRS scheme leads to $I\times log_2(I+1)$ bits of low signal to noise ratio (SNR), while it leads to $log_2(I+1)$ bits at higher SNRs which is acceptable for implementation. Considering the provided improvement along with the limited feedback reveals that the IIRS scheme can be applied as an efficient scheme compared to the other common cooperative schemes. Finally, numerical results indicate the validity of the analysis, especially at high SNRs.

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1- Introduction

Cooperative relaying has been shown to be an effective technique to improve the performance of wireless networks by allowing users to cooperate with each other in their transmissions [1-3]. Due to the broadcast nature of wireless transmissions, cooperative communications enable neighboring network nodes to share resources and cooperate to send information to an intended node. In fact, a cooperative technique by providing virtual antenna array and diversity increases the signal to noise ratio (SNR) at the destination node. Various cooperative relaying protocols, such as decode-and-forward (DF) relaying protocol and amplify-and-forward (AF) relaying protocol were proposed for wireless networks and substantial performance gains of such relaying protocols have been demonstrated compared to conventional non-cooperative transmission approach [4-6]. The diversity order in a cooperative network can be increased by increasing the number of relays, whereas the spectral efficiency is decreased due to applying orthogonal channel. To combat the loss of spectral efficiency, some selection-based cooperation structures were proposed in which only one "best" node is chosen in order to relay [7-12]. In this strategy, a relay with maximum SNR at the destination is selected exploiting some feedback and knowing channel state information (CSI) at the destination, so that it provides maximum diversity, and rationally preserves spectral efficiency.

Another scheme to preserve the spectral efficiency in relay networks is incremental relaying [6] and [13-16]. In this scheme, at first, it is questioned whether the direct link between the source and destination nodes provides the desired reliability or not. Consequently, employing a relay is rejected if the answer is positive; otherwise, a relay is applied in the cooperation. Moreover, the authors in literature [17-24] have studied a combination of the both selection and incremental schemes as the incremental relay selection (IRS) strategy in which it is decided about the cooperation of the best relay only for one iteration. In this case, the spectral efficiency and outage probability are improved significantly although more feedback is needed, compared to the incremental and selection schemes separately.

Here, we propose an iterative incremental selection scheme with the aim of improving the outage performance. In this scheme, at first, the source node sends its message to the destination and all of the relay nodes. Then, the best relay is selected and cooperated in the transmission if the reliability of the direct link is insufficient. Now, if the combination of the direct and relayed links achieves to the desired reliability, the source sends a new message. Otherwise, the best relay among the remaining relays is selected and participated in the cooperation. Clearly, this process is done iteratively until the desired quality is satisfied or reached to the end of relays. It is emphasized that each relay is participated in transmission once iteration only since we want to use the potentials of all relays such as power supply.

The remaining of this paper is organized as follows: the system model is described in the next section, then analytical overview of the common cooperative schemes are presented in section 3, then the proposed scheme is investigated in section 4, in section 5 the numerical results are presented, and finally conclusion is presented in section 6.

2- System Model

Here, a cooperative system with I relays is considered in which all of the nodes are equipped with a single antenna and operate in half-duplex mode. Also, it is assumed the relay nodes apply the AF protocol, and the destination node employs MRC technique. In order to transmit a message, at first, the

Corresponding author; Email: mh_madani@aut.ac.ir

source node sends its signal S with transmission power Es to the destination and all of the relay nodes. Hence, the received signal at the destination and each of relays will be as

$$y_{sd} = \sqrt{E_s}h_{sd}s + n_{sd}$$
$$y_{si} = \sqrt{E_s}h_{si}s + n_{si} \tag{1}$$

Then, each of relays, typically relay R_i, normalizes and amplifies the received signal, and sends it with transmission power E_i to the destination at the pertinent time slot. Also, the additive white noise is considered for the source-destination, source-relay and relay-destination links, respectively with variances N_{sd}, N_{si} and N_{id}. Hence we have

$$y_{id} = \sqrt{E_i}h_{id}\frac{y_{si}}{\sqrt{E\left[|y_{si}|^2\right]}} + n_{id} = \sqrt{\frac{E_sE_i}{E_s|h_{si}|^2 + N_{si}}}h_{si}h_{id}s + \tilde{n}_{id} \tag{2}$$

where

$$\tilde{n}_{id} = n_{id} + \sqrt{\frac{E_i}{E_s|h_{si}|^2 + N_{si}}}h_{id}n_{si}$$

The received signal at the destination node from the source and relay nodes can be represented in the vector y_d as

$$y_d = \left[y_{sd} \quad y_{1d} \quad \cdots \quad y_{id} \quad \cdots \quad y_{Id}\right]^T \tag{3}$$

Now, normalizing the elements of y_d with the power of noise in the relevant links results as

$$y_{d,norm} = \left[\frac{y_{sd}}{\sqrt{N_{sd}}} \quad \frac{y_{1d}}{\sqrt{\tilde{N}_{1d}}} \quad \cdots \quad \frac{y_{id}}{\sqrt{\tilde{N}_{id}}} \quad \cdots \quad \frac{y_{Id}}{\sqrt{\tilde{N}_{Id}}}\right]^T \tag{4}$$

where

$$\tilde{N}_{id} = N_{id} + \frac{E_i|h_{id}|^2N_{si}}{E_s|h_{si}|^2 + N_{si}}$$

Hence, $y_{d,norm}$ can be rewritten as

$$y_{d,norm} = hs + n \tag{5}$$

Hence,

$$h = \left[\frac{\sqrt{E_S}}{\sqrt{N_{sd}}}h_{sd} \quad \frac{1}{\sqrt{\tilde{N}_{1d}}}\sqrt{\frac{E_sE_1}{E_s|h_{s1}|^2 + N_{s1}}}h_{s1}h_{1d} \quad \cdots \quad \frac{1}{\sqrt{\tilde{N}_{Id}}}\sqrt{\frac{E_sE_I}{E_s|h_{sI}|^2 + N_{sI}}}h_{sI}h_{Id}\right]^T \tag{6}$$

Clearly, the power of noise n will be equal to 1.

3- Analytical Reviewing Of The Common Cooperative Schemes

As mentioned earlier, there are some cooperative schemes in wireless networks, such as all participate (AP), relay selection (RS), incremental relaying (IR), and incremental relay selection (IRS) schemes [6-8], [12], and [17]. In the first scheme, AP, all of the relays participate in the signal transmission from the source to the destination in orthogonal time slots. Therefore, the instantaneous capacity of the channel is

$$C_{AP} = \frac{1}{I+1}\log_2(1 + h^Hh) \tag{7}$$

By defining $a_0 = |h_{sd}|^2/N_{sd}$, $a_i = |h_{si}|^2/N_{si}$, and $b_i = |h_{id}|^2/N_{id}$ we have

$$C_{AP} = \frac{1}{I+1}\log(1 + E_0a_0 + \sum_{i=1}^{I}\frac{E_sE_ia_ib_i}{E_sa_i + E_ib_i + 1}) \tag{8}$$

With respect to the distances source-destination, source-relays, and relay-destination, the variances of these links are considered as ratios of N_0. In other words, $N_{si}=\eta_{si}N_0$, and $N_{id}=\eta_{id}N_0$ so that η_{si} and η_{id} are the ratios. Finally, by defining $N_{sd}=N_0$, $N_{si}=\eta_{si}N_0$, $N_{id}=\eta_{id}N_0$, $\alpha_0=E_s|h_{sd}|^2$, $\alpha_i=E_s|h_{si}|^2/\eta_{si}$, $\beta_i=E_i|h_{id}|^2/\eta_{id}$, and $\gamma=1/N_0$ the capacity will be as

$$C_{AP} = \frac{1}{I+1}\log_2(1 + \gamma\alpha_0 + \sum_{i=1}^{I}\frac{\gamma^2\alpha_i\beta_i}{\gamma\alpha_i + \gamma\beta_i + 1}) \tag{9}$$

Hence, the outage probability, meaning the probability that the capacity fall below a predetermined threshold will be as

$$P_{out}^{AP} = \Pr(C_{APN} \le R) = \Pr\left[\alpha_0 + \sum_{i=1}^{I}\frac{\gamma\alpha_i\beta_i}{\gamma\alpha_i + \gamma\beta_i + 1} \le \frac{2^{(I+1)R} - 1}{\gamma}\right] \tag{10}$$

The exact derivation of the above probability is not straightforward. Therefore, in [12], the authors have derived some bounds for it at the high SNRs as follow

$$P_{out}^{AP} \le \frac{\lambda_0\prod_{i=1}^{I}(\lambda_i + \mu_i)}{I+1}\left(\frac{2^{(I+1)R} - 1}{\gamma}\right)^{I+1}$$
$$P_{out}^{AP} \ge \frac{\lambda_0\prod_{i=1}^{I}(\lambda_i + \mu_i)}{(I+1)I^I}\left(\frac{2^{(I+1)R} - 1}{\gamma}\right)^{I+1} \tag{11}$$

where in it $\lambda_0 = \frac{1}{E_s}, \lambda_i = \frac{\eta_{si}}{E_s}$ *and* $\mu_i = \frac{\eta_{id}}{E_i}$

The benefits of the multiple relays cooperative systems are limited due to applying the orthogonal channels. As considered, there are *(I+1)* orthogonal channels, when *I* relay participate in the cooperation in the network. Hence, the spectral efficiency is decreased by the factor of *1/(I+1)* A method to combat with this drawback is selection-based cooperation structure using some feedback in which only one "best" node is chosen as a relay. In [12], maximizing the instantaneous SNR was proposed as the relay selection factor in an AF system. Knowing complete CSI at the destination, and applying limited feedback, this strategy is implemented at the detonation node and leads to a minimizing probability of the outage.

Hence, only one relay participates in cooperation after direct transmission and capacity will be as [12]

$$C_{RS} = \frac{1}{2}\log_2\left(1+\gamma\alpha_0 + \max_i \frac{\gamma^2\alpha_i\beta_i}{\gamma\alpha_i+\gamma\beta_i+1}\right) \quad (12)$$

According to what was presented in [12], the outage probability at high SNRs can be calculated as

$$P_{out}^{RS} = \Pr\left[\frac{1}{2}\log_2\left(1+\gamma\alpha_0+\max_i\frac{\gamma^2\alpha_i\beta_i}{\gamma\alpha_i+\gamma\beta_i+1}\right)<R\right]$$
$$=\prod_{i=1}^{I}\Pr\left[\frac{\gamma\alpha_i\beta_i}{\gamma\alpha_i+\gamma\beta_i+1}<\frac{2^{2R}-1}{\gamma}-\alpha_0\right]$$
$$=\frac{\lambda_0}{(I+1)}\left(\frac{2^{2R}-1}{\gamma}\right)^{I+1}\prod_{i=1}^{I}(\lambda_i+\mu_i) \quad (13)$$

It is considered similar to the AP scheme, *(I+1)* diversity is provided in the relay selection strategy. As it will be seen in the numerical results section, the spectral efficiency and outage performances of relay selection cooperation are better than the case that all relays participate in transmission.

In the next scheme, i.e. IR, the cooperation occurs as follows [6]; at first, the source transmits its signal to the destination and relay nodes with rate *R*, then at the destination it is decided whether the transmission has been done successfully or not. The message of success or failure of the direct transmission is reported to the source and relay node employing a single bit feedback. If the feedback message is positive, the source transmits a new signal and the relay remains silent. Otherwise, the source remains silent and the relay retransmits its received signal to the destination node. Clearly, this scheme works with rate *R* until the relay is not employed, and work with rate *R/2* if the relay participates. Note that this decision and feedback is done for each signal transmission. Assuming that randomly one relay among of *I* relays participated in the cooperation, the outage probability of this scheme is represented as [6]

$$P_{out}^{IR}(\gamma,R) = \Pr[C_D<R]\,P[C_{R_i}<R/2 \mid C_D<R]$$
$$=\Pr\left[C_{R_i}<R/2\right]$$
$$=\Pr\left[\frac{1}{2}\log_2\left(1+\gamma\alpha_0+\frac{\gamma^2\alpha_i\beta_i}{\gamma\alpha_i+\gamma\beta_i+1}\right)<R/2\right]$$
$$=\Pr\left[\alpha_0+\frac{\gamma\alpha_i\beta_i}{\gamma\alpha_i+\gamma\beta_i+1}<\frac{2^R-1}{\gamma}\right] \quad (14)$$

In addition, in order to derive the transmission rate, the expectation *R* should be calculated as

$$h_\gamma(R)=\bar{R}=R.\Pr\left[\alpha_0\ge\frac{2^R-1}{\gamma}\right]+$$
$$\frac{R}{2}.\Pr\left[\alpha_0<\frac{2^R-1}{\gamma}\right]=\frac{R}{2}\left[1+\exp(-\frac{2^R-1}{\gamma})\right] \quad (15)$$

From (14) it is clear that for a given $\bar{R}$, the minimum value of *R* is needed for minimizing the outage probability. Thus, the applied *R* in (13) for the desired rate $\bar{R}$ can be represented as $h_\gamma^{-1}(\bar{R}) := \min h_\gamma^{-1}(\bar{R})$ in order to have an optimal transition from $\bar{R}$ to R [6]. Note that $h^{-1}(.)$ indicates the inverse of h(.). To have a valid comparison with previous schemes, the outage probability is derived for the rate $h_\gamma^{-1}(\bar{R})$. Hence, we have

$$P_{out}^{IR}(\gamma,h_\gamma^{-1}(\bar{R}))=\Pr\left[\alpha_0+\frac{\gamma\alpha_i\beta_i}{\gamma\alpha_i+\gamma\beta_i+1}<\frac{2^{h_\gamma^{-1}(\bar{R})}-1}{\gamma}\right]$$
$$=\frac{\lambda_0}{2}(\lambda_i+\mu_i)\left(\frac{2^{h_\gamma^{-1}(\bar{R})}-1}{\gamma}\right)^2 \quad (16)$$

Using claim 3 in [6], the probability of outage has been derived as

$$P_{out}^{IR}(\gamma,h_\gamma^{-1}(\bar{R}))=\frac{\lambda_0}{2}\left(\frac{2^{\bar{R}}-1}{\gamma}\right)^2(\lambda_i+\mu_i) \quad (17)$$

So far the RS and IR schemes were separately introduced in order to benefit from the degrees of freedom of channel. Generally, selection and participating one relay among multiple relays leads to a complete diversity order, whereas the duration of the signaling is twice of the direct transmission. Also, the incremental scheme applies the relay just in the case of weakness of direct link; therefore, the outage probability and spectral efficiency are better than the RS scheme.

By combining the RS with IR schemes, a more efficient cooperative scheme is resulted which we refer to it as the IRS scheme [17]. This scheme takes the advantages of the both RS and IR schemes simultaneously. For the implementation of this scheme, at first it should be recognized that the direct transmission has been done successfully or not; second, which relay is participated if it is needed. Clearly, $\log_2(I+1)$ feedback is needed for this scheme.

Using the definitions in the previous sections, the outage probability of the IRS scheme is

$$P_{out}^{\mathrm{IRS}}=\Pr[C_D<R]\,P[\max_{i\in[1..I]}C_{R_i}<R/2 \mid C_D<R]$$
$$=\Pr[\max_{i\in[1..I]}C_{R_i}<R/2]$$
$$=\Pr\left[\alpha_0+\max_{i\in[1..I]}\left(\frac{\gamma\alpha_i\beta_i}{\gamma\alpha_i+\gamma\beta_i+1}\right)<\frac{2^R-1}{\gamma}\right] \quad (18)$$

Also, in the case that the average of the transmission rate is equal to $\bar{R}$, the outage probability is

$$P_{out}^{\mathrm{IRS}}(\gamma,h_\gamma^{-1}(\bar{R}))=\frac{\lambda_0}{(I+1)}\left(\frac{2^{\bar{R}}-1}{\gamma}\right)^{I+1}\prod_{i=1}^{I}(\lambda_i+\mu_i) \quad (19)$$

From (19) it is clear that *(I+1)* diversity order is provided by the IRS scheme. Also, as it is seen in the numerical result section, the loss of the transmission rate is very low compared to the RS scheme.

4- Analysis of Iterative Incremental relay selection scheme (IIRS)

Hitherto, the AP, RS, IR and IRS schemes were investigated.

Here, as a new point of view, it is proposed that the incremental relaying is applied in the implementation of the RS scheme. Meaning that, in a multiple relay network, at first, the source transmits its message to the destination and all relay nodes. Then, if the strength of the received signal from the direct link at the destination is higher than the desired threshold, the relays remain silent and the source transmits a new message. Else, the best relay is selected and cooperated in the transmission. Now, if the combination of signals from the direct and relayed links provides the desired reliability, the source sends a new message. Otherwise, the best relay among the remaining relays is selected and participated in the cooperation. Note that each relay participates as a single iteration in transmission since we want to use the potentials of all relays. The stages of this scheme can be represented as follows:

A. The source node broadcast its signal to the destination and all of the relay nodes

B. The signal to noise ratio of the direct link is calculated and considered as default snr

C. If snr is higher than the desired threshold, returns to the step A

D. The signal to noise ratio of the all relayed links are calculated and the relay is arranged with respect to it

E. The signal to noise ratio of the best relay from the list is added to snr, and remove this relay from the list of relays

F. If snr is higher than the desired threshold, return to the step A, else return to the step E

G. If all of the relays are employed, return to the step A

By this description, the amount of the spectral efficiency of this scheme can be calculated as equation (20) at the end of this page. It is remarked that we could not derived a closed form expression for this equation, and it should be solved numerical method. In the following section, we deal with the outage probability analysis and the amount of delay imposed by the IIRS scheme.

$$\begin{aligned}\bar{R} &= R.\Pr\left[\alpha_0 \geq \left(\frac{2^R-1}{\gamma}\right)\right] + \\ &\frac{R}{2}.P\left[\left(\alpha_0+\frac{\gamma\alpha_1\beta_1}{\gamma\alpha_1+\gamma\beta_1+1}\right) > \left(\frac{2^{2R}-1}{\gamma}\right) \mid \alpha_0 < \left(\frac{2^R-1}{\gamma}\right)\right] \\ &+\frac{R}{3}.\Pr[\left(\alpha_0+\sum_{i=1}^{2}\frac{\gamma\alpha_i\beta_i}{\gamma\alpha_i+\gamma\beta_i+1}\right) > \left(\frac{2^{3R}-1}{\gamma}\right) \\ &\mid \left(\alpha_0+\frac{\gamma\alpha_1\beta_1}{\gamma\alpha_1+\gamma\beta_1+1}\right) < \left(\frac{2^{2R}-1}{\gamma}\right)] \\ &\cdots + \frac{R}{(I+1)}.\Pr\left[\left(\alpha_0+\sum_{i=1}^{I-1}\frac{\gamma\alpha_i\beta_i}{\gamma\alpha_i+\gamma\beta_i+1}\right) < \left(\frac{2^{IR}-1}{\gamma}\right)\right]\end{aligned} \tag{20}$$

4- 1- Outage probability

The outage probability of the IIRS scheme can be expressed as equation (21) in the top of next page. We apply the following inequality in order to manipulate (21) to derive closed-form expression for the outage probability

$$\begin{aligned}P_{out}^{IIRS} &= \Pr\left[\log_2(1+\gamma\alpha_0)<R\right]. \\ &\Pr\left[\frac{1}{2}\log_2\left(1+\gamma\alpha_0+\frac{\gamma^2\alpha_1\beta_1}{\gamma\alpha_1+\gamma\beta_1+1}\right)<\frac{R}{2} \,\Big|\, \log_2(1+\gamma\alpha_0)<R\right] \cdots \\ &\cdot\Pr[\frac{1}{(I+1)}\log_2\left(1+\gamma\alpha_0+\sum_{i=1}^{I}\frac{\gamma^2\alpha_i\beta_i}{\gamma\alpha_i+\gamma\beta_i+1}\right)< \\ &\frac{R}{(I+1)}\,\Bigg|\,\frac{1}{I}\log_2\left(1+\gamma\alpha_0+\sum_{i=1}^{I-1}\frac{\gamma^2\alpha_i\beta_i}{\gamma\alpha_i+\gamma\beta_i+1}\right)<\frac{R}{I}\,] \\ &=\Pr\left[\frac{1}{(I+1)}\log_2\left(1+\gamma\alpha_0+\sum_{i=1}^{I}\frac{\gamma^2\alpha_i\beta_i}{\gamma\alpha_i+\gamma\beta_i+1}\right)<\frac{R}{(I+1)}\right]\end{aligned} \tag{21}$$

$$\sum_{i=1}^{I}\frac{\gamma^2\alpha_i\beta_i}{\gamma\alpha_i+\gamma\beta_i+1} > \max_i\frac{\gamma^2\alpha_i\beta_i}{\gamma\alpha_i+\gamma\beta_i+1} \tag{22}$$

Therefore, applying (22) into (21) results

$$\begin{aligned}P_{out}^{IIRS} &\leq \Pr\left[\alpha_0+\max_i\frac{\gamma\alpha_i\beta_i}{\gamma\alpha_i+\gamma\beta_i+1}\leq\frac{2^R-1}{\gamma}\right] \\ &=\Pr\left[\max_i\frac{\gamma\alpha_i\beta_i}{\gamma\alpha_i+\gamma\beta_i+1}\leq\delta-\alpha_0\right]\end{aligned}$$

where $\delta = 2^R - 1/\gamma$ Since α_0 is a random variable with gamma distribution of parameter λ_0, thus we have

$$\begin{aligned}P_{out}^{IIRS} &= \int_0^{\delta}\Pr\left[\max_i\frac{\gamma\alpha_i\beta_i}{\gamma\alpha_i+\gamma\beta_i+1}\leq\delta-x\right]\lambda_0 e^{-\lambda_0 x}dx \\ &=\int_0^1\Pr\left[\max_i\frac{\gamma\alpha_i\beta_i}{\gamma\alpha_i+\gamma\beta_i+1}\leq dx'\right]\delta\lambda_0 e^{-\lambda_0\delta(1-x')}dx' \\ &=\int_0^1\left(\prod_{i=1}^{I}\Pr\left[\frac{\gamma\alpha_i\beta_i}{\gamma\alpha_i+\gamma\beta_i+1}\leq dx'\right]\right)\delta\lambda_0 e^{-\lambda_0\delta(1-x')}dx' \\ &=\delta^{I+1}\lambda_0\int_0^1\left(\prod_{i=1}^{I}\frac{P\left[\frac{\gamma\alpha_i\beta_i}{\gamma\alpha_i+\gamma\beta_i+1}\leq dx'\right]}{\delta x'}\right)(x')^I e^{-\lambda_0\delta(1-x')}dx'\end{aligned} \tag{23}$$

where, the changing of variable $x' = 1 - x/\delta$ has been applied in it. Note that δ is a function of signal to noise ratio, and $\delta \to \infty$ if $\gamma \to \infty$. Thus,

$$\lim_{\gamma\to\infty} e^{-\lambda_0\delta(1-x')} = 1 \tag{24}$$

Also, using lemma 1 from the Appendix reference [2], we have

$$\lim_{\gamma\to\infty}\frac{\Pr\left[\max_i\frac{\gamma\alpha_i\beta_i}{\gamma\alpha_i+\gamma\beta_i+1}\leq dx'\right]}{dx'} = \lambda_i + \mu_i \tag{25}$$

Finally, by substituting (24) and (25) for (23), we have

$$\lim_{\gamma\to\infty}\frac{P_{out}^{IIRS}}{\delta^{I+1}}=\lambda_0\int_0^1\left(\prod_{i=1}^{I}(\lambda_i+\mu_i)\right)(x')^I\,dx' =\frac{\lambda_0\prod_{i=1}^{I}(\lambda_i+\mu_i)}{I+1} \tag{26}$$

Therefore, the upper bound of the outage probability will be as

$$P_{out}^{IIRS}=\frac{1}{(I+1)}\lambda_0\left(\frac{2^R-1}{\gamma}\right)^{(I+1)}\prod_{i=1}^{I}(\lambda_i+\mu_i) \tag{27}$$

Also, we can apply following inequality in order to calculation of a lower bound of P_{out}^{IIRS},

$$\sum_{i=1}^{I}\frac{\gamma^2\alpha_i\beta_i}{\gamma\alpha_i+\gamma\beta_i+1}<I.\left(\max_i\frac{\gamma^2\alpha_i\beta_i}{\gamma\alpha_i+\gamma\beta_i+1}\right) \tag{28}$$

Thus, the desired lower bound can be written as equation (29) at the end of this page. Finally, after some manipulations, the lower bound for the outage probability at high SNRs is calculated as

$$\begin{aligned}P_{out}^{IIRS}&>\Pr\left[\alpha_0+I\left(\max_i\frac{\gamma\alpha_i\beta_i}{\gamma\alpha_i+\gamma\beta_i+1}\right)<\frac{2^R-1}{\gamma}\right]\\&=\Pr\left[\max_i\frac{\gamma\alpha_i\beta_i}{\gamma\alpha_i+\gamma\beta_i+1}<\frac{\frac{2^R-1}{\gamma}-\alpha_0}{I}\right]\\&=\int_0^{\delta}\Pr\left[\max_i\frac{\gamma\alpha_i\beta_i}{\gamma\alpha_i+\gamma\beta_i+1}\le\frac{\frac{2^R-1}{\gamma}-x}{I}\right]\lambda_0e^{-\lambda_0x}dx=\left(\frac{2^R-1}{\gamma}\right)^{I+1}\\&\cdot\frac{\lambda_0}{I^I}\int_0^1\prod_{i=1}^{I}\left(\frac{P\left[\frac{\gamma\alpha_i\beta_i}{\gamma\alpha_i+\gamma\beta_i+1}\le\frac{2^R-1}{\gamma I}x'\right]}{\frac{2^R-1}{\gamma I}x'}\right)(x')^Ie^{-\lambda_0\left(\frac{2^R-1}{\gamma}\right)(1-x')}dx'\end{aligned} \tag{29}$$

$$P_{out}^{IIRS}=\frac{\lambda_0}{(I+1)I^I}\left(\frac{2^R-1}{\gamma}\right)^{I+1}\prod_{i=1}^{I}(\lambda_i+\mu_i) \tag{30}$$

Similar to previous analysis, the bounds of the outage probability when the expectation of the transmission rate is $\bar{R}$, can be derived as

$$\begin{aligned}P_{out}^{IIRS}&\le\frac{\lambda_0}{(I+1)}\left(\frac{2^{\bar{R}}-1}{\gamma}\right)^{I+1}\prod_{i=1}^{I}(\lambda_i+\mu_i)\\P_{out}^{IIRS}&\ge\frac{\lambda_0}{(I+1)I^I}\left(\frac{2^{\bar{R}}-1}{\gamma}\right)^{I+1}\prod_{i=1}^{I}(\lambda_i+\mu_i)\end{aligned} \tag{31}$$

From (31) it is seen that *(I+1)* diversity order is provided by the IIRS scheme, although the loss of transmission rate is ignorable. Note that regarding the framework that was introduced for the IIRS scheme, in the worst case, the maximum number of feedback leads to $I\times\log_2(I+1)$, whereas at higher SNRs it leads to $\log_2(I+1)$.

4- 2- Imposed delay

The average amount of delay in which data is successfully transmitted, i.e., the expected number of transmissions (original transmission plus retransmission) is given by

$$\begin{aligned}E(T)&=1\times\Pr(T=1)+2\times\Pr(T=2)+\\&\cdots+(I+1)\times\Pr(T=I+1)\end{aligned} \tag{30}$$

where

$$\Pr(T=1)=\Pr\left[\alpha_0\ge\left(\frac{2^R-1}{\gamma}\right)\right]$$

$$\Pr(T=2)=$$

$$\Pr\left[\left(\alpha_0+\frac{\gamma\alpha_1\beta_1}{\gamma\alpha_1+\gamma\beta_1+1}\right)>\left(\frac{2^{2R}-1}{\gamma}\right)\Big|\,\alpha_0<\left(\frac{2^R-1}{\gamma}\right)\right],$$

$$\vdots$$

$$\Pr(T=I+1)=$$

$$\Pr\left[\left(\alpha_0+\sum_{i=1}^{I-1}\frac{\gamma\alpha_i\beta_i}{\gamma\alpha_i+\gamma\beta_i+1}\right)<\left(\frac{2^{IR}-1}{\gamma}\right)\right].$$

Clearly, as high SNRs, i.e. $\gamma\to\infty$, $\Pr(T=1)=\Pr[\alpha_0\ge0]=1$,

$$\Pr(T=2)=$$

$$\Pr\left[\left(\alpha_0+\frac{\gamma\alpha_1\beta_1}{\gamma\alpha_1+\gamma\beta_1+1}\right)>0\,\Big|\,\alpha_0<0\right]=0,$$

$$\vdots$$

$$\Pr(T=I+1)=$$

$$\Pr\left[\left(\alpha_0+\sum_{i=1}^{I-1}\frac{\gamma\alpha_i\beta_i}{\gamma\alpha_i+\gamma\beta_i+1}\right)<0\right]=0.$$

Hence, it can be derived that the average amount of delay at high SNRs is 1 symbol period. In contrast, at low SNRs, the average amount of delay reaches to *I+1* symbol period which is undesired. More investigation about imposed delay is presented in the next section.

5- Numerical Results

Here, in order to compare the performance of the cooperative schemes and verify the analysis, the simulation results are presented.

Fig. 1 indicates the outage probability curves of the AP and RS schemes versus SNR defined as $\gamma=1/N_0$. In order to simulate these schemes, it is assumed that the power of signals transmitted at the source and relay nodes is $E_s=E_i=1$. Also, according to what was presented in the system model, all of the channels are assumed to be Rayleigh fading with mean 0 and variance one, i.e. *h~CN(0,1)*. Also, equal power is considered for noise in all links $\eta_{si}=\eta_{id}=1,\forall i$.

In addition, the outage curves result for target rate 1 bit per second and applying two relays.

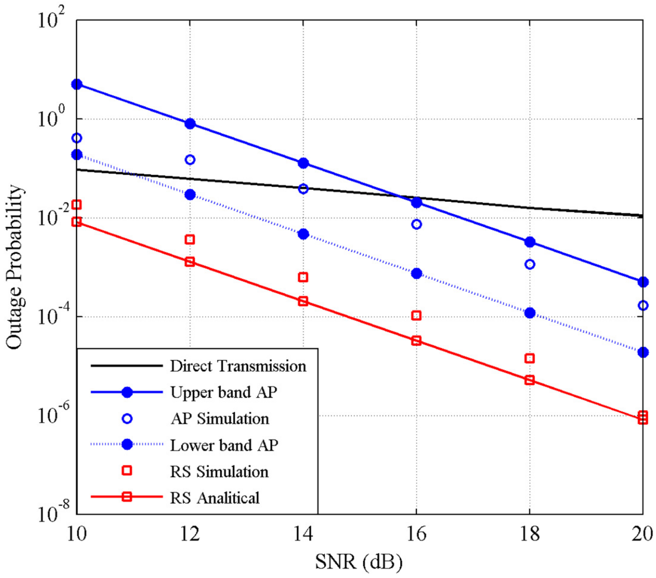

Fig. 1. Outage probability of the AP, RS, and Direct schemes

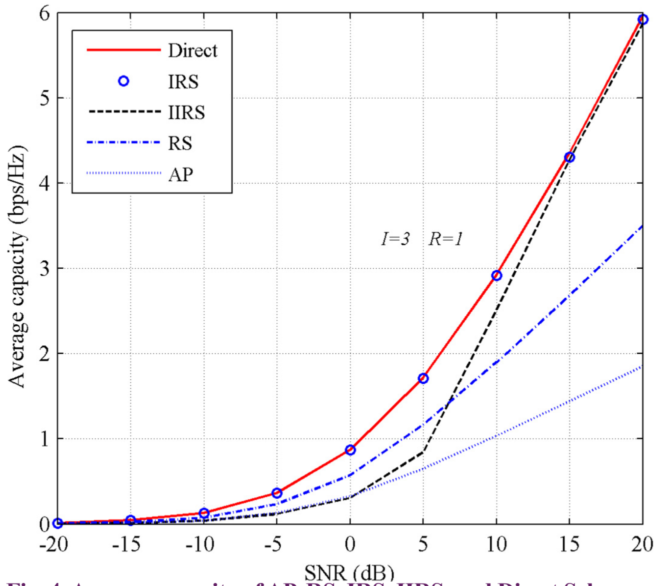

Fig. 4. Average capacity of AP, RS, IRS, IIRS, and Direct Schemes

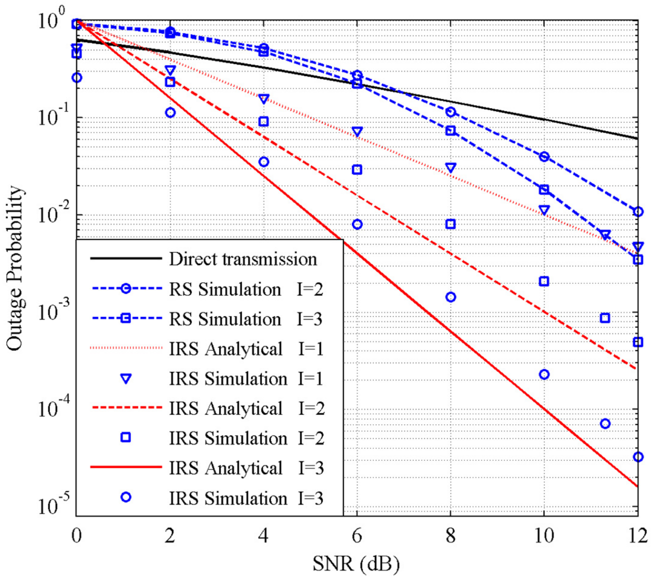

Fig. 2. Outage probability of the RS, IRS, and Direct schemes

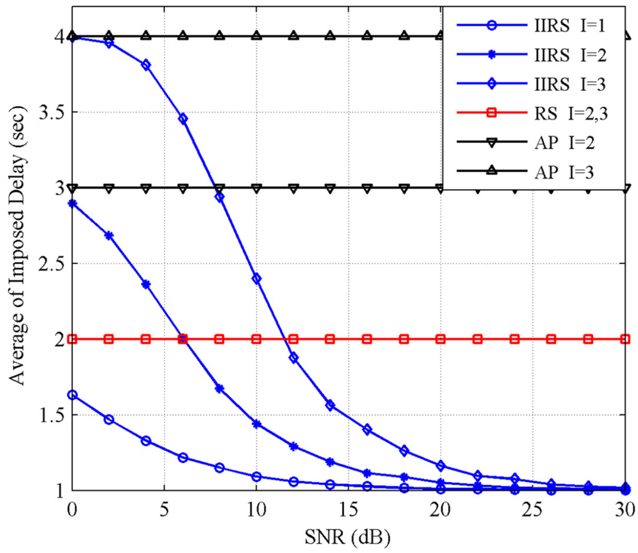

Fig. 5. Average amount of imposed delay with various schemes

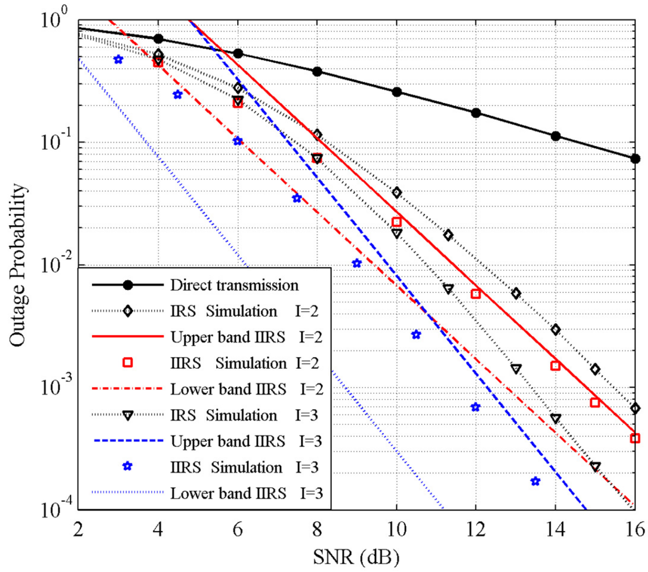

Fig. 3. Outage probability of the IRS, IIRS, and Direct schemes

As seen from Fig. (1), both AP and RS schemes have a better performance compared to non-cooperative transmission although the RS scheme outperforms the RS scheme. Clearly, this improvement is the result of applying feedback.

In Fig. 2, the outage probability of the IRS scheme is shown regarding various SNRs (defined as previous) for the transmission rate 1 bit per second and number of relays 1, 2, and 3. Also, in order to the comparison, the outage curves of the AP scheme and direct transmission are depicted. It is seen the IRS scheme operates better than the RS scheme and direct transmission. In addition, the prosperity of the RS scheme over the AP and direct schemes was shown previously. Therefore, it can be concluded that the IRS scheme has a better outage performance compared to the AP, RS, and Direct schemes. It should be noted that the RS and IRS schemes have a similar manner in a different range of SNR.

Clearly, the reliability of system increased by increasing the number of the relays, i.e. $I=2, 3$. In fact, the IRS scheme required $\log_2(I+1)$ bit feedback to be implemented. Thus, only one-bit feedback is required when there is a single relay. This shows the simple implementation of the IRS scheme.

In Fig. (3), the outage probability of the IIRS scheme is simulated and compared with the outage probability of the Direct, and IRS schemes for various SNRs.

Simulation parameters are considered as previous, except the target rate which here is assumed to be 2 bit per second.

As can be seen in Figure 3, IIRS scheme has a lower outage probability compared to the IRS scheme. Also, as previously shown, the IRS scheme overcomes the AP and RS schemes, thus, it is clear that the proposed IRS scheme has, a better outage performance compared to the other common cooperative schemes. From this figure also it is seen that the performance of the IIRS scheme is improved significantly by increasing the number of relays, i.e. $I=2, 3$. Clearly, this is the result of increasing the diversity order at the destination. Knowing channel state information at the destination, this scheme at high SNRs requires about $\log_2(I+1)$ bit feedback. Comparison of the provided improvement, and added complexity in the context of the mentioned feedback reveals that the IIRS scheme is a more efficient scheme compared to the other cooperative schemes. In addition, it is seen from Fig. 3 that the analytical curves are well approached to simulation curves at high SNRs which indicates the validity of the analysis.

In Fig. 4, the average capacity of the system has been represented for the purpose of comprising the proposed scheme with the other scheme of transmission. The target rate is assumed to be 1 bit per second, 3 relays are employed in the network, and other parameters are considered as previous. In this figure, it is seen that average capacity of the AP scheme is lower than other schemes. In fact, since the AP scheme participates all of the relays in the orthogonal channels, it suffers a significant loss in the rate of transmission compared to direct transmission. Clearly, the number of orthogonal channels is reduced to 2-timeslot by applying the RS scheme. Hence, the average capacity of the RS scheme is better than the AP scheme although there is the loss compared to the direct transmission. On the other hand, if participating the best relay is dependent on the quality of the direct link, i.e. IRS scheme, the average capacity is increased for all SNR ranges and reaches the maximum value as the direct link. Finally, to deal with the IIRS scheme, the capacity curve can be considered in two regions. Generally, at the low SNR regime, its average capacity is similar to the AP scheme which is lower than capacities of the RS and IRS schemes. Whereas at the high SNR regime, the average capacity of IIRS scheme reaches the capacities of the direct and IRS schemes as the maximum value.

Finally, in Fig. 5, the average amount of imposed delay with IIRS scheme is depicted versus SNR for a various number of relays. In addition, the delays of AP and RS schemes are presented for more clarifications. Clearly, it is seen that both AP and RS cooperative schemes, respectively impose $I+1$ and 2 symbol slot as fixe delays at all SNRs. Different from AP and RS, the IIRS scheme has a variable delay which smartly changes proportionally to the links quality. In fact, this scheme employs all of the relays at low SNRs to reach the desired outage threshold while it imposes a delay of $I+1$. By contrast, as SNR increases the average number of participated relay decreases so that for $I=2$ and 3 the average delay of IIRS settles below the delay of RS at SNRs higher than 6.25 and 11.5 dB, respectively. It should be noted that at higher SNRs, the amount of feedback decreases and leads to $\log_2(I+1)$ bits which are acceptable. Hence, it can be concluded that the IIRS scheme is more useful and practical at higher SNRs.

6- Conclusions

In the paper, an iterative incremental relay selection (IIRS) scheme was proposed, and its performance was investigated in the multiple relay cooperative networks. This proposed scheme operates based on a repeat of relay selection which is done incrementally. The outage probability of this scheme was derived analytically. It was shown that the IIRS scheme reaches the spectral efficiency of direct transmission at high SNRs which corresponds to the maximum transmission rate. In addition, this scheme provides the maximum diversity order. Thus, its outage performance is better than other schemes. As the cost of the improvement, in the worst case, this scheme requires $I \times \log_2(I+1)$ bits feedback, while it requires about $\log_2(I+1)$ bits at higher SNRs. Similarly, the IIRS scheme imposes the delay of I+1 symbol time slot at low SNRs whereas its average delay is settled below of the RS scheme delay. Considering the provided improvement and the added complexity of the IIRS scheme indicates that the IIRS scheme can be treated as an efficient scheme compared to the other common cooperative schemes such as AP, RS, and IRS.

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