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Stackelberg game theoretic pricing algorithm for bandwidth allocation in cooperative access

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Abstract

Cooperative access among user devices by sharing wireless access bandwidth opens a new paradigm in heterogeneous networks. However, how to stimulate cooperative relay nodes forwarding service data for others and allocating corresponding bandwidth to support it are two key issues in the cooperative access. This paper proposes a Stackelberg game based framework which is benefit participants including relay nodes and client nodes. This framework generalizes the pricing based bandwidth allocation algorithm by the Stackelberg game model, which optimizes the profit of the cooperative relay nodes while guaranteeing the bandwidth requirements of client nodes. We transform the profit maximization problem into a convex problem and solve it using the convex optimization method. The simulation results demonstrate that the proposed framework and corresponding algorithms outperform the bidding weight proportional fairness and fixed value bandwidth allocation ones significantly.

Keywords cooperative access, pricing, bandwidth allocation, Stackelberg game

1 Introduction

Next-generation wireless broadband networks are supposed to provide a ubiquitous high-data-rate wireless access environment for end users in the most efficient manner. The capacity of wireless access network is gradually increasing as individual user demands rising. However, it costs much higher that deploying more access points (APs) or base stations (BSs) to overcome the shortage of coverage. Meanwhile, the wireless access capability of end user devices is under-utilized as a result of inevitable idle state. For this reason, there is a probability that encouraging these devices to provide cooperative access by bandwidth sharing, through which online devices could sell wireless access bandwidth to other devices. Therefore, this paper exploits a more efficient and economical wireless access manner. In this paper, the cooperative devices act just as relay nodes (RNs) if they are willing to forward service data for other wireless access limited client nodes (CNs), however, RNs will behave in a selfish manner to increase utilization of their scarce radio resource. This opens a new paradigm of cooperative access by bandwidth sharing, especially for those devices in heterogeneous wireless networks.

Cooperative access in heterogeneous networks can help to support user roaming and quality of service (QoS) guarantee [1]. First, it extends the coverage of APs or BSs to a larger area, which is helpful for operators when deploying addition APs or BSs is not possible. Second, it may increase the throughput of CNs that receive weak signals from their access APs or BSs. However, to satisfy bandwidth requirements by CNs via different available heterogeneous wireless access networks and make the available radio resource utilization more efficiently, both technical and economic issues for pricing scheme in

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cooperative access should be addressed further.

Towards the above issues, many research works propose pricing schemes for bandwidth allocation in cooperative networking. They can be classified as cooperative and competitive pricing models by the relationship among the participants [2]. Literatures [3–5] address the utility maximization based on cooperative pricing. And other work [6] focus on rational and selfish behaviors modeled in competitive environments by the game theory. Pricing strategy based on game theory for competing between clients or service providers through setting the proper price to attract clients so as to optimize their profit [7–9]. However, it is evident that the pricing scheme for bandwidth allocation, which can be adjusted according to the client's demand, can further maximize the revenue under meeting the bandwidth requirements. More importantly, how to efficiently support the cooperative access through pricing for bandwidth sharing remains a widely open problem.

In this paper, we focus on the pricing mechanism for bandwidth allocation while employing the Stackelberg game model, and jointly consider the benefits of CNs and RNs in cooperative access. Each CN pays for the cooperative service which is a function with respect to the amount of allocated sharing bandwidth. A complete pricing framework is proposed for maximizing RNs profit during bandwidth allocation. Therefore, the more bandwidth the RN sells for its clients, the more profit it could obtain from its cooperative access service. Thus revenue maximization is a reasonable objective for both RN set and CN set in the cooperative access paradigm.

The remainder of the paper is organized as follows. In Sect. 2, we model the bandwidth demand of CNs and the interaction between each CN and its access RN using the Stackelberg game model, and then transform the game into a convex optimization problem. In Sect. 3, the single-RN scheme is extended to a multi-RN environment, and active behaviors of CNs are modeled to preserve their bandwidth demand. Simulation results and performance comparisons are presented in Sect. 4. Finally, we conclude the whole paper in Sect. 5.

2 Stackelberg-based Single-RN pricing game

In this paper, we consider some CNs associating with an RN through cooperative access and requesting one kind of service traffic as shown in Fig. 1. Access bandwidth allocated by the access RN is employed as the key metric for CN utility function. And each CN is associated with the minimum bandwidth requirement determined by its requested service demand, and pays a price for access bandwidth sharing to its RN. The price is defined as a charge function. Without loss of generality, all CNs and the RN are rational and selfish in this paper. Then the Stackelberg game theory is employed to model the interactions between the RN and its access CNs. Then, the Stackelberg game model is transformed into a convex optimization problem and derived its optimal solution [10– 12]. Given the above pricing model, the goal is to maximize the RN profit under the cooperative access bandwidth demand from all CNs. Note that we intend to investigate a pricing game model for a unit time which is played repeatedly. In this paper, we assume that the QoS requirement for each CN is minimum access bandwidth constraint.

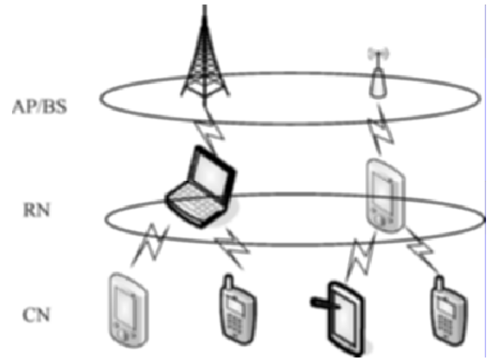

Fig. 1 Cooperative access scenario in heterogeneous networks

2.1 System model

Assumption 1 The utility function of a CN is concave.

The derivation function $u'(x)$ of $u(x)$ is the marginal utility (MU) of the access bandwidth for each CN, where x is its access bandwidth and $u(x)$ is its corresponding utility function. The MU refers to the quantified CN's willing to pay relative to the access bandwidth with access bandwidth supply increasing. According to the law of diminishing marginal utility in microeconomics theory [5], MU is decreasing with the increase of access bandwidth because a CN's desire of getting more access bandwidth does not increase proportionally with each additional unit of bandwidth acquired. So $u'(x)$ is a decreasing function since $u''(x) < 0$ when x is large enough. Thus $u(x)$ is concave when x is large enough.

Then we adopt the utility function for CNs as follows [11],

$$u(x) = \omega \ln(1 + x) \tag{1}$$