Guest Editorial: Smart Data Pricing for Next-Generation Networks

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I. Introduction

THE growing demand for mobile data and the evolution of next-generation networks, particularly fifth-generation (5G) wireless networks, has called for new approaches to pricing and managing the limited capacity of existing network resources and infrastructures. In particular, emerging mobile applications like autonomous vehicles, augmented/virtual reality, and more broadly the Internet-of-Things will have heterogeneous demand patterns and service requirements, raising questions on how they should pay for their data usage and how next-generation networks can meet their demands with limited resources. Several recent policy changes and regulatory initiatives have been proposed to address the shift in demands due to next-generation networks and technologies. These include the FCC's "5G Fast Plan," which outlines strategies for modifying spectrum policies, infrastructure policies, and existing regulations, in light of emerging 5G technologies. This plan has included the rollback of net neutrality rules in June 2018, allowing broadband providers to offer a wider variety of service options.

In addition to these regulatory initiatives, several technologies are needed to enable next-generation 5G networks, including the use of new spectrum frequencies, dense infrastructure deployments, and fog/edge computing. Adopting these technologies presents new challenges for innovative smart pricing strategies, as well as new business opportunities. Examples include pricing and incentive mechanisms for pooling of distributed resources, including IoT pricing, revenue models and incentives for infrastructure sharing, new data plans for bundling 4G and 5G services, and novel auction mechanisms. Untangling the effects of such future pricing mechanisms and their interplay with new regulatory developments will be crucial towards ensuring the commercial success of next-generation networks.

The papers in this special issue explore new types of pricing enabled by 5G technologies and the emerging applications that 5G promises to support. Prior workshops on smart data pricing and related special issues in the IEEE Journal on Selected Areas in Communications have not focused on the specific questions raised by next-generation network technologies, instead examining pricing in the context of developments like edge/fog computing or multimedia applications. Thus, this special issue highlights the need to more broadly examine the technologies that make next-generation networks possible, and in particular the economics of how they should be deployed.

The editors thank Dr. Hung Nguyen and Professor Parinaz Naghizadeh for their assistance in preparing this call and coordinating the review process. We received 35 high-quality submissions to this special issue and accepted 11 of them, for an acceptance rate of about 30%. We have grouped these submissions into three categories: (1) emerging applications, (2) infrastructure sharing, and (3) two-sided pricing. Below, we summarize the accepted papers.

II. Emerging Applications

As new applications emerge that require different combinations of network and computing resources, new pricing and incentive mechanisms may be needed to shape their demands. The papers in this category characterize usage patterns under smart data pricing and propose such incentive mechanisms.

A. Mobile App Usage Patterns Aware Smart Data Pricing

Data pricing has been proven to be an effective way to enhance both the service quality and ISP's profit. However, traditional data pricing schemes do not consider the real mobile application usage patterns (MAUPs) among large scale cellular networks. In this paper, Yin *et al.* [7] consider the MAUPs-aware smart data pricing scheme in large scale cellular networks. The authors first extract and model the users' application behaviors from approximately 9 600 cellular towers as two-dimensional MAUPs (i.e., time and app category), and then propose a two-dimensional dynamic MAUPs-aware smart traffic pricing scheme, which jointly considers the impacts of these two important factors. They perform numerical experiments based on large-scale real world dataset to evaluate the performance of the proposed pricing scheme. Numerical

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results demonstrate that it can improve the ISP's profit, consumer surplus, capacity utilization, and traffic efficiency significantly, comparing with the traditional data pricing scheme without considering MAUPs.

B. Online Combinatorial Auctions for Resource Allocation With Supply Costs and Capacity Limits

Tan *et al.* [6] study a general online combinatorial auction problem in cloud computing and other multiresource settings in which a provider has to allocate bundles of capacity-limited resources (e.g., CPU and RAM) to customers. The authors use an online posted-pricing mechanism to achieve optimal competitive ratios, which characterize the social welfare performance of the mechanism. The theoretical results are validated with empirical studies of online resource allocation in cloud computing.

C. Optimal Pricing of Internet of Things: A Machine Learning Approach

Alsheikh *et al.* [1] consider an IoT market model consisting of data vendors who sell data to service providers, and service providers who offer IoT services to customers. They study the issue of optimal pricing and bundling of machine learning-based IoT services for profit maximization for the service provider. Their model demonstrates the benefits of bundling IoT services over standalone selling, and uses insights from cooperative game theory to provide profit-sharing mechanism among the service providers of the bundling coalition.

III. Infrastructure Sharing

One of the most important characteristics of future 5G networks will be the need for users to share network infrastructure (e.g., base station or caching infrastructures belonging to different operators) in an efficient way. The papers in this category investigate the impact of such sharing on resource allocation within each technology as well as offloading from one technology to another.

A. The Impact of Unlicensed Access on Small-Cell Resource Allocation

Chen *et al.* [3] investigate how the unlicensed spectrum affects the allocation of resources in HetNets consisting of macro and small cells, which are deployed within the licensed spectrum and operated by a cellular service provider or by competing service providers. The work demonstrates how the unlicensed spectrum affects the service provider's willingness to allocate resources to small cell networks. Using these models and results and taking into account the service provider's (or providers') strategic decision(s), the authors also quantify the social welfare provided by the unlicensed spectrum and compares it with the welfare generated by the licensed spectrum.

B. Regulating Competition in Age of Information Under Network Externalities

Hao and Duan [5] consider an Age of Information (AoI) management problem, where N platforms update their crowdsourced data over a common content delivery network. Each platform must contend with a trade-off between AoI and sampling cost while selecting a sampling rate for the information supply side. Additionally, the common network is bandwidth limited, and therefore, each platform must compete non-cooperatively with all other platforms for network capacity. This competition is modeled as a one-shot game played by N platforms, where each platform chooses a sampling rate to maximize a cost function capturing the trade-off previously mentioned. It is shown that the price of anarchy for this game is infinite, meaning that platform selfishness heavily degrades network performance. Following this, the game is extended to a multistage game with an infinite time horizon. Under the assumption that all platforms have complete information of all cost functions, an indirect mechanism is designed that punishes the platforms for breaking from a cooperative strategy. An approximated mechanism is demonstrated for the case where the assumption of complete information is relaxed.

C. DRAIM: A Novel Delay-Constraint and Reverse Auction-Based Incentive Mechanism for WiFi Offloading

Zhou *et al.* [11] propose a novel Delay-constraint and Reverse Auction-based Incentive Mechanism (DRAIM) for WiFi data offloading. They model the reverse auction-based incentive problem as a nonlinear integer problem, with the goal of maximizing the revenue of the Mobile Network Operator (MNO), while considering the delay constraint of different applications in the optimization problem. To solve this problem, they propose the Greedy Winner Selection Method (GWSM) and the Dynamic Programming Winner Selection Method (DPWSM), both of which are of low complexity. Through extensive simulations, the authors show that the proposed DPWSM achieves the best performance in terms of the MNO's utility and traffic load under different scenarios.

D. Contracts for Joint Downlink and Uplink Traffic Offloading With Asymmetric Information

Zhang *et al.* [9] consider the problem of motivating potential offloading nodes (PONs) to cooperate with the offloading request nodes (ORNs) for traffic offloading in 5G networks. The authors propose a contract-based framework to tackle this challenging issue, where the PONs are agents characterized by a two-tuple type, while the ORNs are the principles providing contracts in the form of (offloading quality, monetary reward). The ORN considers the tradeoff between offloading quality and monetary reward when designing the contract, and optimizes the utility under the constraints of individual rationality and incentive compatibility conditions. Simulation results demonstrate that the proposed scheme achieves higher offloading utility and energy efficiency compared with the existing schemes.

E. Cache Subsidies for an Optimal Memory for Bandwidth Tradeoff in the Access Network

Ahmadi *et al.* [2] propose a joint pricing and caching scheme developing a method to subsidize Content Providers (CPs) so as to incent CPs to install caches at the Access Network Operators (ANOs). Authors apply coalition game theory to design the required subsidy framework and model how cost of caching should be shared between CPs and ANOs. The proposed solution provides new ideas towards the solution of a core problem affecting the telecommunication industry, that is the free riding by CPs of the last trunk of ANOs infrastructures due to the massive demand of multimedia contents. A distributed algorithm is proposed to optimize the memory-to-bandwidth tradeoff.

IV. Two-Sided Pricing

A particularly popular emerging pricing mechanism is that of two-sided, or sponsored, pricing. In such a pricing scheme, the content or application provider can sponsor (i.e., subsidize) the data usage for their specific content on behalf of the users. The papers in this category investigate the resulting changes in user demand, content provider revenue, and service provider profit.

A. Dynamic Game and Pricing for Data Sponsored 5G Systems With Memory Effect

Feng *et al.* [4] examine a 5G non-orthogonal multiple access (NOMA) network operator that offers sponsored data to its users: that is, application providers can subsidize the data usage fees that users incur when using their applications. Unlike prior works on sponsored data, the authors assume that users decide whether to utilize the application by taking into account the utility they have previously received. They formulate the resulting sequence of user and network operator decisions as an evolutionary game, which they show has a unique solution. Numerical simulations confirm their theoretical results and show that offering sponsored data allows for greater spectral efficiency and data usage.

B. Understand Love of Variety in Wireless Data Market Under Sponsored Data Plans

Sponsored Data Plan (SDP) is an emerging pricing model for the wireless data market where the Content Provider can sponsor the data usage for specific content on behalf of the users. Zhao *et al.* [10] develop a new model to understand the love of variety in the wireless data market under SDPs. The model demonstrates that such a variety is important to understand the complex gaming between Internet Service Providers, Content Providers, and users in both short-run and long-run markets. For example, the analysis indicates that the advantage of Content Providers with higher revenue will be significantly reduced when users have a greater love of variety. Moreover, to help the ISP better adopt the proposed model in the real market, the authors also develop a practical method to calibrate the related parameters.

C. Monetizing Mobile Data via Data Rewards

Yu *et al.* [8] propose a scheme for mobile operators to increase their advertisement-based revenues by given data incentives for its users to watch these ads. In this scheme, the operator offers its users data units in proportion to the number of ads they watch. The proposed scheme results in a higher quota of data for the users, an increase in revenue for the operator, and an improved ad visibility for the advertisers. The proposed scheme is modeled as a Stackelberg game in which the operator fixes the data units per ad view and the price of the ad slots. The mobile users and the advertisers then react to these quantities by respectively choosing how many ad slots to watch and how many ad slots to buy. Ye *et al.* derive a characterization of the equilibrium for a two stage Stackelberg game, which involved in the game users, operator and advertisers. The equilibrium strategies are computed for the case when incentives are available for subscribers of data-plans only (SAR), for both all types of subscribers (SUR) and when there is a differentiation between subscribers with data-plans and those without. Numerical results compare the revenue of the operator under these three cases.

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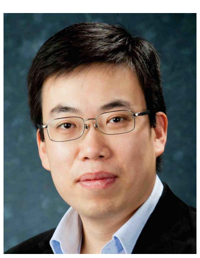

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