Trust-based Incentive Cooperative Relay Routing Algorithm for Wireless Networks

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***Abstract*—Recently, cooperative communication has been proposed as an effective approach to enhance system performance in wireless networks. Cooperative communications fundamentally change the abstraction of a wireless link and offer significant potential advantages for wireless communication networks. In this paper, we propose a novel cooperative relay routing scheme based on the trust-based incentive mechanism. To maximize the network performance, the proposed scheme can take into account the measure of the probability of a relay node succeeding at a given relay service. By considering the current network condition, we can select the most adaptable relay node and pay the incentive-price for relay service. Evidences from simulations demonstrate that the proposed scheme outperforms the existing schemes.**

Keywords-Cooperative communication; Relay selection; Trust evaluation; Incentive mechanism; Vickrey-Clarke-Groves (VCG) mechanism.

I. INTRODUCTION

Today, wireless communication systems are primarily designed based on point-to-point links whose performance is limited by the resources of a single transmitter. In particular, bandwidth and transmit power constraints often prevent a source node from achieving a desired data rate or communication range. Cooperative communications have emerged as a new novel approach that enables a source to tap into the available resources of local neighboring nodes in order to increase throughput, range and covertness [1]. Therefore, a cooperative communication improves performance in wireless systems, but it requires some nodes to expend energy acting as relays. Since energy is scarce, wireless nodes refuse to cooperate in order to conserve resources. However, only when relay node expends extra energy on its behalf, network performance can increase. Due to this realistic constraint, cooperative communication has yet to see widespread use in practical wireless systems [2]. Therefore, it is necessary to design incentive-aware relay routing algorithms for stimulating cooperation among nodes. But, despite the concerns, not much work has been done in this direction. In this article, we address this problem by examining the trust based incentive mechanism. In the proposed scheme, the attenuation window technique is adopted to estimate the trust value based on historical data [3]. Based on the individual trust value, we select an adaptive relay node and cooperative routing takes place with the help of the relay node, which is incentivized by the relay service price. To calculate the service price for a relay node, the basic concept of *Vickrey-Clarke-Groves* (*VCG*) mechanism [4] is used.

Usually, mechanisms that implement efficient social choice functions in environments in which participants have private information about their preferences have been studied extensively in the economics literature. A well-known class of such mechanisms are the *VCG* mechanisms [5]. It is a generalization of the famous *Vickery* auction where bidders submit written bids without knowing the bid of the other people in the auction. The important property of the *VCG* mechanism is that it is truthful; each bidder reveals his/her true value no matter what strategies the other bidder chooses. The main result in this setting provides an incentive compatible for the most natural social choice function [5].

In this work, the proposed scheme adapts in order to obtain the trust values in the real-time, online. This approach is able to select the relay node under dynamic changing wireless network environments; it is essential in order to maximize the network performance. Recently, several cooperative communication schemes – the *Threshold based Cooperative Communication* (*TCC*) scheme [6] and the *Distributed Relay Routing* (*DRR*) scheme [7] - have been presented for wireless network systems. This research implicates that cooperative communication is envisioned to achieve high diversity gain in terms of outage probability and outage capacity and scaling network capacity. The *TCC* scheme [6] is a new approach to relay selection using a threshold-based transmission protocol for a wireless system. The *DRR* scheme [7] is a decentralized and localized algorithm for joint dynamic routing, relay assignment, and spectrum allocation in a distributed and dynamic environment. All the earlier work has attracted a lot of attention and introduced unique challenges to efficiently solve the cooperative communication problem. Compared to these schemes [6][7], the proposed scheme attains better performance in cooperative communications.

This paper is organized as follows. Section II presents the proposed algorithms in detail. In Section III, performance evaluation results are presented along with comparisons with

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other schemes. Finally, concluding remarks are given in Section IV.

II. PROPOSED COOPERATIVE COMMUNICATION ALGORITHM

In this paper, trust-based *VCG* mechanism is used to design a new cooperative communication algorithm. Based on the trust value of each relay node, the most adaptable relay node is selected. To induce selfish relay nodes to participate cooperative communications, the relay service price is provided for the relay service. Finally, an effective solution can be obtained in the constantly changing environment.

A. Trust Evaluation for Relay nodes

In this paper, we assume a wireless network situation where there is a set (N) of potential relay nodes, $N = \{1,2..,i..,n\}$. Each relay node (i.e., $i \in N$) has a service value and privately-known relay cost of performing the service request τ. Let σ denote a particular relay service acceptance within the space of possible acceptances Ψ and τ^i represent that the node i allows to relay call service τ; $\sigma \in \Psi$ and $\Psi = \{\emptyset, \tau^1, \tau^2 \ldots \tau^n\}$, where $\emptyset$ denotes the case where the relay request is rejected. If $\Psi = \{\tau^i\}$, the relay node i participates the cooperative communication. The set of available power levels ($\mathbb{S}$) for each relay node is assumed as below.

$$\mathbb{S} = \{\Pi_{i \in N} p_i | p_i \in [p_{min}, p_{max}]\} \quad (1)$$

where p_i is the power level of relay node i. The p_{min}, p_{max} are the pre-defined minimum and maximum power levels, respectively. Each relay node selects a power level from the $\mathbb{S}$, and estimates the expected value ($v_i(\tau)$) as follows.

$$v_i(\tau) = \left(W \times \log_2\left(1 + \frac{\gamma_i(\mathbb{P})}{\Omega}\right)\right) / p_i$$
$$\text{s.t., } \gamma_i(\mathbb{P}) = \frac{p_i h_{ii}}{\vartheta_i + \sum_{j \neq i} p_j h_{ji}} \quad (2)$$

where $\mathbb{P}$ is the power level vector for all nodes and W is the channel bandwidth of relay node i, and Ω ($\Omega \geq 1$) is the gap between uncoded M-ary Quadrature Amplitude Modulation (M-QAM) and the capacity, minus the coding gain [6]. Usually, service value is defined as the number of information bits that are transmitted without error per unit-time. In wireless networks, it can be achieved with the Signal to Interference plus Noise Ratio (SINR) in the effective range. Therefore, to estimate the service value, the SINR should be obtained. The $\gamma_i(\mathbb{P})$ is a general formula for the relay i's SINR, where ϑ_i is the background noise within the relay node i's bandwidth, h_{ji} is the path gain from the node j to the node i [8].

Under a dynamically changing network environment, there exists uncertainty about relay nodes successfully completing their assigned relay services. In the proposed scheme, we take into account the trust value (T) of relay nodes. $T_i(t)$ is the relay node i's trust value at the time t. After the t^{th} iteration, $T_i(t)$ is using the number of packets successfully serviced in the relay node i (α_t^i) divided by the total number of packets that have been sent from the source node to the relay node i ($\alpha_t^i + \beta_t^i$).

$$T_i(t) = \frac{\alpha_t^i}{\alpha_t^i + \beta_t^i} \quad (3)$$

$T_i(t)$ is a general average function over the whole span of communication historical records. However, for a long-term period evaluation, the α_t^i and β_t^i will be accumulated and are growing into a very large value. In such case, a small amount of the recent malicious behaviours will be hard to be counted and thus has impact on the overall rating of trust. To solve this problem, attenuation window was introduced [3]. By considering more on the up-to-date records, we can calculate the trust value ($T_i(t)$) while fade away the out-of-date records. Based on the attenuation window, the α_t^i and β_t^i values is obtained as below.

$$\alpha_t^i = \sum_{\lambda=k}^{n} e^{-\left(\frac{n+m-t(\lambda)}{c}\right)}$$
$$and\ \ \beta_t^i = \sum_{\lambda=j}^{m} e^{-\left(\frac{n+m-t(\lambda)}{c}\right)} \quad (4)$$

where the e is Euler's constant, and c is the coefficient to adjust the speed of decreasing in the results of α_t^i and β_t^i. The n and m are the total number of successfully serviced and non-successfully serviced packets, respectively. The k and j are the most out-of-date time for successfully serviced and non-successfully serviced packets, respectively. $t(\lambda)$ is the time t when λ occurs. For example, there are 3 successful service records regarding to the packet relaying but 2 non-successful service records, i.e., n=3 and m=2. Here, the successful service time set are t = {1, 3, 5} and non-successful service time set are t = {2, 4}. Thus the k=1 and j=2. As the time t is from ascending order that it reflects from oldest to latest in time sequence [2]. While t is growing bigger and bigger, the value of (n+m-t) will become smaller and smaller, and finally $e^{-\left(\frac{n+m-t}{c}\right)}$ has a strong impact on the recent information. Moreover, the bigger value of coefficient c, the slower in speed of decreasing slopes of the value in $e^{-\left(\frac{n+m-t}{c}\right)}$ between 0 and 1. In such way, attenuation window can emphasize the most up-to-date records and fade away the out-of-date records by the speed controlled by the coefficient c.

B. Relay Selection and Relay Service Price Computation

The proposed scheme adopts the basic concept of *T-VCG* mechanism to provide a normative guide for the payments of relay service [4]. Even more importantly, we consider the trust value in computing the relay payment. With the estimated trust value, the expected payoff value of relay node, $\bar{\chi}(\tau,\sigma,\mathbb{T})$, can be calculated as:

$$\bar{\chi}(\tau,\sigma,\mathbb{T}) = v_{\sigma}(\tau) \times T_{\sigma}(\tau), \text{ s.t., } \sigma \in \Psi \tag{5}$$

where $v_{\sigma}(\tau)$ is the expected value with relay task τ and $T_{\sigma}(\tau)$ is the trust value in the selected relay node σ, which performs the requested relay service τ. To implement the execution uncertainty by a given relay node, the network system needs to require relay nodes to report their trust value. $\mathbb{T} = \langle T_1(\tau) \ldots T_{\sigma}(\tau) \ldots T_n(\tau)\rangle$ is the vector of trust values of all the relay nodes. In this paper, $\widehat{\mathbb{T}}$ represents the vector of reported trust values $\langle \widehat{\mathbb{T}}_1(\tau), \ldots, \widehat{\mathbb{T}}_n(\tau)\rangle$; the superscripting the latter with '^' indicates that nodes can misreport their true types. With the expected payoff value, service execution cost is necessary to estimate the total profit. The cost function defines the instantaneous expense for the relaying service σ. It would be a linear function of the tower level, and given by $K \times (p_{\sigma})^q$, where K and q are estimation parameters and p_{σ} is the power level for the σ service.

In the proposed scheme, relay connections are adaptively controlled based on the accurate analysis of costs and payoffs to select the most suitable relay node. In more detail, the relay selection is determined as follows to maximize system efficiency.

$$S^*(\Psi,\widehat{\mathbb{T}}) = arg \max_{\sigma\in\Psi} \left[\bar{\chi}(\tau,\sigma,\widehat{\mathbb{T}}) - K \times (\hat{p}_{\sigma})^q\right] \tag{6}$$

In the real world operation, $\mathbb{T}$ and p_{σ} can be misreported (i.e., $\widehat{\mathbb{T}}$ and $\hat{p}_{\sigma}$). After selecting a relay node, the next step is to compute the relay price, which is an incentive to encourage relay communications. In this paper, the relay service price is similar to that of the traditional *VCG* mechanism in that the marginal contribution of the selected relay node to the wireless network system; it is extracted by comparing the second best decision, excluding the selected relay node. Without the best relay node $S^*(\Psi,\widehat{\mathbb{T}})$, the second-best expected payoff for the relay service ($EU_{\sigma\in\Psi_{-S^*(\Psi,\widehat{\mathbb{T}})}}(\Psi,\widehat{\mathbb{T}})$) is given by

$$EU_{\sigma\in\Psi_{-S^*(\Psi,\widehat{\mathbb{T}})}}(\Psi,\widehat{\mathbb{T}}) = \max_{\sigma\in\Psi_{-S^*(\Psi,\widehat{\mathbb{T}})}} \left(\bar{\chi}(\tau,\sigma,\widehat{\mathbb{T}}) - K \times (\hat{p}_{\sigma})^q\right) \tag{7}$$

where $\Psi_{-S^*(\Psi,\widehat{\mathbb{T}})}$ is the set of possible acceptances (Ψ) excluding the best relay node $S^*(\Psi,\widehat{\mathbb{T}})$. If the selected relay node ($S^*(\Psi,\widehat{\mathbb{T}})$) can success to provide relay service, the relay service price ($RSP_{S^*(\Psi,\widehat{\mathbb{T}})}$) is achieved based on the expected marginal contribution, which is the difference between the best and the second-best expected payoff.

$$RSP_{S^*(\Psi,\widehat{\mathbb{T}})} = \left[\bar{\chi}(\tau, S^*(\Psi,\widehat{\mathbb{T}}),\widehat{\mathbb{T}}) - K \times (\hat{p}_{S^*(\Psi,\widehat{\mathbb{T}})})^q\right] - EU_{\sigma\in\Psi_{-S^*(\Psi,\widehat{\mathbb{T}})}}(\Psi,\widehat{\mathbb{T}}) \tag{8}$$

Sometimes, the selected relay node (i.e., $S^*(\Psi,\widehat{\mathbb{T}})$) can fail to provide relay service. In this case, the $RSP_{S^*(\Psi,\widehat{\mathbb{T}})}$ is given by.

$$RSP_{S^*(\Psi,\widehat{\mathbb{T}})} = -EU_{\sigma\in\Psi_{-S^*(\Psi,\widehat{\mathbb{T}})}}(\Psi,\widehat{\mathbb{T}}) \tag{9}$$

Finally, $RP_i(\widehat{\mathbb{C}},\widehat{\mathbb{P}},\sigma)$ can be obtained as follows by considering success and fail cases .

$$RSP_{S^*(\Psi,\widehat{\mathbb{T}})} = T_{S^*(\Psi,\widehat{\mathbb{T}})}(t) \times \left(\left[\bar{\chi}(\tau, S^*(\Psi,\widehat{\mathbb{T}}),\widehat{\mathbb{T}}) - K \times \left(\hat{p}_{S^*(\Psi,\widehat{\mathbb{T}})}\right)^q\right] - EU_{\sigma\in\Psi_{-S^*(\Psi,\widehat{\mathbb{T}})}}(\Psi,\widehat{\mathbb{T}})\right) + \left(1 - T_{S^*(\Psi,\widehat{\mathbb{T}})}(t)\right) \times \left[-EU_{\sigma\in\Psi_{-S^*(\Psi,\widehat{\mathbb{T}})}}(\Psi,\widehat{\mathbb{T}})\right] \tag{10}$$

III. PERFORMANCE EVALUATION

In this section, the effectiveness of the proposed scheme is validated through simulation. Recently, the TCC scheme [6] and the DRR scheme [5] have been published and introduced unique challenges for cooperative communications. Using a simulation model, we compare the performance of the proposed scheme with these existing schemes to confirm the superiority of the proposed approach. The assumptions implemented in simulation model are as follows. Each relay service is considered Constant Bit Rate (CBR) traffic with having a different deadline. In order to adaptively adjust the control parameters, we partition the time-axis into equal intervals of length (i.e., a short time duration). Every interval, the current system condition is examined periodically by a real-time online approach, and the performance measures obtained on the basis of 50 simulation runs. Relay transmitters use variable-rate M-QAM, with a bounded probability of symbol error and trellis coding with a nominal coding gain. Table 1 shows the system parameters used in the simulation.

For dynamically changing network environments, the design goal of the proposed scheme is to improve the overall network performance. Figures 1 and 2 show the performance comparison for the network throughput and energy efficiency, respectively. All the schemes have similar trends. However, the proposed scheme constantly monitors the current network condition and effectively operates relay routing through the trust based incentive mechanism. Under various network operation times, the system performance of the proposed scheme is better than the other schemes.

TABLE I. SYSTEM PARAMETERS USED IN THE SIMULATION EXPERIMENTS.

Parameter	Value	Description	
N	5	number of relay stations (n)	
W	256 Kbps	bandwidth requirement for service	
P_{min}, P_{max}	50mW, 100mW	pre-defined minimum and maximum power levels	
c	1	control the decreasing slopes of e curve	
K	1	power parameter power cost function	
q	0.7	cost function parameter about power	
ϑ	1×10^{-10}	AWGN background noise	
Ω	1	gap between uncoded M-QAM and the capacity, minus the coding gain	
Parameter	**Initial**	**Description**	**Values**
P_i	50mW	communication power for the users i	50,60,70,80,90,100mW

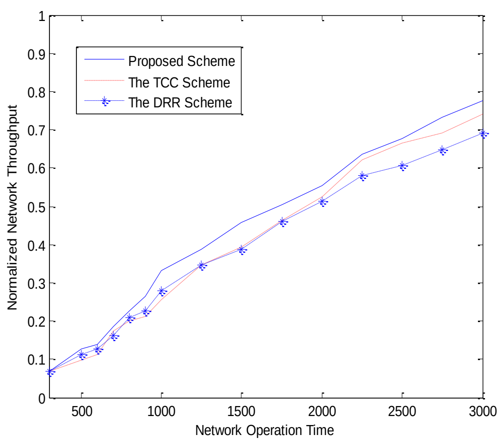

Figure 1. Network Throughput

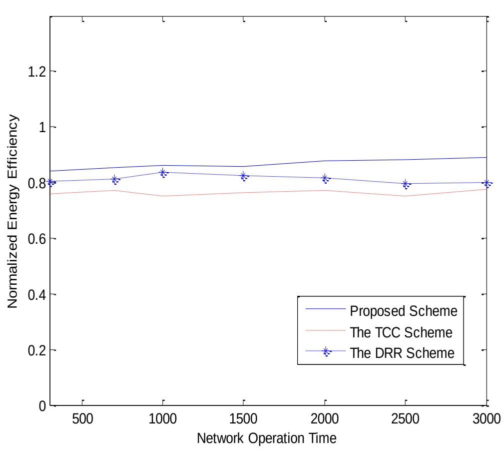

Figure 2. Energy Efficiency

IV. CONCLUSIONS AND FUTURE WORK

With the rapid growth of mobile Internet, offering seamless connectivity and high-speed multimedia services in different types of wireless networks are important features in next generation wireless networks (4G networks). For next-generation wireless networks, cooperative communication is an emerging technology to overcome the current limitations of traditional wireless systems. This promising technique has been considered in the IEEE 802.16 standard, and is expected to be integrated into LTE multi-hop cellular network. In this paper, we have introduced a new trust-based incentive relay routing algorithm for wireless networks. Based on the trust-based VCG mechanism, the proposed algorithm dynamically estimates relay nodes' trust levels and adaptively selects the most adaptable relay node for the data transmission. Moreover, we suggest the new trust estimation mechanism. Our model is designed to adapt to various changes, such as changes in trust behaviors and trust accuracy requirement. Usually, traditional routing methods cannot solve the problem of malicious behavior and build the trusted transfers route between nodes. In the proposed scheme, the subjective confidence for the routing behavior has transform into trust evaluation with the probability model to solve the trust measurement and routing. Simulation results clearly indicate that the proposed algorithm generally exhibits superior performance compared with the other existing schemes. Future work in progress is to study efficient power control and relay selection schemes for green cooperative communications based on the game theory.

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