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A Novel Multi-hop Threshold based Relay Selection Scheme

K.Shamganth*
Research Student,
School of Computing & Engineering
University of Huddersfield,UK

Dr.Martin Sibley
Reader
School of Computing & Engineering
University of Huddersfield,UK

Dr.Sammi Ghnmi
Head of Department
Engineering Department
Ibra College of Technology,Oman

Abstract— Relay selection in co-operative networks plays a vital role in increasing the efficiency of networks. If the selected relay is not the best relay then the end-to-end co-operative network will be in failure. In this proposed relay selection scheme, threshold-based relay selection is applied in the first-hop the source-to-relay link. From the destination, the best relay will be selected based on Output Threshold Multiple Relay Selection (OT-MRS) scheme [8]. If the relay selected by the source and destinations are different then multi-relay transmission will take place between the relays. In this paper closed form SER formulations of the system are derived.

Keywords— Co-operative networks; Relay selection; Outage probability; Interference; Co-operative relaying

I. INTRODUCTION

Co-operative communication is one of the fastest growing research areas, and it will be the key enabling technology in LTE – (Long Term Evolution) -Advanced standard. The key idea in user co-operation [1] is resource sharing among multiple network nodes. Exploration of user co-operation leads to savings of overall network resources. Relay selection is one important research area in co-operative communication where there is numerous relay selection approaches proposed in the literature [2]. Different relay selection schemes were compared based on Relaying candidate selection, optimal relay assignment criterion, Co-operative transmission scheme and type of relay selection i.e. reactive or proactive in [3]. Threshold based relay selection using Amplify and Forward (AaF) relaying scheme [4] and Decode and Forward (DaF) relaying scheme is widely analysed in the literature [5-7]. In threshold based relay selection schemes the relays were selected based on those relays having a received SNR higher than a threshold value. Threshold based schemes are of two types: destination based and source based scheme. Relay selection is performed based on received SNR at the destination during the last hop. In this paper we propose a hybrid threshold based scheme, which has the combination of source based relay selection and destination based relay selection schemes. In the first part of the relay selection the source selects the best relay based on the SNR value greater than the threshold SNR, and the destination selects the best relay based on OT-MRS scheme [8]. If the relays selected by the source and the destination are different, then multi-relay communication will take place between the relays. In the Multi-Relay Selection (MRS) schemes in the literature the number of active relays is many and so the power consumption is very high. In the MRS schemes like OT-MRS [8] threshold is checked for the output SNR at the destination. But in the proposed method the relays will forward the amplified version of the source information only when the SNR at the relays is above the threshold.

The rest of this paper is organized as follows. In Section II, we describe the system model and the proposed algorithms in Section III, performance analysis is presented in Section IV and Section V concludes the paper with the summary of results.

II. SYSTEM MODEL

We consider a half-duplex, multi-hop system where there are source *S1*, destination *D1* and N relay nodes with R_i i∈ {1,2,….N}. Relay selection is classified into two types, reactive and proactive [6]. In reactive mode, the source broadcasts its information and selects the best relay. On the other hand, in proactive mode the source transmission takes place only after selection of the best relay. In this paper the proactive approach is used. In the system model shown in Fig.1, the source S1 transmits information to the destination D1 though the best relay. Each relay in the system model uses the amplify and forward relaying scheme. It is assumed that all the relays use half-duplex communication and each relay has one antenna. So each relay amplifies the received signal and retransmits it to the destination.

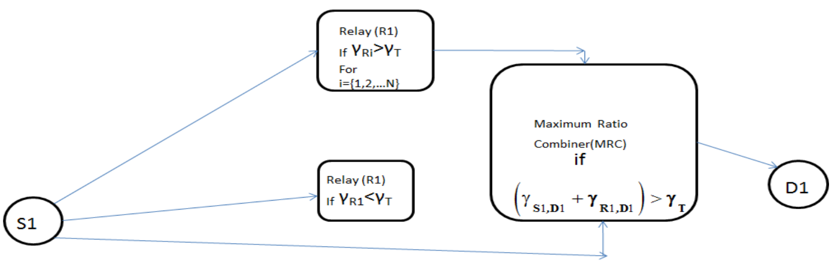

Fig. 1 System Model

There are two-phases followed in this work: In the first phase the source broadcasts its information. In this phase, destination D1 receives the signal transmitted by source S1 direct link and from the relays. If the SNR for the link between $S_1 \rightarrow R_1$ is above the threshold i.e $\gamma_{S_1R1} > \gamma_T$ then the relay R1 will forward the amplified version of the source information. If not, the first relay will be in silent mode. All other relays will compare $\gamma_{S_1Ri} > \gamma_T$ for $i \in \{1,2....M\}$ the SNR of the first hop is above the threshold then the relays will be in active mode. Relays in active mode will forward the amplified version in the first time slot. The combiner at destination D1 combines the signal received from the source and from the relays. If the combiner output exceeds the threshold value then that relay will be selected as the best relay from the destination side. The destination will send the best relay information to the source S1. The relays with $\gamma_{S_1Ri} > \gamma_T$ calculate the maximum SNR between the Source and the relays i.e $max\{\gamma_{S1,Ri}\} > \gamma_T$ for $i \in \{1,2....M\}$. The best relay from the source S1 will be selected based on the above condition. If the relays selected by the source S1 and destination D1 are different then multi-relay transmission will take place between the source S1 and destination D1 as shown in Fig.1.

The received signals $y_{s1,D1}$ and $y_{s1,Ri}$ at the i[th] relay can be written as

$$y_{s1,D1} = \sqrt{P_1} h_{s1,D1} x + n_{s1,D1} \tag{1}$$

$$y_{s1,Ri} = \sqrt{P_1} h_{s1,Ri} x + n_{s1,Ri} \quad \text{for } i = \{1,2...N\} \tag{2}$$

Notations followed in the equations of this paper are as follows:

- P_1 – Transmitted power at the source
- $h_{s1,Ri}$ – Channel coefficient from the source to i[th] relay
- $\gamma_{s1,Ri}$ –SNR between source S_1 to the relay node R_i
- $n_{s1,Ri}$ – Additive noise added in the channel between source S_1 and Relay R_i
- P_i – i[th] relay node power.

The received signal at the destination node in phase2 due to the i[th] relay transmission is

$$y_{Ri,D1} = \frac{\sqrt{P_i}}{\sqrt{P_1 |h_{s1,Ri}|^2 + N_0}} h_{Ri,d1} y_{s1,Ri} + n_{Ri,D1} \tag{3}$$

The channel coefficients $h_{Ri,D1}$ and $h_{s1,Ri}$ are modelled as zero-mean, complex Gaussian random variables with variances $\sigma^2_{Ri,D1}, \sigma^2_{s1,Ri}$, at the receiving node but not at the transmitting nodes. The noise terms are modeled as zero-mean, complex Gaussian random variable with variance N_0. The signal received from the source and from relays is combined at the destination by the use of Maximum Ratio Combining (MRC).

III. REVIEW OF OT-MRS SCHEME

OT-MRS scheme is proposed in [4] selects the Lc relays out of total L relays when the combined SNR of the Lc relayed paths and the direct path exceeds the pre-set threshold (γ_{th}). In this relay selection scheme, the destination (D) receives the signal transmitted by source (s1) during the first phase. Next, the first relay R1 forwards the amplified version of the source information to the destination in the second phase. The combiner at the destination combines this signal from the relay and the direct path signal. If the SNR at the output of the combiner at the destination exceeds the threshold, then no more relays will be selected. Otherwise, the relays R2,R3……RN will be selected in the subsequent timeslots until the sum of the output SNR exceeds the threshold.

The instantaneous output SNR $\zeta_i \Big|_{i=1}^{L}$ at D with *i* active AF given in [8] as

$$\zeta_i = \gamma_{s1,D1} + \sum_{i=1}^{N} \frac{\gamma_{s1,Ri}\gamma_{Ri,D1}}{\gamma_{s1,Ri} + \gamma_{Ri,D1} + 1} \tag{4}$$

To analyse the system performance, the distribution of ζ_l is required, so ζ_l is replaced by a tight upper bound ζ_l^{ub} in [4] and it is written as

$$\zeta_l < \zeta_l^{ub} = \gamma_{s1,D+} \sum_{i=1}^{N} \gamma_i \tag{5}$$

$$\gamma_i = min(\gamma_{s1,Ri}, \gamma_{Ri,D}) \quad (6)$$

The tight lower bound for ζ_i is given by

$$\zeta_l \geq \zeta_l^{lb} = \gamma_{s1D} + \sum_{i=1}^{N} \left(\frac{1}{2}\right) \gamma_i \quad (7)$$

IV. PROPOSED RELAY SELECTION SCHEME

In this section, we describe the proposed relay selection algorithm. The main idea of this algorithm is to reduce the channel estimation and power at the relay nodes. Since the power control is applied in this algorithm the lifetime of the relay node is maximized. In the algorithm proposed in [8] the bandwidth consumption is more due to increased signalling message exchange between the source and the relay node.

To overcome the problems of power consumption and complexity issues, we propose the relay selection algorithm with the predetermined threshold at the relay nodes and at the destination node. Mode of operation in the proposed algorithm is described as follows:

Step1: Initialize $i = 0$

Step2: Set $i \leftarrow i + 1$ for $i = \{1, 2, ...N\}$, if $i = N + 1$, go to Step 6

Step3: If $\gamma_{s1,Ri} \leq \gamma_T$ go to step 2 else go to step 4

Step4: If Relays with $\gamma_{S1,Ri} > \gamma_T$ then it will be in listening mode, all other relays will be in sleep mode. So power consumption is reduced.

Step5: Relays in listening mode will amplify and forward the Source (S1) information to the destination (D1).

Step6: Compute $\alpha_1 = \max\{\gamma_{s1,Ri}\}$

Step7: Destination D1 will combine the signal received directly from the source s1 and the relayed transmission by using optimal combiner as in [4], if the value of the particular relayed transmission is above the predetermined threshold i.e, $\alpha 2 = \max\{\gamma_{Ri,D1}\} + \gamma_{s1,D1} \succ \gamma_T$ then the relay will be chosen as the best relay from destination.

Step8: If $\alpha_1 \neq \alpha_2$ then multi-relay transmission will takes place between the best relay selected by the source S1 and destination D1.

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A. *Difference of Proposed algorithm from OT-MRS scheme*

In the proposed algorithm, in the first timeslot the source broadcasts its information so the relays in the coverage area and the destination D1 will receive source s1 information. During this phase the SNR at the relays will be calculated and compared with the predefined threshold γ_T. This SNR threshold can be chosen to be the minimum required SNR for successful symbol decoding for a given modulation scheme.

Relays with SNR $\gamma_{Ri} > \gamma_T$ for i= {1, 2…N} will be in active mode and all other relays will be in sleep mode. By this proposed method the power consumption due to the relays is less. Also spectral efficiency is good in the proposed method since only relays with SNR $\gamma_{Ri} > \gamma_T$ will be in listening mode and all other relays will not forward the source information as in OT-MRS. If more than one relay has a SNR more than the threshold SNR then the relays will forward to the destination. In the destination node the SNR of the direct path and the best relayed path will be combined by the maximal ratio combining (MRC) technique and this output compared with preset threshold SNR set at the destination. If the cumulative SNR of the best relay and the direct path is greater than the threshold SNR then the relay will be chosen as the best relay by the destination.

B. *Numerical Example*

Consider there are four relays Ri for {i=1,2,3,4} during the first phase source broadcasts its information, so all the four relays and destination D will receive the source information. In the relays, a predefined threshold is set and if two relays R1 and R2 with SNR greater than the threshold value, then both relays R1 and R2 will amplify and forward source information to the destination.

If $\gamma_{Ri} > \gamma_T$ and $\left(\gamma_{s1,D1} + \gamma_{R1}\right) < \gamma_T$

In this case relay R1 will not be selected as the best relay by the destination. So the destination will combine the SNR of the second best relay R2 with the destination SNR $\gamma_{s1,D}$ and if this output is more than the threshold value at the destination then relay R2 will be chosen as best relay by the destination.

V. SER FORMULATIONS OF THE PROPOSED RELAY SELECTION ALGORITHM

A closed form derivation of SER expression for AF cooperation protocol [9] of BPSK signal is presented. With the knowledge of the channel coefficients $h_{s1,D1}$ and $h_{Ri,D1}$, the destination detects the transmitted symbols by jointly combining the received signal $y_{s1,D1}$ from the source and $y_{Ri,D1}$ from the relay.

The combined signal at the output of MRC detector [11]is given by

$$y_{D1} = a_1 y_{s1,D1} + \sum_{i=1}^{N} a_i y_{Ri,D1} \tag{8}$$

where a_1 and a_2 are the combining factors,

$$\mathbf{a}_1 = \frac{\sqrt{\mathbf{P}_0}\,\mathbf{h}^*_{\mathbf{s1,D1}}}{\mathbf{N}_0}$$

$$\mathbf{a}_\mathbf{i} = \frac{\dfrac{\sqrt{\mathbf{P}_0\mathbf{P}_\mathbf{i}}}{\sqrt{\mathbf{P}_0\left|\mathbf{h}_{\mathbf{s1,Ri}}\right|^2 + \mathbf{N}_0}}\,\mathbf{h}^*_{\mathbf{s1},\boldsymbol{Ri}}\,\mathbf{h}^*_{\mathbf{Ri,D1}}}{\left(\dfrac{\mathbf{P}_\mathbf{i}\left|\mathbf{h}_{\mathbf{Ri,D1}}\right|^2}{\mathbf{P}_0\left|\mathbf{h}_{\mathbf{s1,Ri}}\right|^2 + \mathbf{N}_0}\right)}$$

If we assume the transmitted symbol 'x' has an average energy of 1, then the SNR at the MRC detector output is

$$\boldsymbol{\gamma}_{\mathbf{D1}} = \boldsymbol{\gamma}_{\mathbf{s1}} + \sum_{\mathbf{i=1}}^{\mathbf{N}} \boldsymbol{\gamma}_\mathbf{i} \tag{9}$$

Where $\boldsymbol{\gamma}_{\mathbf{s1}} = \dfrac{\mathbf{P}_0\left|\mathbf{h}_{\mathbf{s1},\boldsymbol{D}1}\right|^2}{\mathbf{N}_0}$ and $\boldsymbol{\gamma}_\mathbf{i} = \dfrac{\mathbf{P}_0\mathbf{P}_\mathbf{i}\left|\mathbf{h}_{\mathbf{s1,Ri}}\right|^2\left|\mathbf{h}_{\mathbf{Ri,D1}}\right|^2}{\mathbf{P}_\mathbf{i}\left|\mathbf{h}_{\mathbf{Ri,D1}}\right|^2 + \mathbf{P}_0\left|\mathbf{h}_{\mathbf{s1,Ri}}\right|^2 + \mathbf{N}_0}$

The instantaneous SNR γ_i can be tightly upper bounded [11]as

$$\tilde{\boldsymbol{\gamma}}_\mathbf{i} = \frac{\mathbf{P}_0\mathbf{P}_\mathbf{i}\left|\mathbf{h}_{\mathbf{s1,Ri}}\right|^2\left|\mathbf{h}_{\mathbf{Ri,D1}}\right|^2}{\mathbf{P}_\mathbf{i}\left|\mathbf{h}_{\mathbf{Ri,D1}}\right|^2 + \mathbf{P}_0\left|\mathbf{h}_{\mathbf{s1,Ri}}\right|^2 + \mathbf{N}_0} \tag{10}$$

It is the harmonic mean of

$\dfrac{\mathbf{P}_0\left|\mathbf{h}_{\mathbf{s1,Ri}}\right|^2}{\mathbf{N}_0}$ and $\dfrac{\mathbf{P}_\mathbf{i}\left|\mathbf{h}_{\mathbf{Ri,D1}}\right|^2}{\mathbf{N}_0}$

For BPSK modulation with instantaneous SNR $\boldsymbol{\gamma}_\mathbf{i}$, the SER with the CSI is given by

$$\mathbf{P}^{\mathbf{PSK}}_{\mathbf{CSI}} = \boldsymbol{\psi}_{\mathbf{PSK}}(\boldsymbol{\gamma}) \approx \frac{1}{\boldsymbol{\pi}}\int_0^{\pi/2} \boldsymbol{exp}\left(-\frac{\boldsymbol{sin}^2\left(\frac{\pi}{2}\right)}{\boldsymbol{sin}^2(\theta)}\right)\mathbf{d}\boldsymbol{\theta} \tag{11}$$

Let us denote the MGF of a random variable

$$\mathbf{M}_\mathbf{z}(\mathbf{s}) = \int_{-\infty}^{\infty} \boldsymbol{exp}(-\mathbf{sz})\mathbf{P}_\mathbf{z}(\mathbf{z}) \tag{12}$$

Averaging the conditional SER over the Rayleigh fading channels the SER of BPSK signals is given by

$$\mathbf{P}_{\mathbf{SER}} \approx \frac{1}{\boldsymbol{\pi}}\int_0^{\pi/2} \mathbf{M}\boldsymbol{\gamma}_\mathbf{s}\left(\frac{\boldsymbol{sin}^2\left(\frac{\pi}{2}\right)}{\boldsymbol{sin}^2(\theta)}\right)\prod_{\mathbf{i=1}}^{\mathbf{N}}\mathbf{M}\tilde{\boldsymbol{\gamma}}_\mathbf{i}\left(\frac{\boldsymbol{sin}^2\left(\frac{\pi}{2}\right)}{\boldsymbol{sin}^2(\theta)}\right)\mathbf{d}\boldsymbol{\theta} \tag{13}$$

Derivation of MGF of γ_S is shown in Appendix A, and it can be written as

$$\mathbf{M}\boldsymbol{\gamma}_\mathbf{s} = \frac{1}{1 + \dfrac{\mathbf{s}\mathbf{P}_0\boldsymbol{\sigma}^2_{\mathbf{s1,D1}}}{\mathbf{N}_0}} \tag{14}$$

VI. CONCLUSION

In this paper, we introduced the idea of combining two different relay selection schemes; threshold based relay selection and OT-MRS schemes. It has been shown that the proposed scheme reduces the power consumption of the relay nodes and also improves the spectral efficiency. Closed form expressions of SER for the proposed scheme were derived.

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APPENDIX A

If $\mathbf{X}_1$ and $\mathbf{X}_2$ are two independent exponential random variable with parameters β_1, β_2 and $\mathbf{z} = \frac{\mathbf{X}_1\mathbf{X}_2}{\mathbf{X}_1 + \mathbf{X}_2}$ is the harmonic mean of z. MGF of z in [10] is given as

$$\mathbf{M_z}(\mathbf{s}) = \frac{(\beta_1 - \beta_2)^2 + (\beta_1 + \beta_2)\mathbf{s}}{\Delta^2} + \frac{2\beta_1\beta_2\mathbf{s}}{\Delta^3}\frac{\boldsymbol{ln}(\beta_1 + \beta_2 + \mathbf{s} + \Delta)^2}{4\beta_1\beta_2} \tag{15}$$

Where $\Delta = \sqrt{(\beta_1 - \beta_2)^2 + 2(\beta_1 + \beta_2)\mathbf{s} + \mathbf{s}^2}$

With $\beta_1 = \frac{\mathbf{N}_0}{\mathbf{P}_0\sigma^2_{\mathbf{s1,Ri}}}$ and $\beta_2 = \frac{\mathbf{N}_0}{\mathbf{P_i}\sigma^2_{\mathbf{Ri,D}1}}$

At high SNR, for any relay if both β_1 and β_2 is zero then $\Delta = \mathbf{s}$

Thus MGF of (15) can be approximated as

$$\mathbf{M_z}(\mathbf{s}) \approx \frac{\beta_1 + \beta_2}{\mathbf{s}} + \frac{2\beta_1\beta_2}{\mathbf{s}^2}\boldsymbol{ln}\left(\frac{\mathbf{s}^2}{\beta_1\beta_2}\right) \tag{16}$$

At high SNR, the MGF can be further simplified as

$$\mathbf{M_z}(\mathbf{s}) \approx \frac{\beta_1 + \beta_2}{\mathbf{s}}$$