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Reverse spectrum auction algorithm for cellular network offloading

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ABSTRACT

The explosion of mobile traffic and highly dynamic property often make it increasingly stressful for a cellular service provider to provide sufficient cellular spectrum resources to support the dynamic change of traffic demand in a day. In this paper, considering the dynamic characteristics of the cellular network traffic demands, we propose an optimal, truthful reverse auction incentive framework, which can minimize the leasing costs sustained by the mobile network operator at the premise of meeting the traffic demand of each time period. Such an issue is formulated as an Integer Programming (IP) optimization problem and we use an adaptive Lagrangian relaxation algorithm to solve the optimal reverse auction allocation problem. Besides, we propose a payment rule satisfying the truthfulness property (incentive compatibility) and the individual rationality property. Numerical results demonstrate that our proposed adaptive algorithm well captures the economical and networking essence of the reverse auction allocation problem, thus representing a promising approach to solve the optimal reverse auction allocation problem.

1. Introduction

As the world embraces wireless and mobile technologies, the rapid consumer adoption of smart phones, Netbooks, e-readers and Web-ready video cameras, are continuing to place unprecedented demands on mobile networks [1]. Given the limitation of cellular spectrum resources, it is drastically increasing the burden for the cellular network operator to ensure adequate cellular resources for all consumers, especially considering the significant change of traffic demand (e.g., Cellular traffic load is a dynamic change in a day [2]).

Offloading, a promising solution to smoothly handle sudden peaks of traffic demand, represents the opportunistic utilization of low-cost and low-power third-party hotspots (e.g., Wi-Fi and femtocells), which is massively deployed over the wireless cellular network areas by the operator or third-party entities. Measurement studies show that through a third-party hotspot offload the cellular network traffic is feasible (e.g., [3] showed that more than 65% of the cellular base station power consumption can be saved through WiFi offloading).

Cellular network operator, however, faces a challenge before the application of the offloading technology, i.e., these privately owned third-party hotspots are too selfish to allow the access of non-registration users. A feasible solution is that the cellular network operator leases the spare spectrums from third-party hotspot owners and in return the individual owners get paid. On-demand purchase of such third-party hotspot spare resources can potentially lead to a win-win solution: (1) The cellular network operator achieves significant savings by not having to upgrade the network; (2) The third-party hotspot owners get extra income from the otherwise wasted spare resources; (3) Improving quality-of-service provided to mobile users.

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In order for this approach to be successful, we propose a novel reverse auction based incentive framework to motivate third-party hotspot owners to help cellular network operator dynamic offloading while guaranteeing truthfulness and individual rationality. We give an overview of the reverse auction based incentive framework, the cellular network operator according to the traffic demands in each period of time to purchase spectrum resources from third-party hotspot owners, where the goods of interest are spectrum resources, third-party hotspot owners serve as bidders and submit their bids while cellular network operator or a trusted third party serves as an auctioneer, who collects the bids from all third-party hotspot owners and determines: (1) the allocation, i.e., the cellular network operator decides which bidder is the winner in a certain period of time; and (2) the price, i.e., the cellular network operator decides how much money to pay for each winner to offload the cellular traffic.

The main contributions of our paper are summarized as follows:

1. We put forward and analyze a combinatorial reverse auction to implement an innovative marketplace both for meeting the traffic demands of any period of time and minimizing the cost of the cellular network operator.
2. We propose an adaptive Lagrangian relaxation (ALR) algorithm to obtain a near-optimal solution to the reverse auction problem, which has been proved to be a non-deterministic polynomial (NP) complete type optimization problem.
3. We present an innovative payment rule and demonstrate that it guarantees both individual rationality and truthfulness.
4. Extensive numerical results are provided to analyze the proposed optimal and adaptive Lagrangian relaxation algorithm.

The rest of the paper is organized as follows: In Section 2, we briefly review the related works. Section 3 describes the details of our system model. In Section 4, optimal reverse auction for mobile data offloading is presented in detail. Section 5 indicates the details of our payment rule, and proves its desirable properties. Section 6 evaluates the performance through simulations and Section 7 concludes the paper.

2. Related work

Offloading, which has been widely investigated in recent years [4], is a cost-effective solution for network operators to extend their transport capacity. Several works addressed the problem of offloading the cellular network traffic while distributing common content to a group of mobile devices that cooperate during the download process by forming device-to-device communication networks [5,6]. A quantitative study on offloading cellular traffic to WiFi networks has been presented in [7,8]. Chen et al. [9] proposed a code offloading framework, which consists of mobile devices, nearby cloudlets and public cloud services, to improve the performance and availability of the Mobile cloud computing services. In [5], the authors exploited opportunistic communications to facilitate information dissemination in the emerging Mobile Social Networks (MoSoNets) and thus a large fraction of data can be offloaded from the cellular network. The authors in [10] analyzed that utilizing other access networks for cellular traffic offloading may result in a nonnegligible delay. Moreover, they investigated the tradeoff between the amount of traffic being offloaded and the users' satisfaction, and provided an incentive framework to motivate users to offload.

Auction, which has been widely applied in wireless communication, is a powerful tool to solve efficiently resource allocation problems. Some early works in this field include revenue maximization auction [11], truthfulness guaranty auction [12–14], collusion-resistant auction [15], and so on. In particular, a few papers have established different auction mechanisms to address the incentive issues of offloading yet. In [16], the authors designed a combinatorial reverse auction mechanism for access permission owners to bid their unused capacity to the operator. In [17], the scholars proposed EasyBid, a new auction model that provides guarantee for truthfulness even when considering a system with imprecise valuations and a dynamic programming based algorithm on partial truthfulness and imprecision loss. The authors in [18] proposed TRUST, a general framework for truthful double spectrum auctions. TRUST based on McAfee mechanism is to achieve truthfulness and other economic properties while significantly improving spectrum utilization. The authors in [19] proposed a VCG-based auction mechanism that can motivate the mobile users with high delay tolerance and large offloading potential to offload their traffic to other intermittently available networks. The authors in [20] proposed iDEAL, a novel auction-based incentive framework that can effectively foster competition among third-party resource owners in different regions, resulting in significant savings to the cellular service provider.

To the best of our knowledge, all the existing offloading studies have not considered the traffic demands of operator. In our design, we propose an incentive framework based on reverse auction, which takes into account the dynamic characteristics of traffic demand and offloading simultaneously. Besides, an adaptive Lagrangian relaxation (ALR) algorithm is used to solve the optimal reverse spectrum auction problem.

3. System model

In this section, we propose a novel auction-based incentive framework to dynamically offload the cellular traffic. The offloading is transparent to clients and does not affect the cellular traffic pricing (i.e., users pay for the data usage regardless of whether it is provided by the cellular network provider or third-party hotspot owners).

3.1. Cellular network offloading model

In this section, the communication and network model considered in our work is described in detail, and then we introduce some fundamental properties adopted in the design of our reverse auction mechanisms.

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