博士論文概要

論文題目
Studies on Congestion Control Using Pricing in Wireless Local Area Networks
無線LANにおける料金設定を利用した輻轍制御に関する研究

申請者
Bo Gu
古 博
国際情報通信学専攻
情報通信ネットワーク研究II

2013年1月
Along with the success of wireless local area networks (WLANs), large numbers of wireless access points (APs) are getting rapidly deployed all over the world by different businesses and homes. Especially in dense metropolitan areas, such as Tokyo, there is sufficient density of APs to achieve near-ubiquitous WLANs by sharing access amongst residents. However, most owners encrypt their networks to prevent the public from accessing them due to the increased traffic and security risk. Without a mechanism for a potential user to compensate the owner of the AP, the owner has no reason to accept the increased network traffic load and security risk that would come from allowing the public to access the network. Pricing could be used as an incentive mechanism to encourage self-interested AP owners to participate in a public wireless network.

Congestion control is of great importance when the network capacity is insufficient. Specifically, users for wireless access services, tend to localize themselves in particular areas of the network for various reasons, such as the availability of favourable network connectivity, proximity to power outlets, or geographic constraints for applying services somewhere else. Furthermore, users located in overlapping cells, tend to scan all available channels and associate themselves to the AP that has the strongest Received Signal Strength Indicator (RSSI). A key consequence of these behaviours is that the traffic load is often distributed unevenly amongst the APs, and the quality of service (QoS) cannot be guaranteed very well at heavily loaded APs.

The hot-spot congestion problem can be alleviated by: (i) balancing the load amongst multiple APs via intelligently selecting the user-AP association; and (ii) introducing connection admission control (CAC) policy for each AP. From an economic point of view, an incoming user means a potential gain to the network revenue due to the improved resource utilization. On the other hand, the incoming user may cause congestion and degradation in QoS provided for the existing users. In case that the utility decreases below the price charged, an existing user may reject the price and leave, which in turn results in a loss to the network revenue. Therefore, congestion control should play an important role in both QoS provisioning and revenue maximization.

This dissertation studies applying game theoretic techniques to modelling the pricing in conjunction with congestion control problems in WLANs. Three correlated studies with different game theoretic formulations are presented in Chapter 3, Chapter 4 and Chapter 5, respectively.

Chapter 1 offers an introduction to the background and motivation of this dissertation. Moreover, Chapter 1 provides an overview for this dissertation.

Chapter 2 describes the related work as well as the necessary fundamentals of game theory, pricing and congestion control, forming the basis of this dissertation.

There has been a growing interest in adopting game theoretic techniques to model many communications and networking problems. In particular, game theoretic techniques have been successfully applied to the problems, such as congestion control
and resource sharing in wireless networks, in which the action of one component impacts that of any other component.

Generally, there are two types of approaches to compensate the AP owners: centralized approach and decentralized approach. In the centralized approach, a third-party server is deployed to receive and process the service requests from users; while in the decentralized approach, users negotiate and pay the AP directly. There are a number of benefits in using the centralized approach. Since a third-party server maintains the system state for all APs in the network, it can monitor and control the use of the wireless bandwidth in the network. Global knowledge of the system state enables the server to easily identify heavily loaded APs and hence distribute users from a heavily loaded AP to a lightly loaded one. The decentralized approach has its advantages as well. First, as the pricing process can be done in AP locally, there is no need for the AP to carry the user’s traffic into the wired network for negotiation. This stops all unauthenticated traffic at the edge of the wired network and is thus a relatively low-risk design. Second, decentralization transfers decision-making processes to individual APs, thus reducing network management overhead and considerably increasing network scalability.

Congestion control mechanisms are used to limit the amount of traffic admitted into a particular service class so that the level of QoS guarantee of the existing users will not be degraded, while at the same time the medium resources can be efficiently utilized.

Chapter 3 proposes a “federated network” concept, in which radio resources of various WLANs are managed together. In the federated network, a third-party server involves APs deployed by different businesses, and attaches its brand name to the APs so as to ensure that a consistent QoS is offered amongst the federated APs.

The contributions of this chapter are two-fold: (i) to provide right incentives for APs that join the federated network; and (ii) to guarantee at least a minimum level of QoS to users.

The price announcements of APs are modelled as a novel second-price auction game. For each AP that accurately broadcasts her cost, it results in convergence to a Nash equilibrium solution. The proposed algorithm identifies two candidate APs (i.e., local candidate and remote candidate, if available) with the lowest price being offered for each user. The algorithm decreases the degree of blocking probability, and improves the degree of social welfare in the system in comparison to the best existing algorithms. Simulation results show that the social welfare is increased by over 40% and 10%, respectively, compared with that of fixed rate algorithm and fixed rate with roaming algorithm.

Chapter 4 takes the diversity in users’ QoS provisioning into account. Each user contends for channel access according to some user-chosen access probability. The QoS differentiation is achieved when users with high access probability transmit more often than those with low access probability. The reason why this simple MAC model
is employed is because we want to abstract out the essential features of QoS-aware MAC, and hence can avoid being overwhelmed by the complexity of realistic MAC protocols.

The contribution of this chapter is to introduce and analyze an incentive-compatible load balancing approach, in which user-AP associations are intelligently determined based on not only the signal strength but also the load level at each AP.

A Stackelberg leader-follower game is structured to analyze the interaction between the federated network (leader) and users (followers). Given the best response of each user, the federated network can derive the private utility information of each user through backward induction, and determine the optimal AP-user association.

The game is composed of three steps: (i) the federated network predefines a usage-based pricing scheme; (ii) users choose their access probabilities to optimize their payoffs, namely, best response strategies; (iii) the federated network uses the best response information to determine the AP-user association, which in turn maximizes its total revenue.

In order to exploit users’ mobility for load balancing, a remote AP can also be selected by the federated network. The remote AP with better QoS guarantee (i.e., saturation throughput) encourages the users to connect. The proposed algorithm alleviates load imbalance and the consequent ineffective bandwidth utilization via intelligently selecting user-AP association within the federated network. Simulation results show that the overall revenue is increased by 8% and 5%, respectively, compared with that of network directed roaming (NDR) algorithm and distributed myopic selection (DMS) algorithm which are presented in literatures.

Chapter 5 focuses on learning the economic behaviours of an AP and users in a decentralized model, where there is no third-party server to maintain the system state for all APs in the network. Each self-interested AP first estimates the probable utility degradation of existing users consequent upon the admission of an incoming user. Then the AP decides: (i) whether the incoming user should be accepted; and (ii) the price to be announced in order to maximize the overall revenue.

The main contribution of this chapter is to propose a distributed pricing scheme in conjunction with a CAC policy for revenue maximization in WLANs.

The interactions amongst the AP and wireless users are modelled as a multi-stage non-cooperative game. The condition, under which the proposed scheme results in a perfect Bayesian equilibrium (PBE), is investigated. In the PBE, the AP cannot increase the revenue by unilaterally deviating from the PBE strategy at any point in the game. The proposed CAC policy is completely distributed and can be implemented by individual APs using only local information. Simulation results show that the overall revenue is increased by over 50%, compared with that of fixed rate algorithm.

Finally, Chapter 6 concludes the results achieved in this dissertation and summarizes the future work.