Trust-based Relay Selection in Relay-based Networks

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Abstract

It has been demonstrated that choosing an appropriate relay node can improve the transmission rate for the system. However, such system improvement brought by the relay selection may be degraded with the presence of the malicious relay nodes, which are selected but refuse to cooperate for transmissions deliberately. In this paper, we formulate the relay selection issue as a restless bandit problem with the objective to maximize the average rate, while considering the credibility of each relay node, which may be different at each time instant. Then the optimization problem is solved by using the priority-index heuristic method effectively. Furthermore, a low complexity algorithm is offered in order to facilitate the practical implementations. Simulation results are conducted to demonstrate the effectiveness of the proposed trust-based relay selection scheme.

Keywords: Probability, relay selection, stochastic optimization, trust.

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1. Introduction

The increasing demand on ubiquitous wireless broadband access drives the development of the next generation wireless communications. To come with the tide of trend, multihop relaying has gained much attention in recent years as an appealing strategy in future communication systems [1][2]. Using relay nodes to relay traffic between the base stations (BSs) and the mobile users is a promising approach to improving the capacity, coverage and quality of service enhancement in cellular networks. Many efforts have focused on cellular networks to deploy relaying technology [3]. More recently, the IEEE 802.16 standard committees have been working on the extension of the basic IEEE 802.16 standard, known as IEEE 802.16j [4], to incorporate functions of relay nodes into WiMAX networks.

The performance of using relay nodes in wireless communications has been widely investigated. Although it has been proved in [5] that using cooperative communications may achieve full diversity, the agreeable performance can only be achieved when the appropriate transmission route in the target cell is selected. Hence, which relaying route is selected is critically important. There have been some works on relay selection (RS) to improve the system performance, such as [6][7]. Reference [6] developed and analyzed a distributed RS method to select the best relay from a set of available relays based on local measurements of the instantaneous channel conditions for cooperation between the source and the destination, where no topology information is required. A general, yet simple, class of RS rules was optimized in [7] to select the number of relays based on the set of nodes that decode data from the source with the objective to minimize total energy consumption.

Although the system performance can be improved shown in the aforementioned works, the principle of RS was mostly based on the fact that all relay nodes are available to assist others for transmissions. In fact, a relay can refuse to cooperate when it is selected for cooperation or deliberately drop the received packets [8]. We refer to such a relay as a malicious relay. If this type of relay node is selected because of the better channel condition, the performance would be degraded largely due to its uncooperative behavior. Therefore, the reliability of the selected relay node is a critical issue. Trust is usually used to depict the reliability of a relay node, which has been defined early as the probability that the chosen relay node performs a specific action expected of it in [9]. Effort has been gradually given to the issue of trust in relay-based networks. In [8], a trust establishment method was proposed for cooperative wireless networks using Bayesian framework. A trust-assisted cooperative scheme that can detect attacks and has self-healing capability was designed to improve the combined signals from the source and relay nodes in [10]. Most of their works mainly focused on the establishment of the fundamental concepts of trust for relay nodes and the method to defend against unreliable behaviors caused by malicious relay nodes. Therefore, the importance of considering of the reliabilities of relay nodes in relay-based networks is self-evident. Nevertheless, still little attention was paid to the issue of creditability or trust of the relay node in the RS scheme.

In this paper we address the RS problem with the consideration of the trust value of relay nodes in a cooperative network. Firstly we formulate the trust-based RS issue as a restless bandit problem. Since the channel states are time-related random variables in wireless fading environments, a first-order finite-state Markov channel (FSMC) is used to model the wireless channels, which is widely accepted and can overcome the unpractical assumption of memoryless channel in most of literatures, where the estimated channel state information (CSI) of the current frame is simply taken as the predicted CSI for the next frame [11][12]. The optimal RS policy can be obtained by solving the restless bandit problem with the linear programming (LP) relaxation and priority-index (PI) heuristic algorithm. For reducing the quantity of signaling overheads, a distributed RS method is offered for the practical implementations. Through the simulation results, the effectiveness and usefulness of the proposed trust-based RS scheme are confirmed.

The remainder of the paper is organized as follows. In Section 2 we describe the system model. The problem of RS with the consideration of trust is formulated as a restless bandit system in Section 3 to obtain the maximization of the reward functions. We then present some implementation issues in Section 4. Simulation results are shown in Section 5 to demonstrate the performance of the proposed RS method. Finally, Section 6 concludes the paper.

2. System Model

We consider a cooperative network, which is shown in **Fig.1**, where a source node communicates with a destination node with the presence of a certain number of relay nodes. Relay nodes are randomly and uniformly distributed in the network. Here, the available relay nodes are referred to those which have the reliable source-to-relay link, and thus can correctly decode the signals received from the source node.

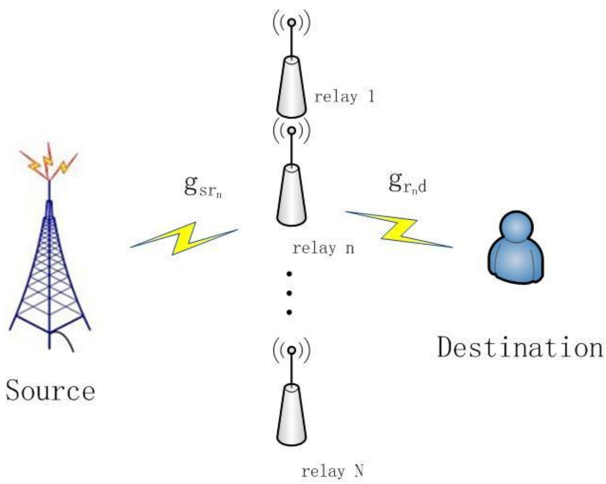

Fig. 1 System diagram

Without loss of generality, we assume that all the nodes are equipped with single antenna and work in half-duplex mode, that is, they cannot receive and transmit at the same time. In this paper, the discussion will focus on the decode-and-forward (DF) relaying scheme since it has advantages in digital processing and avoids noise amplification. In order to prevent the collision of the signals from the source and relay node, channel time is divided into equal length time slots, one of which is for one packet transmission. In the DF mode, during the odd time slots, the source node transmits to the relay node. The relay node then decodes the received signal and forwards to the destination node in the next time slot (i.e., an even time slot).

Let s, r_n, d denote the source node, n_{th} relay node, and destination node associated with network, respectively, where $n \in \mathrm{N}$, $\mathrm{N} = \{1, 2, ..., N\}$ and N is the total number of available relay nodes within this network. Denoting by g_{ij} the link gain between the node i and node j, where the node pair ij could be sr_n, sd, or r_nd. It is assumed that the link gains remain constant for at least one time slot. Let Es and Er_n be the transmit power of the source node and the transmit power of the n_{th} relay node, respectively. Our expectation of the optimization problem is to maximize the average rate, since this is a good indicator of the channel efficiency in the real wireless systems without considering complex coding, detecting and decoding procedures [7]. Given the physical designs of the transceivers, such as modulation and coding schemes (MCSs), the transmission rate between two directly communicating nodes is a monotonically increasing function of the received signal-to-noise-ratio (SNR). In other words, once the received SNR is obtained, the MCS can be mapped, and then the transmission rate could be determined based on the corresponding MCS. When using adaptive modulation, the transmission rate can be represented as $\theta(\gamma_{ij})$, which is the function of the received SNR γ_{ij} between the node i and node j. Accordingly, the transmission rate for DF with the relay node n is given by [5]

$$C_{r_n}^{DF} = \frac{W}{2}\min(\theta(\gamma_{sr_n}), \theta(\gamma_{r_n d})) \quad , \tag{1}$$

where W is the bandwidth, $\gamma_{sr_n} = \frac{E_s g_{sr_n}}{\sigma^2}$ and $\gamma_{r_n d} = \frac{E_{r_n} g_{r_n d}}{\sigma^2}$ are the received SNR at the relay node n and the destination node, respectively, σ^2 is the variance of noise. The factor 1/2 comes from the fact that every source or relay node transmits for half of the time slots.

The first-order FSMC models have been widely accepted in the literature as an effective approach to characterizing the correlation structure of the fading process [13]. In the FSMC, the channel state is characterized via the received SNR γ. The range of the average SNR of a received packet is partitioned (quantized) into K levels, and each level is associated with a state of a Markov chain, which has a finite state space denoted as $\Upsilon = \{Y_1, Y_2, \ldots, Y_K\}$. The channel varies over these states at each time slot according to a set of Markov transition probabilities. Let $\Gamma = \{\Gamma_0, \Gamma_1, \Gamma_2, \ldots, \Gamma_K\}$ be received SNR thresholds in the increasing order, where $\Gamma_0 = 0$ and $\Gamma_K = \infty$. The channel is in state k, if the received SNR γ of a packet is located in the range $[\Gamma_{k\text{-}1}, \Gamma_k)$. We assume that a one-step transition in the model corresponds to the channel state transition after one packet time slot t. Let $p_{\gamma(t),\gamma(t+1)}$ denote the probability that SNR moves from state $\gamma(t)$ at time instant t to state $\gamma(t+1)$ at time instant $t+1$. The channel state transition probability of the relay node is defined as:

$$p_{\gamma(t),\gamma(t+1)} = \Pr(\gamma(t+1) \mid \gamma(t)) \quad , \tag{2}$$

where $\gamma(t), \gamma(t+1) \in \Upsilon$. Based on the SNR threshold, the transition probability can be obtained [13].

We then provide some backgrounds on trust evaluation of a relay node. Generally, a malicious relay node can refuse to cooperate when it is selected for cooperation or deliberately drop the received packets with a certain probability. This kind of property can be measured by the trust value ω, which is defined as the degree of belief about the behavior of another entity [9]. Each relay node is associated with a real value ω from the interval [0, 1] which is called trust representing to what extent it is trustworthy. The larger the trust value is, the more the relay node can be worthy of trust and vice versa. For convenience, the trust value is partitioned (quantized) into V discrete levels in this paper, which has a finite state space denoted as $\Omega = \{\omega_1, \omega_2, \ldots, \omega_V\}$. Accurately speaking, the trust value for each relay node may be different at each time instant, which varies according to a certain transition probability. We can describe it with a state of a Markov chain, too. In other word, the trust value of a relay node will change to another based on a certain probability. Let $p_{\omega(t),\omega(t+1)}$ be the transition probability of trust value from one state to another for one relay node. The corresponding transition probability matrix of the relay node is given by

$$\Omega(t) = [p_{\omega(t),\omega(t+1)}]_{V\times V} \quad , \tag{3}$$

where $p_{\omega(t),\omega(t+1)} = \Pr(\omega(t+1)\,|\,\omega(t))$, $\omega(t),\omega(t+1)\in\Omega$, and V is the number of the trust levels.

In real systems, the values in the aforementioned transition probability matrices, including the channel state and trust level, can be obtained from the history observation, or measured in real field tests, when the threshold and state number are determined properly.

3. Restless Bandit Formulation

3.1 Problem Formulation

Before presenting the details, we first provide some background on the restless bandit problem. The restless bandit problem we address is as follows: Consider a collection of N projects, labeled $n \in \mathrm{N} = \{1, ... , N\}$. Project n can be in one of a finite number of states $i_n \in S_n$, where S_n represents the state set for project n. At each discrete time epoch $t \in \{0, 1, ...T-1\}$, exactly $M < N$ projects must be worked on, or set active. If project n, in state i_n, is worked on, then an active reward $R_{i_n}^1$ is earned, and its state changes in a Markovian fashion, according to an active transition probability matrix (into state j_n with probability $p_{i_n j_n}^1$). If the project is not worked on, then a passive reward $R_{i_n}^0$ is received, and its state then changes according to a passive transition probability matrix (into state j_n with probability $p_{i_n j_n}^0$). Rewards are time-discounted by a discount factor $0 < \beta < 1$. Projects are selected over time according to a Markovian scheduling policy u. Let U denote the class of admissible (Markovian) policies. The problem consists of finding a scheduling policy that maximizes the total expected discounted reward over an infinite horizon, which can be expressed by

$$Z^* = \max_{u\in U} E_u[\sum_{t=0}^{\infty}(R_{i_1(t)}^{a_1(t)} + R_{i_2(t)}^{a_2(t)} + ... + R_{i_N(t)}^{a_N(t)})\beta^t]. \tag{4}$$

In sum, the restless bandit problem can be simply generalized as M projects selected from N projects to maximize the specified discounted reward. Fortunately, the RS problem in this paper can also be describe as M relay nodes selected from N relay nodes. In terms of the analogy between these two problems, we can formulate the original RS-based optimization problem as the restless bandit problem as follows. Available N relay nodes to be selected can be mapped into the N projects in the restless bandit model. Because of only one relay node is chosen at each scheduling period, $M = 1$ will be active accordingly.

Then we describe the five important elements in this Markovian decision model, including the decision epochs; states; state transition probability; actions; rewards.

1) The source controller has to make a decision about which relay node is selected at each scheduling period. The instant times are called decision epochs.

2) The state of relay node is characterized by the received SNR $\gamma_{sr_n}(t)$ at the relay node, the received SNR $\gamma_{r_n d}(t)$ at the destination node and the trust value $\omega_n(t)$ for this relay node. Hence, the composite state of the relay node n can be represented by:

$$i_n(t) = \{\gamma_{sr_n}(t), \gamma_{r_n d}(t), \omega_n(t)\} \ , \tag{5}$$

where $\gamma_{sr_n}(t)$, $\gamma_{r_n d}(t)$ and $\omega_n(t)$ are channel state for the source-to-relay and relay-to-destination link, and the trust value for the relay node *n* at the time instant *t*, respectively. Relay node *n* can be in one of a finite number of states $i_n \in S_n$, where S_n represents the state set for relay node *n*.

3) The state transition probability function for the relay node *n* from the current state $i_n(t)$ to the next state $i_n(t+1)$ is denoted as $p_{i_n(t), i_n(t+1)}$, which is given by:

$$\begin{aligned} & p_{i_n(t), i_n(t+1)} \\ &= \Pr[i(t+1) \mid i(t)] \\ &= \Pr[\gamma_{sr_n}(t+1) \mid \gamma_{sr_n}(t)] \Pr[\gamma_{r_n d}(t+1) \mid \gamma_{r_n d}(t)] \Pr[\omega_n(t+1) \mid \omega_n(t)] \\ &= p_{\gamma_{sr_n}(t), \gamma_{sr_n}(t+1)} \, p_{\gamma_{r_n d}(t), \gamma_{r_n d}(t+1)} \, p_{\omega_n(t), \omega_n(t+1)} \quad . \end{aligned} \tag{6}$$

In practice, the changes of channel state for the source-to-relay link and for relay-to-destination link are independent with each other, i.e., the random variables $\gamma_{sr_n}(t)$ and $\gamma_{r_n d}(t)$ are independent. Because the relay state will change in a Markovian fashion, the transition probability matrix for relay node *n* can be expressed by

$$P_n(t) = [p_{\gamma_{sr_n}(t), \gamma_{sr_n}(t+1)}, p_{\gamma_{r_n d}(t), \gamma_{r_n d}(t+1)}, p_{\omega_n(t), \omega_n(t+1)}]_{(L \times Q \times V) \times (L \times Q \times V)} \ , \tag{7}$$

where *L*, *Q* and *V* are the number of the states for the source-to-relay link, relay-to-destination link, and trust levels, respectively.

4) The action for the relay node *n* is a binary variable, where $a_n(t) = 1$ when the n_{th} relay node is selected at the time epoch *t*; otherwise, $a_n(t) = 0$.

5) In the restless bandit problem, the system reward represents the optimization objectives. The wireless resource will be of waste if the chosen relay node with the best channel condition refuses to cooperate for transmissions. Consider a relay node has the best channel condition at that time. But this relay node refuses to transmit messages for others. Even the channel condition of this relay node is preferable, the relay node should not be selected in this scenario. Therefore, it is required to take account of the trust value in the optimization objective. Consequently, the system reward can be defined as

$$R_{i_n(t)}^{a_n(t)} = a_n(t) \omega_n(t) C_{r_n}^{DF} \ , \tag{8}$$

where the instantaneous reward $R_{i_n(t)}^{a_n(t)}$ is earned for the relay node *n* in state i_n when it takes action a_n in time slot *t*. For a stochastic process, a maximum immediate value does not mean the maximum expected long-term accumulated value. Therefore, we need to think about more than just the instantaneous reward that the system can receive.

3.2 Solution to the Restless Bandit Problem

To solve the aforementioned problem, the above stochastic control system can be naturally formulated as a linear program and be solved with LP relaxation and PI heuristic algorithm in terms of [14]. To formulate the problem mathematically, some transition performance measures are introduced as

$$x_{i_n}^1(u)=E_u[\sum_{t=0}^{T-1}(I_{i_n}^1(t)\beta^t)] \quad , \tag{9}$$

$$x_{i_n}^0(u)=E_u[\sum_{t=0}^{T-1}(I_{i_n}^0(t)\beta^t)] \quad , \tag{10}$$

where

$$I_{i_n}^1(t)=\begin{cases}1, \text{ if relay } n \text{ is in state } i_n \text{ and active at time } t \\ 0, \text{ otherwise}\end{cases} \quad , \tag{11}$$

$$I_{i_n}^0(t)=\begin{cases}1, \text{ if relay } n \text{ is in state } i_n \text{ and passive at time } t \\ 0, \text{ otherwise}\end{cases} \quad . \tag{12}$$

Let α_{i_n} denote the probability that the initial state is in state i_n. The first-order relaxation of (4) can be formulated as the linear program as

$$(\mathrm{LP}^1) \qquad Z^1=\max\sum_{n\in\mathrm{N}}\sum_{i_n\in S_n}\sum_{a_n\in\{0,1\}}R_{i_n}^{a_n}x_{i_n}^{a_n} \tag{13}$$

Subject to: $x_{i_n}^{a_n}\in\Xi$,

$$\sum_{n\in\mathrm{N}}\sum_{i_n\in S_n}x_{i_n}^1=\frac{1}{1\text{-}\beta} \quad ,$$

where Ξ is the projection of restless bandit polyhedron over the space of the variable $x_{i_n}^{a_n}$ for project n, which is given by $\Xi=\{x_{i_n}^{a_n}|x_{i_n}^0+x_{i_n}^1=\alpha_{j_n}+\beta\sum_{i_n\in S_n}\sum_{a_n\in\{0,1\}}p_{i_n j_n}^{a_n}x_{i_n}^{a_n}, j_n\in S_n\}$.

In order to solve this program, the heuristic method is presented, which uses information contained in optimal primal and dual solutions to the first-order relaxation LP^1. The dual function of the original linear program LP^1 is

$$(\mathrm{D}^1) \qquad Z^1=\min\sum_{n\in\mathrm{N}}\sum_{j_n\in S_n}\alpha_{j_n}\lambda_{j_n}+\frac{1}{1\text{-}\beta}\lambda \tag{14}$$

Subject to: $\lambda_{i_n}\text{-}\beta\sum_{j_n\in S_n}p_{i_n j_n}^0\lambda_{j_n}\ge R_{i_n}^0$,

$$\lambda_{i_n}\text{-}\beta\sum_{j_n\in S_n}p_{i_n j_n}^1\lambda_{j_n}+\lambda\ge R_{i_n}^1 ,$$

$$\lambda \geq 0, \qquad .$$

where λ_{i_n} , λ are the Lagrange dual variables. Define { $x_{i_n}^{a_n}$ } and { λ_{i_n} , λ } be the optimal primal and dual solution pair to the first-order relaxation LP^1 and its dual function D^1.

To facilitate the practical implementation, the primal-dual heuristic can be interpreted as a PI heuristic in terms of [14]. Let { $\varepsilon_{i_n}^{a_n}$ } be the corresponding optimal reduced cost coefficients:

$$\varepsilon_{i_n}^0 = \lambda_{i_n} - \beta \sum_{j_n \in S_n} p_{i_n, j_n}^0 \lambda_{j_n} - R_{i_n}^0 , \tag{15}$$

$$\varepsilon_{i_n}^1 = \lambda_{i_n} - \beta \sum_{j_n \in S_n} p_{i_n, j_n}^1 \lambda_{j_n} + \lambda - R_{i_n}^0 , \tag{16}$$

which must be nonnegative. The optimal reduced costs can be interpreted as the rate of decrease in the objective value of the linear program LP^1 per unit increase in the value of the variables $x_{i_n}^0$ and $x_{i_n}^1$, respectively. Then, the priority index of relay node n with the current state i_n is defined as

$$\delta_{i_n} = \varepsilon_{i_n}^1 - \varepsilon_{i_n}^0 \quad . \tag{17}$$

The rule of the PI is to select the relay node with the smallest priority index δ_{i_n} . Because of the length of this paper, please refer to [14] for more details.

4. Implementation Issues

Below we propose a low complexity algorithm for implementing the trust-based RS scheme. Since the priority indices can be computed and stored into a table offline before transmission, the proposed RS process can be divided into the offline stage and the online stage. Before any transmission starts, the offline computation should be performed first. The trust level for each relay node is known to the source node by observing the previous behaviors. The related system parameters, like the SNR threshold and the available state number, are given according to system requirements. It takes the state transition probability matrix, the reward function, the discount factor, and the initial state probability as input. Then priority indices { δ_{i_n} } as output are obtained according to Section 3. Each relay node stores these priority indices and the corresponding input parameters in an index table.

The detailed online procedure is described as follows. It assumes that the signaling information can be received by every node without error and the relay nodes within one network can directly communicate with each other perfectly. Before each time slot, the source node broadcasts a pilot signal with full power. Every potential relay node and destination node can detect its own SNR based on it. Then the destination node feeds back its clear-to-send-like message to the source and relay nodes. After receiving the message from both the source and destination nodes, each relay node n can compute its own index δ_{i_n} by looking up the offline-established index table and broadcasts a PI packet, which contains this index and the corresponding MCS. When other available relays receive this PI packet, they will compare the received index with their own indices and broadcast their own PI packet only if their own indices are smaller than the received index. Otherwise they will keep silent. We can set a timer on each scheduling instant. After the timer expires, the source receives all the PI packets, and the relay node with the smallest index will not receive any PI packet and will be selected at this scheduling instant. The destination node adopts the relay node with the smallest index at the same time. In this way, the optimal relay node can be selected while considering its creditability of relay nodes simultaneously.

5. Simulation Results

In this section, we present simulation results to demonstrate performance of the proposed solution in a cooperative network. We use the M-ary quadrature amplitude modulation (MQAM) and binary phase shift keying (BPSK) with modulation levels {2, 4, ...} as the available modulation schemes. We assume that the state of the source-to-relay channel can be ordinary for QAM or good for 16QAM, the MCSs of the relay-to-destination channel can be BPSK, QAM, or 16QAM based on different channel states. For explicit expressions, we define $\Phi_n(t)=[p_{\gamma_{sr_n}(t),\gamma_{sr_n}(t+1)}]_{L\times L}$, $\Psi_n(t)=[p_{\gamma_{r_nd}(t),\gamma_{r_nd}(t+1)}]_{Q\times Q}$ as the probability matrices of the source-to-relay and relay-to-destination channel for relay node n, respectively. The state transition probability matrices of the source-to-relay and relay-to-destination channels are respectively

$$\Phi_n=\begin{pmatrix}0.7 & 0.3\\ 0.3 & 0.7\end{pmatrix},\ \Psi_n=\begin{pmatrix}0.7 & 0.2 & 0.1\\ 0.15 & 0.7 & 0.15\\ 0.1 & 0.2 & 0.7\end{pmatrix}.$$

The available level of trust value ω_n for relay node n can be chosen from the set { 0.25, 0.5, 0.75, 1 }. The corresponding trust state transition probability matrix is

$$\Omega_n=\begin{pmatrix}0.8 & 0.1 & 0.05 & 0.05\\ 0.05 & 0.8 & 0.1 & 0.05\\ 0.05 & 0.1 & 0.8 & 0.05\\ 0.05 & 0.05 & 0.1 & 0.8\end{pmatrix}.$$

Consequently, there are 24 states for each available relay node. Given the state γ_{sr_n} , γ_{r_nd} and ω_n, the overall state transition probability matrices of each relay node P_n can easily be acquired through Kronecker tensor product, i.e., $P_n = \Phi_n \otimes \Psi_n \otimes \Omega_n$. The corresponding transmission rate of BPSK, QAM, and 16QAM are 1, 2, and 4, respectively. We set the discount factor $\beta = 0.8$.

Some relevant RS methods are simulated for comparisons. The principle of RS in the first method is based on the *Memoryless RS* method [15], where the estimated CSI of the current frame is simply taken as the predicted CSI for the next frame. The second method is the proposed *Trust-based RS* scheme. The method without considering the reliability of the relay node is compared here, denoted as the *No-trust RS* method. In the *Random RS* method, each link randomly selects one of the *N* relay nodes with probability *1/N*. Based on Monte Carlo method over sufficient trials, the average performances are obtained.

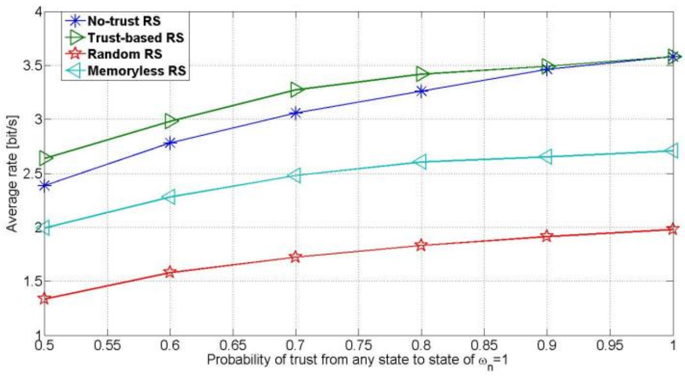

Fig. 2. Average rate versus trust

The influence of trust on the performance is first investigated. Ten relay nodes are placed within the network. **Fig. 2** depicts the average rate versus the probability of trust level from every state to the best state of $\omega_n = 1$, i.e., the value of last column of Ω_n. As seen in **Fig. 2**, the *No-trust RS* method is worse than the proposed *Trust-based RS* method, which indicates that the trust levels for relay nodes will have a great influence on the system performance. However, with the increase of the transition probability to the trust level of $\omega_n = 1$, the performance of the *No-trust RS* method is approaching to that of the proposed *Trust-based RS* method. This is because the *No-trust RS* is equivalent to the proposed *Trust-based RS* method when all relay nodes are ready to cooperate for transmissions. It is also observed that the performance by the *Memoryless RS* method is inferior to that by the proposed method since the *Memoryless RS* method selects a relay node for the subsequent time slot according to the current state, which however may change in the subsequent time slot.

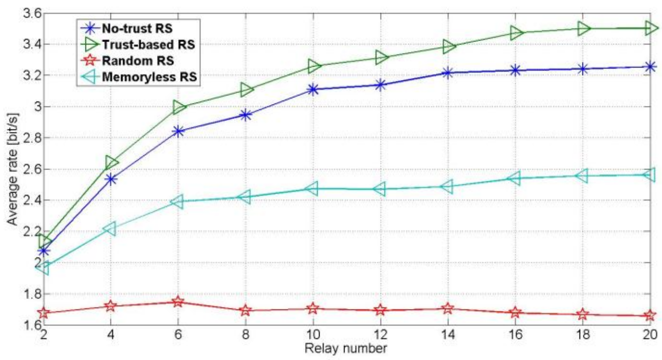

Fig. 3. Average rate versus relay number

Results of the average rate with different numbers of relay nodes are shown in **Fig.3**. We have similar observations with respect to other methods as the aforementioned figure. As in **Fig.3**, better performances for the average rate are obtained when a large number of relay nodes are deployed due to more available opportunities.

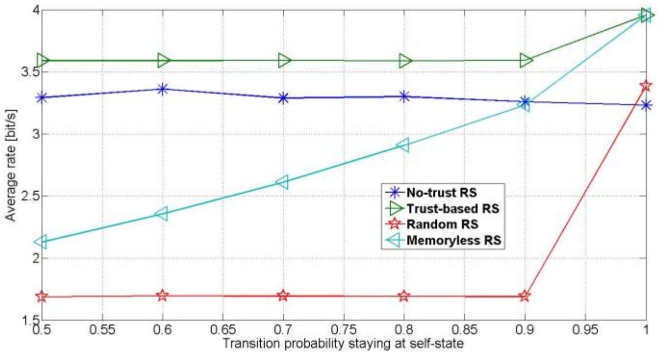

Fig. 4. Average rate versus transition probability

The advantage of the proposed method in the time-varying channel environment is also investigated. We assume the best transmission rate can be achieved at the initial state of source-to-relay and relay-to-destination channels. That means the source-to-relay channel and the relay-to-destination channel at this initial state are good enough to use the QAM and 16QAM, respectively. **Fig. 4** shows the average rate with different state-transition probabilities of staying in this initial state. Ten relay nodes are placed within the network. It can be seen that the performance of the *Memoryless RS* method is getting closer to that of the proposed *Trust-based RS* scheme with the increase of the state transition probability of staying in the initial state, and this method performs as good as the proposed scheme when the channel is absolutely static, in which the state transition probability that the channel will be staying at the same initial state approaches one. This indicates that the performance of the *Memoryless RS* method will be better if the wireless channel is nearly static. It is also noticed that the performance of the *Random RS* method becomes good sharply when the transition probability of staying in the initial state is equal to one. This is due to the fact that the best channel condition can be obtained at each relay node when relay nodes are always staying at the initial state. Much gain could be brought, whichsoever relay node is selected.

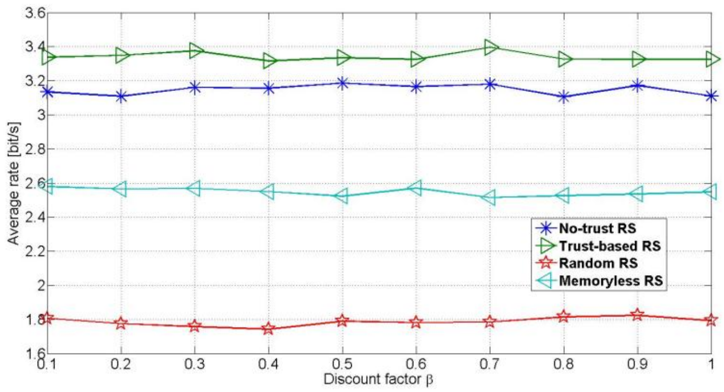

Fig. 5. Average rate versus discount factor

Finally, the impact of discount factor on the system performance is studied in **Fig. 5.** To account for the time value of rewards, we often introduce a discount factor β ($0 < \beta < 1$), which measures the value at current time instant of a one unit reward received at next time instant. Note that the performance of the proposed *Trust-based RS* method is still better than any other methods, regardless of the discount factor. It is also observed that taking the discount factor into account does not affect any theoretical results or algorithms.

6. Conclusion

In this paper we have studied the issue of the RS in relay-based networks, where relay nodes have different credibility. This RS problem, in which the trust levels for relay nodes are considered, is formulated as a restless bandit problem and then solved by the PI heuristic method. According to the proposed low complexity algorithm, the RS process can be easily performed in practical networks. Extensive simulation results are conducted to verify that this proposed trust-based RS method can yield great improvements on the system performance with low complexity.

Due to the scope of this paper, merely the security is considered for the RS method. To further understand the performance, more sophisticated issues, like the delay and uncertainty of channel estimation, are required to be taken into account.

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