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Monitoring strategy for relay incentive mechanism in cooperative communication networks☆

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ABSTRACT

Cooperative communication is a promising technique to improve wireless network's capacity and resource management's efficiency. However, due to the limited wireless network resource, the potential selfish relay nodes may not be willing to cooperate without any extra incentives. In this paper, a contract-based relay incentive mechanism is investigated under the *dual asymmetric network information* scenario. The optimal contract design is proposed to achieve the twin objectives of *ability-discrimination* and *effort-incentive*. Considering the feature of asymmetric information, the various monitoring strategies are designed by introducing a monitoring node. The optimal contract designs with the *information-monitoring* and the *action-monitoring* strategies are presented. Simulation results show that the optimal contract design effectively incentivizes relay nodes' participation, and the performance of the *action-monitoring* strategy yields a significant enhancement compared with the *non-monitoring* and the *information-monitoring* strategies.

1. Introduction

Cooperative communication has emerged as a powerful technique to exploit user diversity and provide high capacity in wireless networks [1]. Individual wireless nodes cooperate to improve network capacity and provide rich services and applications. The cooperation can be achieved either by installing fixed relays within the network coverage or by making the other mobile nodes act as relays. Due to the minimal changes required in existing infrastructures, cooperation strategy with mobile nodes has been received extensive attentions.

However, designing a cooperative communication mechanism is considerably challenging. As each mobile node has limited battery and providing relaying assistance would incur significant energy consumption, the potential selfish relay nodes (RNs) may not be willing to cooperate without any extra incentives. Moreover, the various relay selection algorithms require near complete network information to select the potential RNs effectively. However, due to the mobility of wireless nodes, the shadowing and fading effects of the wireless channels, network information (i.e., node locations, channel conditions, QoS requirements, relay actions) may not be available to all the wireless nodes [2]. Furthermore, this network information may belong to the RNs privately and the RN may not be willing to share this information with others, which results in

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information asymmetry between the source and the RNs. Therefore, the objective of this work is to address these challenging issues with a robust *relay incentive mechanism*.

The *relay incentive mechanisms* have been investigated recently, which can be broadly divided into the following three categories. In *payment-based mechanisms*, the virtual money is exchanged between nodes to reward and encourage the RNs to cooperate. These mechanisms have been widely considered in wireless networks [3]. Another adopted approach is *reputation-based mechanism*, where a centralized authority keeps records of cooperative behaviors and punishes non-cooperating users [4]. However, these mechanisms always rely on the usage of tamper-proof hardware to store and check reputation credits. In *resource-exchange based mechanisms*, wireless nodes can trade their own resources for the partner nodes' relay help directly [5]. However, when the source's own spectrum demand is high, there will be hardly any spectrum left for exchange. Therefore, in this study, we concentrate on an alternative payment-based mechanism, *contract theory*, towards cooperative communication under the *dual asymmetric information* scenario.

Contract theory [6] is an economic concept which investigates how to design the mutually agreeable contract among the economic players under the asymmetric or incomplete information scenarios. Recently, contract-based solutions have been suggested for spectrum trading [7], cooperative networks [2,8], traffic offloading [9], and device-to-device communication [10]. However, most existing works considered the *single asymmetric information* (i.e., either the RNs' private information or hidden action); while this work focuses on *relay incentive mechanisms* under the *dual asymmetric information* scenario, which means that the source is not only unaware of the RNs' relay static information (i.e., relay cost) but also the dynamic information (i.e., relay actions). Furthermore, as the RNs' relay cost and actions are unobservable, the RNs may be prone to shirk cooperation. Guided by monitoring theory [11], this work proposes the contract-based monitoring strategy to combat shirking. To the best of our knowledge, the problem of the *dual asymmetric information* with the monitoring strategy has not been studied yet.

The main contributions of this paper are as follows.

- By exploiting the *cooperative mechanisms* and design challenges in multi-user cooperative communication, the contract-theoretic model is proposed to incentivize the RNs to cooperate effectively under the *dual asymmetric information* scenario. The optimal contract is designed to achieve the twin objectives of *ability-discrimination* and *effort-incentive*.
- To effectively incentivize the potential RNs to cooperate, the various monitoring strategies are investigated in the contract-theoretic model by introducing a monitoring node. We analytically derive the optimal contract design with the *non-monitoring*, the *information-monitoring* and the *action-monitoring* strategies, and numerically compare their performances.
- The performance of the optimal incentive and monitoring cooperative mechanism is demonstrated through simulations. The optimal contract design with the monitoring strategies can achieve the better source's utility than that with the *non-monitoring* strategy under the *dual asymmetric information* scenario. The contract design with the *action-monitoring* strategy achieves the RNs' most relay effort and the source's most utility.

The remainder of the paper is organized as follows. The system model and problem formulation for the contract-based cooperative communication are introduced in Section 2. Optimal contract designs with the three monitoring strategies are investigated in Section 3, Sections 4 and5. Numerical simulation results are given and discussed in Section 6, and Section 7 concludes the paper.

2. System model and problem formulation

We consider a typical cooperative network with one source and N RNs. Since the source has the poor channel condition between its transmitter and receiver, it needs the RNs' cooperative help. Due to the selfish nature of wireless nodes, the source wants to get the RNs' cooperation as much as possible, which is against the RNs' interests. The RNs want to offer a little help with the large reward. Thus, to deal with the conflicting objectives between the source and the RNs, this cooperative communication scheme is conceptually like a labor market. A *principal-agent* model [6] for the source and the RNs is utilized, where the source acts as a principal to offer a contract and each RN as an agent may accept or decline the contract.

In this contract-based incentive mechanism, the characteristic of the asymmetric information between the source and the RNs should be considered. On the one hand, before contracting with the RNs, the source may not know the RNs' exact relay abilities due to information asymmetry, which would affect the source's valuation of the potential RNs' abilities. Thus, the RNs' hidden relay information gives rise to the *adverse selection* problem. On the other hand, after contracting with the RNs, the source may not monitor the RNs' exact relay actions because of information asymmetry, which would influence the performance of cooperative relay. In this case, the RNs' hidden relay actions give rise to the *moral hazard* problem. Therefore, the contract-based cooperative mechanism should incentivize the RNs to participate efficiently and credibly under the *dual asymmetric information* scenario.

In this paper, by introducing a monitoring node (MN), the optimal contract design with the monitoring strategy is presented under the *dual asymmetric information* scenario. Instead of employing some RNs to cooperate directly, the source recruits the MN to monitor the RNs' cooperative information or action. Then, the MN recruits the RNs to help the source to cooperate. In this case, the source mainly concentrates on data transmission. The task of monitoring the RNs' cooperation is achieved by the third party, the MN.