Design of Incentive Compatible Protocols for Wireless Networks: A Game Theoretic Approach

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Thesis Abstract:

In this thesis work, we design rigorous and efficient protocols/mechanisms for different types of wireless networks using a mechanism design [1] and game theoretic approach [2]. Our work can broadly be viewed in two parts. In the first part, we concentrate on ad hoc wireless networks [3] and [4]. In particular, we consider broadcast in these networks where each node is owned by independent and selfish users. Being selfish, these nodes do not forward the broadcast packets. All existing protocols for broadcast assume that nodes forward the transit packets. So, there is need for developing new broadcast protocols to overcome node selfishness. In our paper [5], we develop a strategy proof pricing mechanism which we call *Immediate Predecessor Node Pricing Mechanism* (IPNPM) and an efficient new broadcast protocol based on IPNPM. We show the efficacy of our proposed broadcast protocol using simulation results.

Protocols for wireless ad hoc networks suffer in network performance that includes large routing overhead, low throughput, and large end-to-end delay. In such networks, the issues of quality of service (QoS) are even more complicated because of the lack of reliable methods to distribute information in the entire network. The integration of heterogeneous wireless technologies can improve the network performance, thereby meeting the demands for different quality of service (QoS). Motivated by this interesting research problem, we concentrate on heterogeneous wireless networks in the second part of our thesis work. In particular, we try to answer some of the resource allocation problems that arise in these networks. We consider the situation where a mobile/wireless user has to perform some parallel applications where each parallel application can be split over different wireless networks for execution. The mobile user is having access to heterogeneous wireless networks provided by a set of non-cooperative and selfish service providers. These service providers charge for allocating the radio resource to the mobile/wireless users. Ultimately, the problem of the mobile user is to procure the radio resource from these service providers to perform its applications while minimizing the total amount for it to pay to the set of network service providers. In our paper [6], we design an optimal procurement mechanism to solve the problem of mobile user using game theory and mechanism design. Our solution satisfies important game theoretic properties such as *Individual Rationality* and *Bayesian Incentive Compatibility*.

We now briefly elaborate on each part of our work to provide more details.

Part-1: Truthful Broadcast Problem for Wireless Ad hoc Networks

In many applications, in particular civilian applications, of wireless ad hoc networks, wireless nodes are owned by rational and intelligent users. We call nodes *selfish* if they are owned by independent users and their objective is only to maximize their individual goals. In a broadcasting task for wireless ad hoc networks, a source node sends the same message to all the nodes in the network. Broadcast is useful in route discovery, and paging a particular host or sending an alarm signal. So, it is interesting to study broadcast in which to consider incentives because wireless nodes are belonging to independent, self-interested users. Most of the existing protocols for broadcast assume that nodes voluntarily follow the prescribed protocols without deviation. These protocols will not work if the nodes exhibit selfish behavior. Thus there is a need for truthful computing in this context. We call this problem the *truthful broadcast problem* for wireless ad hoc networks. Truthful computing refers to a stimulation mechanism to make selfish nodes cooperate with each other. Providing incentives and pricing the transactions are well known approaches to stimulate cooperation.

There is a considerable amount of research in the literature on truthful unicast and truthful multicast problems in wireless ad hoc networks with selfish nodes. However, we show that applying the solution approaches of truthful unicast and multicast problems to solving the truthful broadcast problem lead to inefficient solutions. So, in order to solve the truthful broadcast problem, we present a game theoretic framework for this problem and a strategy proof pricing mechanism called *Immediate Predecessor Node Pricing Mechanism* (IPNPM). The phrase strategy proof here means that truth revelation of cost is a weakly dominant-strategy (in game theoretic terms) for each node. In order to steer our mechanism-design

approach towards practical implementation, we compute the payments to nodes using a distributed algorithm. We also propose a new protocol for broadcast in wireless ad hoc network with selfish nodes based on IPNPM. The features of the proposed broadcast protocol are reliability and a significantly reduced number of packet forwards compared to the number of network nodes, which in turn leads to less system-wide power consumption to broadcast a single packet over the network. Our simulation results show the efficacy of the proposed broadcast protocol.

A fundamental difficulty that arises in the design of strategy proof pricing mechanisms for wireless ad hoc networks is design to optimality. Here optimality means achieving minimal total payment for packet forwards to broadcast a single packet over the network. In the settings where the network nodes are free to act according to their own interests, it is more difficult to impose optimal strategies for designing a pricing scheme. The central question in such a scenario is *how much the overall payment for packet forwards suffers from lack of regulation*. We use the symbol Ψ to denote this degradation in total price to broadcast. We finally show the bounds on the degradation ratio (Ψ).

As the existence of dominant strategy equilibrium is difficult in some real world situations, we need a weaker equilibrium concept (in game theoretic sense) such as Bayesian equilibrium. We are currently working on designing Bayesian incentive compatible mechanisms to solve the truthful broadcast problem for wireless ad hoc networks with selfish networks.

Part-2: Resource Allocation in Non-Cooperative Heterogeneous Wireless Networks

With the development in new radio access technologies and increase in user demand for ubiquitous high speed access are driving the deployment of a wide array of wireless networks, ranging from wireless WAN to wireless MAN, Wireless LAN and Wireless PAN. These kind of networks provide incomparably high data rates. With complementary characteristics especially in terms of data rate and coverage of the various wireless communication technologies, the co-existence of these technologies results in a heterogeneous set of wireless communications systems that can provide better communication and service facilities to the mobile/wireless nodes. Such networks are called *heterogeneous wireless networks* [7]. In civilian applications of such networks, each entity of the network is possibly owned by independent and selfish organizations. In such situations, each participating entity tries to maximize its utility by charging the network functions appropriately. Being selfish, service providers charge the mobile users for using the radio resource.

In our work, we consider the radio resource allocation problem for a mobile user having access to a heterogenous wireless network. To make it possible, the mobile user is equipped with multiple network interfaces. We assume the existence of heterogeneous wireless access networks provided by a set of non-cooperative and selfish service providers. We also assume that mobile users are able to split parallel applications over multiple heterogenous networks. Under this setting, the mobile user announces the time slots in which it requires the radio resource channel to perform the parallel applications. Each wireless access network service provider is having his own preferences over these time slots. A service provider's preferences are only known to him and and are not known to others. Then we say that each service provider holds private information. Now on receiving bids for the time slots from the heterogenous wireless network service providers, the mobile user is required to find a set of winning bids which minimize the total cost for it to pay for the service providers, while satisfying some essential game theoretic properties.

In technical terms, we propose an optimal mechanism to solve the problem of the mobile user which can access a heterogenous wireless network. Our mechanism design problem is to develop a reverse optimal procurement auction for the mobile user. Here bidders are the different wireless network service providers. As each service provider holds private information on the time slots, we are in an incomplete information setting. We restrict ourselves to the implementation in Bayesian Nash equilibrium. The proposed approach incorporates important game theoretic properties like Individual Rationality (IR) and Bayesian Incentive Compatibility (BIC) into the design. By the construction of the mechanism, each wireless network service provider voluntarily participates to bid for the time slots, i.e., by participating in the mechanism, the service provider gets non-negative utility.

In the above design, we assumed the wireless networks service providers are selfish and non-cooperative. But in real world situations, the service providers can collude with each other to improve their utilities rather than being individual. We are currently looking into these aspects using cooperative game theory.

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