Pricing for Reconfigurable Intelligent Surface Aided Wireless Networks: Models and Principles

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***Abstract*—Owing to the recent advancements of meta-materials and meta-surfaces, the concept of reconfigurable intelligent surface (RIS) has been embraced to meet the spectral and energy efficient, and yet cost-effective solutions for sixth-generation (6G) of wireless networks. From an operational standpoint, RISs can be easily deployed on the facades of buildings and indoor walls. Albeit promising, in the actual network operation, the deployment of RISs may face challenges because of the willingness and benefits of RIS owners from the aspect of installing RISs on their properties. Consequently, RIS-aided wireless networks make fail to balance the wireless service providers and RIS owners in terms of their own interests. For alleviating this problem, we focus on the applications of pricing models in RIS-aided wireless networks, toward a win-win solution for both sides. In particular, we adopt and present the RIS pricing approaches with their potential application in RIS networks, first review existing pricing models developed for RIS, and then outline the importance of RIS pricing for benefiting both the RIS owners and wireless entities. Specifically, a Stackelberg game theoretic model is also presented to determine the profit-maximization pricing. Finally, we highlight open issues and future research directions of applying pricing models to the RIS-aided wireless networks.**

***Index Terms*—Reconfigurable intelligent surface, resource management, pricing models, 6G.**

I. Introduction

WITH the commercialization of the fifth generation (5G) wireless networks and the exploration and development of their applications in vertical industries, the vision of the sixth generation (6G) wireless networks has gradually attracted the attention of scholars. 6G wireless networks aim to propose higher performance indicators and introduce new application scenarios, such as seamless global connectivity, higher spectral/energy efficiency, ultrareliable communications, and security, etc. Owing to the rapid development of internet of things (IoTs) and the prolific spread of various smart services such as virtual reality, telemedicine, and smart home, etc., the biggest challenge for the communication technology is to meet the soaring demand for data rate to ensure that a volume of heterogeneous devices are serviced. In traditional communications, the transceiver module of the system is a symmetrical architecture with independent radio frequency (RF) chains, including high energy consumption components such as power amplifiers and oscillators, to generate and receive RF signals. Nevertheless, a large number of access devices in 6G networks will inevitably lead to a sharp increase in power consumption. Therefore, the implementation of high data rate with low power consumption for 6G wireless networks is still imperative.

Recently, reconfigurable intelligent surface (RIS) has been proposed as a promising technology out of the abovementioned gridlock, driving by the artificial intelligence theory, emerging meta-materials, and integrated antenna related technologies [1], [2]. RIS benefiting from the breakthrough on the fabrication of programmable meta-material, has been speculated as one of the key enabling technologies for the future 6G wireless networks to construct smart radio environment. The main function of RIS is to control the reflection phase and amplitude of the incident signal through software programming according to the communication link information [3]. In essence, the RIS proactively modifies the wireless environment via the adjustment of capacitance, resistance, and inductance. Consequently, the received power, capacity, and coverage can be significantly enhanced by exploiting the reflected signal from other paths. Meanwhile, RIS-aided modulation is also widely developed toward reduced implementation cost, where the data can be modulated by tuning the reflection coefficient and reflection mode. Since the RIS only reflects the signal without additional energy consumption and wireless resources, it is considered as RIS is an environment friendly technology for future wireless networks.

In the vision of 6G, RISs will be ubiquity due to the global seamless coverage indicator. Consequently, in actual network operation, the diversity of 6G entities and their objectives may introduce challenges for the RIS deployment and multi-resource management. The reasons are described as (i) the diverse and dense deployment of wireless devices; (ii) the willingness of owners to install large RIS; (iii) the inherent constraints of the service range of RIS; (iv) a large number of wireless users and RIS's owners with different objectives. The inherently heterogeneous nature of an ecosystem in which traditional wireless networks and RISs coexist is intuitively attributed to the different dimension of components. More precisely, in RIS-aided wireless network, the fundamental infrastructures such as BSs and RISs may belong to or being operated by different entities, e.g., wireless service providers and RIS holders, while they have different objectives and constraints. Therefore, system optimizations that support a single objective may fail to model and determine an optimal interaction among these self-interested and rational entities. On the other hand, pricing approaches have been recently developed and adopted as useful tools to address resource management issues in the 5G wireless networks, where wireless service providers and RIS holders are with different objectives, such as high data rate, low latency, and revenue maximization. Each entity reaches the best decision according to equilibrium analysis via the interactions among all the entities involved in a process. Accordingly, the inherently partially information exchange nature of pricing approaches make them suitable for autonomous decision making in a distributed method. In short, they may be applicable for the RIS-aided wireless network which consists of a volume of autonomous entities. Accordingly, pricing approaches are suitable for autonomous decision making in a distributed method. Therefore, they meet the demand for diverse objectives of a large number of entities

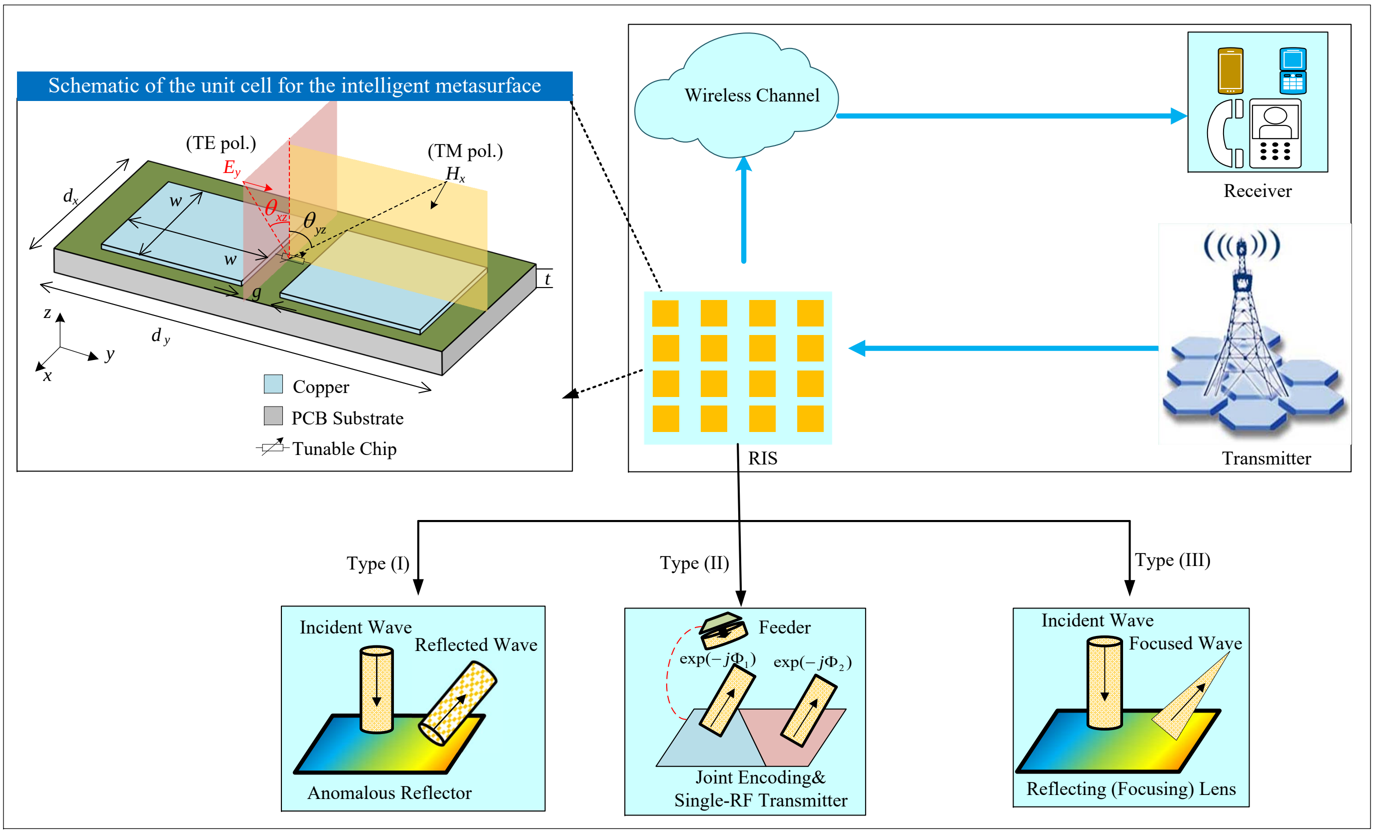

Fig. 1. Prototype/schematic of the RIS-aided wireless communication.

in RIS-aided wireless networks.

In this paper we focus particularly on the applications of pricing models in RIS-aided wireless networks, while pricing issues include cost-benefit analysis, member utility, and pricing. We first highlight the factors that make pricing issues imperative for RIS-aided wireless networks, and then review related works of pricing models developed for RIS services and applications. Specifically, two major directions are presented, i.e., the heterogeneous architecture of RIS-aided wireless networks and proper pricing of RIS. Next, we present a demonstrative pricing model based on game theory to study RIS service competition. Finally, open research directions are outlined.

The remainder of this article is organized as follows. We first present a general structure of heterogenous RIS-aided wireless network and discuss the applications of pricing models. Then introduce the concept of price-based bargaining process and its potential applications are described in RIS networks. Furthermore, we propose a game theoretic model to analyze price competition of RIS services, before concluding the paper.

II. Overview of RIS-aided Wireless Networks

This section first introduces an overview of RIS. Then we discuss heterogeneous characteristics and techniques used in RIS-aided wireless networks.

A. Overview of RIS

RIS is a man-made reconfigurable metasurface composed of a large number of regularly arranged passive reflecting elements and a smart controller [4]. Figure 1 shows the representative structure of RIS and universal software radio peripherals [4], [5]. Through modifying the amplitude and/or phase shift of the radio signal impinging upon its reflecting elements, RIS is able to achieve highly accurate radio wave manipulation in desired manners, which thus offers a new paradigm of wireless communication system design via controlling the radio propagation environment for various purposes, such as signal enhancement, interference suppression and transmission security. Furthermore, different from the conventional relays, the radio signal reflected by RIS is free from self-interference and noise in an inherently full-duplex transmission manner.

Among the recent contributions in RIS-aided networks, there are roughly four types of applications, as follows:

- *Anomalous reflection/transmission described in Fig. 1:* The RIS is configured in order to reflect the impinging radios waves towards specified directions that do not necessarily adhere to the laws of reflection. The advantage of this application is that the operation of the RIS is independent of the fading channels and the locations of the receivers. The limitation is that, in general, the SINR is not maximized and the system capacity is not achieved.
- *Beamforming described in Fig. 1:* The RIS is configured in order to focus the impinging radio waves towards demonstrate areas. The advantage of this application is that the SINR is maximized at the locations of interest. The challenge is that, in general, the optimization of the RIS depends on the fading channels and the locations of the demonstrate terminals.
- *Joint transmitter described in Fig. 1:* The RIS is configured in order to optimize the system capacity. The advantage of this application is that the specific status of the metasurfaces is exploited to modulate additional data. The setup of the RIS depends on the fading channels and the

locations of the receivers.

- *Single-RF multi-stream transmitter design described in Fig. 1:* This operation is similar to Type II, with the difference that the transmitter is a simple RF feeder located in close vicinity of the RIS. The feeder emits an unmodulated carrier towards the RIS, which reflects multiple data-modulated signals. This approach is suitable to realize multi-stream transmitters by employing a limited number of RF chains.

B. Applications of RIS in Various Wireless Networks:

By autonomously tuning the phase shifts of the reflecting elements of the RIS, the reflected signals can be constructively enhanced by other paths for increasing the desired signal power, or destructively combined for mitigating deleterious effects of multiuser interference. Hence, RISs provide additional degrees of freedom to further improve the system performance. By deploying the RIS in wireless communication environment, e.g., coated on walls of buildings and carried by aerial platforms, the RIS can turn the radio environment into a smart space that can assist information sensing, analog computing, and wireless communications [7], [8]. Figure 2 illustrates several applications of RISs in diverse wireless communication networks.

- In Fig. 2(a), RIS-enhanced mmWave networks are illustrated, where RIS is deployed for bypassing the obstacles between BS and destination areas. Thus, the QoS and coverage in mmWave communications are improved and extended, perspectively.
- Fig. 2(b) shows the three dimensional networking architecture enabled by aerial RIS, for which RIS is mounted on unmanned aerial vehicles (UAVs), so as to enable intelligent reflection from the sky.
- As shown in Fig. 2(c), a user far from the mobile edge computing (MEC) node in conventional networks, may suffer from a low data offloading rate due to severe path loss, thus RIS can be deployed at the location between the MEC node and users to reduce the excessive offloading delays.
- RISs can be deployed to strengthen the received signal power of cell-edge users and mitigating the interference from neighbor cells, and the power loss over long distances can be compensated in simultaneous wireless information and power transfer (SWIPT) networks (shown in Fig. 2(d)). On the other hand, as shown in Fig. 2(e), RISs can act as a signal reflecting hub to support massive connectivity via interference mitigation.
- Multicast transmission based on content reuse has attracted wide research attention, since it is capable of mitigating the tele-traffic, and hence will play a pivotal role in future wireless networks. In multi-group multicast communications, identical content is shared within each group, and each group's data rate is limited by the user with the weakest channel gain. To deal with this issue, a RIS-aided multicast network was introduced in Fig. 2(f).
- Fig. 2(g) shows the use of RIS for improving the physical layer security (PLS). When the link distance from the BS to the eavesdropper is smaller than that to the legitimate user, the achievable secrecy communication rates are highly limited. However, if a RIS is deployed in the vicinity of the eavesdropper, the reflected signal by RIS can be tuned to cancel out the signal from the BS at the eavesdropper, thus effectively reducing the information leakage.
- As shown in Fig. 2(h), in the conventional cognitive radios (CR), the beamforming gain is limited when the link from secondary user transmitter to secondary user receiver is weak, while the channel gain between the secondary user transmitter to the primary user receiver is much higher. To address the above issue, a RIS-aided CR network was proposed, so as to enable interference mitigation toward the primary user receiver, while improving the signal power at the secondary user receiver.

The above resource management schemes reached high spectrum efficiency, high energy efficiency, improve coverage, fairness, and interference elimination, etc., on one premise that RIS holders are all selfless. However, considering that RIS will be ubiquitous in the future wireless networks, the unilateral system performance optimization could be unfair for the RIS holders.

III. Pricing Issues and Incentive Approaches

A. What and Why Pricing Approaches

Heterogeneity of RIS-aided Wireless Networks: RIS-aided wireless networks are one key technology in future communications, which can be commonly referred as supplementary and enhancement of 6G. Therefore, the heterogeneity of RIS-aided wireless networks are intuitively determined by the inherently heterogeneous nature of 6G. This means that the adoption of the emerging RIS technology introduces challenges for wireless resource management such as beamforming, site selection, spectrum allocation, and user schedule. These challenges result from two dimensions, i.e., 6G infrastructures (e.g., dense deployment of wireless devices, the coverage and data rate nonuniform of base stations, and the limitations of capacities) [9] and the introduction of RIS (e.g., appropriate site selection, willingness of RIS owners, the service constraints of RIS, and numerous stakeholdes with diverse objectives). The traditional resource management solutions focused exclusively on entire system maximization, which rely on a centralized entity, resulting in the considerable information exchange between users and the network operator. In addition, RIS-aided wireless networks not only add a new dimension in resource management, but also many users may have multiple identities, e.g., the owners of RIS or wireless users. Therefore, the traditional resource management strategies are not suitable for the complex RIS-aided wireless network.

Multiple Entities and Rationality: The inherently heterogeneous nature of an ecosystem in which traditional wireless networks and RISs coexist is intuitively attributed to that they may belong to or operated by different entities, such as RIS owners, wireless service providers, and community developer, and they have different interests and limitations. The traditional resource management solutions that support a single objective may fail to model and determine an optimal interaction among these self-interested and rational entities. Considering that pricing approaches have been recently developed and adopted as useful tools to address resource management issues in the 5G wireless networks, where wireless service providers and RIS holders also have different objectives, such as high data rate, low latency, and revenue maximization [10].

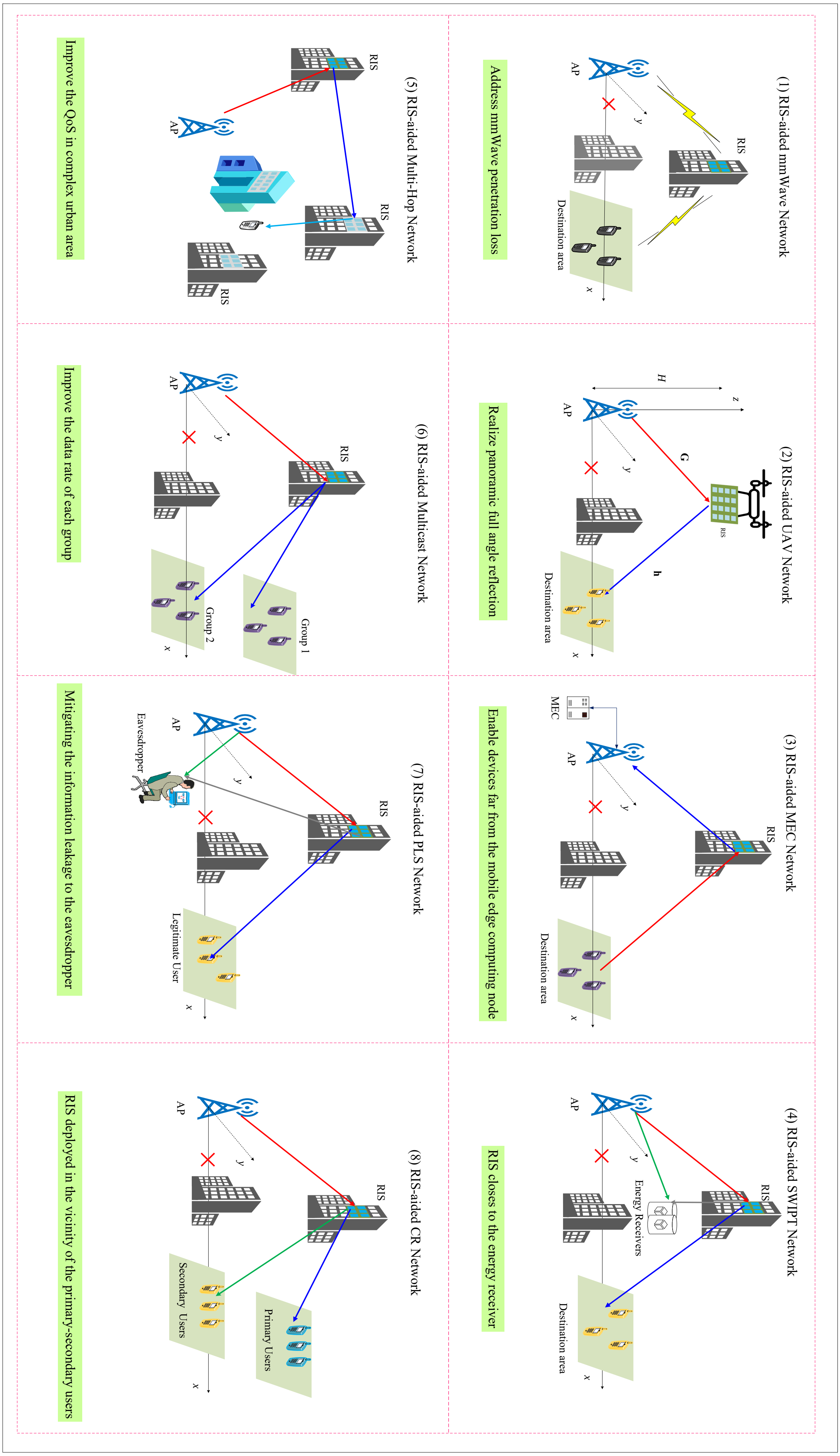

Fig. 2. Applications of RIS in multiple wireless networks.

Naturally, by bring pricing approaches from the existing works in 5G to the design of resource management strategies for RIS-aided wireless networks, the diverse objectives can be reached. Each entity reaches the best decision according to equilibrium analysis via the interactions among all the entities involved in a process. Accordingly, the inherently partially information exchange nature of pricing approaches make them suitable for autonomous decision making in a distributed method. In short, they are applicable for the RIS-aided wireless network which consists of a volume of autonomous entities. Accordingly, pricing approaches are suitable for autonomous decision making in a distributed method. Therefore, they meet the demand for diverse objectives of a large number of entities in RIS-aided wireless networks.

Advantages of Pricing Approaches: A flexible resource management method can be developed by pricing approaches to deal with the complex and fast variations of the wireless communication environment. Also, through negotiation mechanisms, pricing approaches enable the different entities to achieve multiple objectives such as energy consumption minimization, coverage improvement, high reliability, and fairness.

B. Fundamentals of Pricing Approaches

According to the incentive mechanism design, there are several different pricing models, such as profit-maximization pricing, noncooperative game, Stackelberg game, auctions, and utility maximization. In particular for this survey, the price is commonly determined using Stackelberg game. This in essence attributes to the fundamental supplementary function of RIS in future wireless communications where RIS can well overcome the shortcomings of poor signal penetration in mmWave and even higher frequency communications. For example, in the indoor environment, the transmitters and RISs can be deployed according to the requirements, so as to avoid the emergence of blocked links. Likewise, in outdoors, cities with high-rise buildings are very easy to block the communication link. Installing RISs on walls of buildings can improve the coverage of high-frequency communications. 6G is an era when everything is interconnected. In this context, the RIS can carry out flexible network deployment, support flexible network architecture and various data applications, and improve the terminal experience. On the other hand, the RIS holders and wireless service providers usually have their own individual benefits when the RIS is used to modify the transmission environment, their benefits may conflict with each other, which calls for flexible and decentralized resource management strategies. In addition to system performance and QoS requirements, from a business perspective, incentives economic factors such as cost, revenue, and profit are essential drivers to sustain RIS development and operation. Thus, it is necessary to design incentive mechanisms whereby the wireless providers pay for the RISs' services. In the spirit of existing works in 5G [9], Stackelberg game theory plays an important role.

Non-cooperative game is a game with competition among players. The players are selfish to maximize only their own utilities without forming coalitions with each other. Generally, the Nash equilibrium is a stable strategy profile and is the major solution concept of the non-cooperative game. Since the non-cooperative game models the conflict of selfish players, it has been commonly applied in environments with high competition or limited resources. Stackelberg game is a sequential game in which players consist of leaders and followers. The leaders choose their strategies first, and then the followers make corresponding strategies based on the leaders' strategies.

Therefore, Stackelberg game approaches are considered as an alternative when designing and implementing RIS services. The approaches aim to analyze how RIS pricing works and how RIS network entities interact economically. In the following, we discuss important pricing approaches and RIS-aided wireless networks related works. Among the early contributions in this ares, Ref. [11] studied the wireless resource management in RIS-aided networks given the assumption that the BS and RIS belong to different operators. In the spirit of this work, the authors of [12] investigated the *true* reflection resource management in RIS-aided peer-to-peer networks by defining the modular structure of RIS builds on the premise of that the access points and RIS belonging to different operators.

IV. Pricing Models for RIS-aided Wireless Networks

In this section we demonstrate an example model of RIS pricing to address RIS service pricing competition. We first describe the system model of the RIS-aided network. Then we present a Stackelberg game formulation. Some numerical results and outlooks for possible extensions are discussed afterward.

We consider S RIS services that competitively forward the BS's signal to K single-antenna mobile users, where the BS is equipped with M antennas. Without loss of generality, each RIS s consisting L_s reflection elements. In addition, in the following analysis–for the sake of simplicity–we consider that the reflecting coefficient $\phi_s^l = \beta_s^l e^{j\theta_s^l}$ with continuous phase shift and continuous amplitude attenuation as $\mathcal{X} = \{\phi_s^l : |\phi_s^l| \leq 1, 1 \leq s \leq S, 1 \leq l \leq L_s\}$. The maximum transmit power budget of the BS is $p_{\max}$. The BS can buy RISs' usage right for their own applications. The BS is charged the price $q(s) > 0$ to lease the usage right of RIS s. The BS can lease the usage right from a single RIS or multiple RISs.

A. Stackelberg Game Formulation

Given the above RIS services, we tended to study the competition in setting the price of RIS usage right. For the substitute case, in this section, we present the Stackelberg game formulation for the price-based resource management. The Stackelberg game model [13] is thus applied in this scenario. Stackelberg game is a strategic game that consists of leaders and followers competing with each other on certain resources. The leaders move first and the followers move subsequently. In this paper, we formulate the RISs as leaders, and the BS as the followers. The RISs (leaders) imposes a set of prices on per use of RIS. Then, the BS (follower) update its active-passive beamforming strategies to maximize its individual utility based on the assigned use prices.

Under the above game model, it is easy to observe that the RISs' objective is to maximize its revenue obtained from selling the usage right to the BS. Mathematically, the revenue of RIS s can be expressed as

$$V_s(q(s), \boldsymbol{q}_{-s}) = q(s)||\boldsymbol{\Phi}_s||_F, \tag{1}$$

where $\boldsymbol{q}_{-s}$ is a vector of use prices for all RISs except RIS s, i.e., $\boldsymbol{q}_{-s} = [q(1), \dots, q(s-1), q(s+1), \dots, q(S)]^T$, $\boldsymbol{\Phi}_s \in \mathcal{C}^{L_s \times L_s}$ is the phase shift matrix of RIS s, and $|| \cdot ||_F$ is the Frobenious norm of matrix.

At the BS side, the received SINR at user k can be written as

$$\gamma_k(\boldsymbol{w}_k, \boldsymbol{\Phi}) = \frac{|(\boldsymbol{h}_{d,k}^{\dagger} + \boldsymbol{g}_k^{\dagger}\boldsymbol{\Phi}(||\boldsymbol{\Phi}||_F)\boldsymbol{H})\boldsymbol{w}_k|^2}{\sum_{i \neq k}^{K} |(\boldsymbol{h}_{d,k}^{\dagger} + \boldsymbol{g}_k^{\dagger}\boldsymbol{\Phi}(||\boldsymbol{\Phi}||_F)\boldsymbol{H})\boldsymbol{w}_i|^2 + \sigma^2}, \tag{2}$$

where $\boldsymbol{w}_k \in \mathcal{C}^{M \times 1}$ is the transmit beamforming vector for user k, σ^2 is the background noise at user k, and $\boldsymbol{\Phi}(||\boldsymbol{\Phi}||_F)$ is a diagonal block matrix composed of the phase shift matrices of RISs being used.

The utility of the BS is defined as follows:

$$U(\boldsymbol{\omega}_k, \boldsymbol{\Phi}, \boldsymbol{q}) = \sum\nolimits_{k=1}^{K} \log_2(1 + \gamma_k) - \delta \sum\nolimits_{s=1}^{S} ||\boldsymbol{\Phi}_s||_F, \tag{3}$$

where $\delta > 0$ is the weight of the cost of leasing RIS s and $\boldsymbol{q}$ is the use price vector with $\boldsymbol{q} = [q(1), q(2), \dots, q(S)]^T$, with $q(s) > 0$ denoting the use price for RIS s. It is observed from (3) that the utility function of the BS consists of two parts: *profit* and *cost*. If the BS increases its transmit power and the size of the RISs, the transmission rate increases, and so does the profit. As a result, it has to buy more RISs usage right, which increases the cost. Therefore, resource management strategies are needed at the BS to maximize their own utilities.

The objective of this Stackelberg game is to find the Stackelberg Equilibrium point from which neither the leaders nor the followers have incentives to deviate. The point $(\boldsymbol{q}^*, \boldsymbol{\omega}^*, \boldsymbol{\Phi}^*)$ is the Stackelberg Equilibrium for the proposed Stackelberg game if for any $(\boldsymbol{q}, \boldsymbol{\omega}, \boldsymbol{\Phi})$, the following conditions are satisfied, i.e., $U(\boldsymbol{q}^*, \boldsymbol{\omega}^*, \boldsymbol{\Phi}^*) \geq U(\boldsymbol{q}^*, \boldsymbol{\omega}, \boldsymbol{\Phi})$ and $V_s(\boldsymbol{q}^*, \boldsymbol{\omega}^*, \boldsymbol{\Phi}^*) \geq V_s(q(s)^*, \boldsymbol{q}_{-s}^*, \boldsymbol{\omega}^*, \boldsymbol{\Phi}^*)$. To compute the Stackelberg Equilibrium, the backward induction method [14] is commonly used.

B. Numerical Results

We exhibit the numerical results to demonstrate the performances of the proposed resource management strategies based on the approach of RIS usage pricing. For simplicity, we set the balance parameter δ to 0.1. To keep the complexity of simulations tractable, we focus on the scenario, where the $K = 4$ users are randomly deployed within a circle cell centered at $(200, 0)$m, and the cell radius is 10 m, the BS and RISs are deployed at $(0, 0)$ m and $(50, 50)$ m, respectively, where the number of reflecting elements of each RIS is set as $L = 8$. We assume that the BS is equipped with 4 antennas. From [15], we set the path loss exponent of the direct link as 3.5, and the path loss at the reference distance 1 m is set as 30 dBm for each individual link. For the RIS-aided link, 2 is the value of the path loss exponent from the BS to the RISs and that from the RISs to users. For simplicity, we assume the Rayleigh fading model to account for small-scale fading.

The performance of the Stackelberg game-based scheme is evaluated against one existing benchmark scheme, i.e., random pricing scheme. In the random pricing scheme, the RISs randomly determines their strategies, without considering the existence of the BS. Figures 3 and 4 show the effect of the maximum transmit power $p_{\max}$ on the utility of the BS and all the RISs, respectively, when the number of RISs is 5. Correspondingly, Fig. 5 depicts the service prices versus the maximum transmit power at BS. For the BS and RISs, the Stackelberg game-based scheme achieves the highest utility value compared with random pricing, which indicates that the proposed pricing-based Stackelberg game scheme performs best in resource management for RIS-aided networks. From the results, we observe that the utility values of the BS increases as $p_{\max}$ grows from -5 dBm to 10 dBm. Meanwhile, the utility value of each RIS achieved by the Stackelberg game-based scheme decreases by increasing the value of $p_{\max}$. This is because that the cost of power consumption is not considered in the utility function of the BS, and thereby, the BS will tend to buy a small number of RISs when the transmit power is sufficient. Meanwhile, for $p_{\max} > 0$ dBm, the RISs need to incentive the BS to buy reflection resource through low price, which can be observed from Fig. 5.

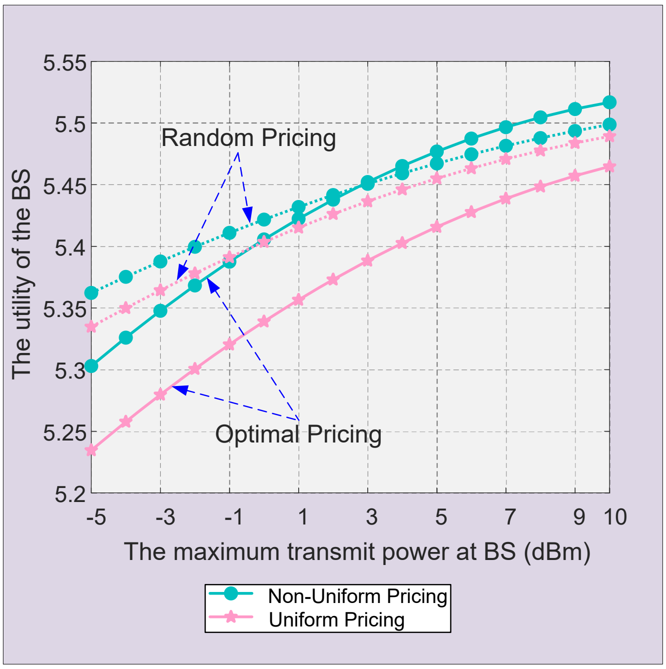

Fig. 3. Utility of the BS vs. $p_{\max}$.

C. Future Research Directions

Pricing for RIS-aided wireless networks is a meaningful research area. Since it is an emerging topic, there are still many open issues to be addressed, some of which are listed as follows.

- **Community Pricing:** It is necessary to investigate the *community pricing* for the RIS-aided wireless networks in complex urban environment, since there are a large number of residents in each community. To be more specific, during the construction of communities, the community developer can price the deployment of RISs rather than householders. Community pricing can well reduce the complexity, since all the RISs in one community belong to one holder.
- **Function Pricing:** Function pricing is needed to meet diverse user requirements in different communication scenarios. The function pricing is based on serving different communication needs, which can provide guidance of the deployment and size of RIS.
- **Vickrey Auction Pricing:** With the increasing contradiction between the shortage of wireless resources and soar-

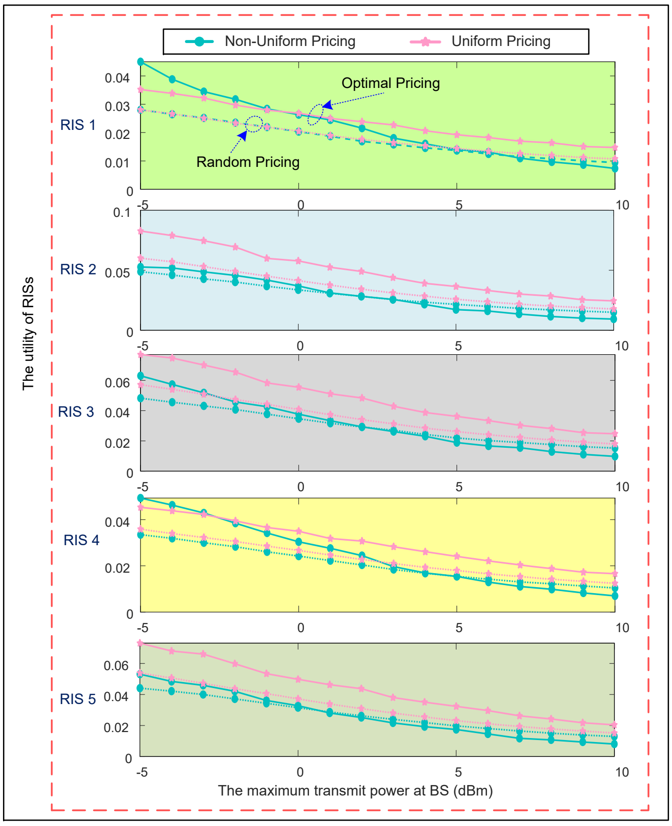

Fig. 4. Utility of each RIS vs. $p_{\max}$.

ing performance requirements, the on-demand resource allocation is significantly important. Fortunately, auction is an efficient way of scheduling resources to buyers which value the resources the most. In the Vickrey action, wireless service providers (bidders) bidding prices that they are willing to pay for using RISs to the auctioneer. The highest bidder will win, as determined by the auctioneer. In the end, the winner will pay the second-highest price rather than his own submission.

V. Conclusion

RIS has emerged as one of the promising technologies for 6G wireless networks. In this paper we have considered the pricing approaches for resource management in RIS-aided wireless networks. Firstly, we have described the principles and some typical RIS applications in various emerging systems. Then, we have specifically introduced the heterogeneous characteristic of RIS networks with the aim to understand the motivations of using pricing models in RIS-aided networks. Afterwards, to demonstrate the application of pricing model, we presented the Stackelberg game theoretic model for RISs service competition.

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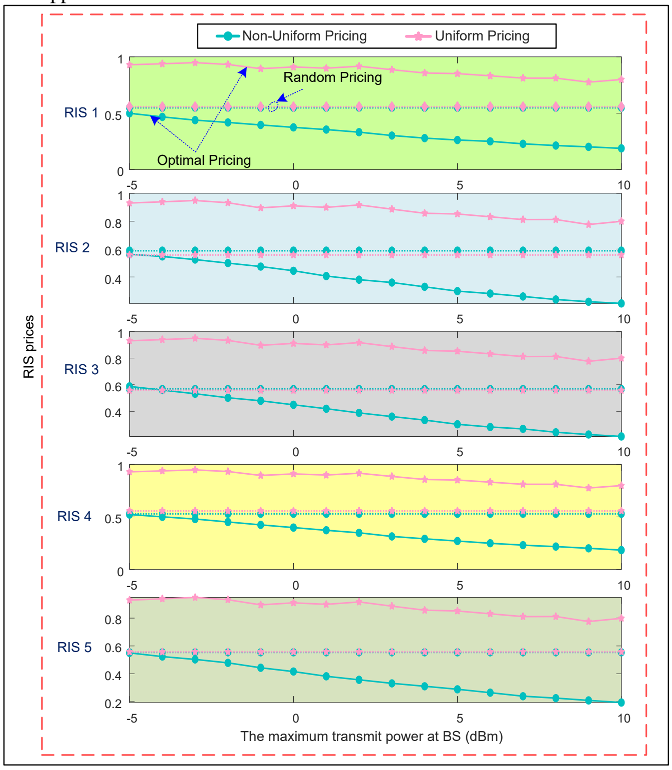

Fig. 5. Price of each RIS vs. $p_{\max}$.

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