Toward User-Centric Resource Allocation for 6G: An Economic Perspective

Jiacheng Chen, Bo Qian, Yunting Xu, Haibo Zhou, and Xuemin (Sherman) Shen

Abstract

This article presents an economics-inspired solution for realizing user-centric resource allocation for 6G. Particularly, the user-centric criterion is proposed based on users' subjective values, that is, quality of experience (QoE) on services, thereby satisfying the most desired demands of all users. Furthermore, the price is utilized as the indicator of users' values, and the total value of information conveyed to users is prioritized so that the user-centric resource allocation is economically efficient. In addition, a Cybertwin-assisted core network is introduced as a practical solution for implementing user-centric resource allocation. A resource market with appropriate market rules is developed from auction theory. It is demonstrated through simulations that our proposed user-centric resource allocation solution can convey more personalized value to users.

Introduction

One of the fundamental principles of economics is the scarcity of resources. More formally, resources are limited with respect to all the purposes they could possibly serve. In cellular networks, wireless resources are scarce mainly due to the lack of available spectrum. The problem will become more serious in the next generation mobile network, namely 6G [1], with the ever growing bandwidth consumption of services, and the upcoming era of Internet of everything, which will bring trillions of devices connected. As a result, resource shortage will occur when users' total demands on services exceed the throughput that network can provide. Then, users' quality of experience (QoE) will be degraded, including low video streaming quality, high mobile gaming latency, and even disconnection. What is worse, since the current network is not designed from the user side, users have no way to guarantee their QoE, regardless of the value of services to them. Besides, as the trend of development for general commercial goods and services in economics, the trend for future 6G is to provide personalized services to users so as to create more added values, since 3G has realized the basic Internet access functions, 4G has greatly improved the experience, and 5G has begun to focus on vertical scenarios.

In current cellular networks, the widely-used criteria for allocating wireless resources are based on network performance, such as throughput and delay. In many research works, resource allocation is formulated as an optimization problem tailored for a specific scenario, with a selected quality-of-service (QoS) criterion. However, only a single objective can be optimized for each scenario, while different scenarios can have distinct criteria for resource allocation. As shown in Fig. 1, naive resource allocation criteria are given for enhanced mobile broadband (eMBB), ultra reliable and low latency communication (uRLLC) and massive machine type communication (mMTC) scenarios, respectively. As an example, throughput-optimized resource allocation will not work well for delay-sensitive services. Also, although compromise among contradictory objectives can be made, it is actually difficult to reach a "perfect balance point," which itself is difficult to define. The dilemma of resource allocation will be more formidable with more diversified scenarios coming beyond 5G, such as uplink centric broadband communication (UCBC), real-time broadband communication (RTBC), and harmonized communication and sensing (HCS) in 5.5G proposed by the industry [2], as shown in Fig. 1. Currently, the network slicing technology is helpful to realize resource isolation for different scenarios, but it may become both complex and inefficient to make virtual slices for all possible scenarios in the future.

In this article, we introduce personalized resource allocation for 6G by allowing users to decide how good their received services are, based on how important the services are to them, that is, their subjective values on services, and their personalized requirements on the services. The so-named user-centric criterion can also be explained through general economic principles. On the one hand, a personalized scenario for a user comes from how he evaluates both the benefits of service and the costs he should pay for acquiring the services. The evaluation is strongly subjective and environment-dependent. For example, different users usually have different values on the same service, and a user usually has different requirements on the same service under different conditions. Consequently, the network should be aware of users' intentions such that customized transmission services can be provided. On the other hand, the final goal of network services is to deliver information and essentially the values contained therein to users. Hence, the network should satisfy the most desired demands of all users, so that the total value conveyed by the network can be maximized. In other words, evaluation of a resource unit should be based on the value it can potentially bring to a user. If a user is not allocated enough resources, then it is not because of performance-related reasons such as

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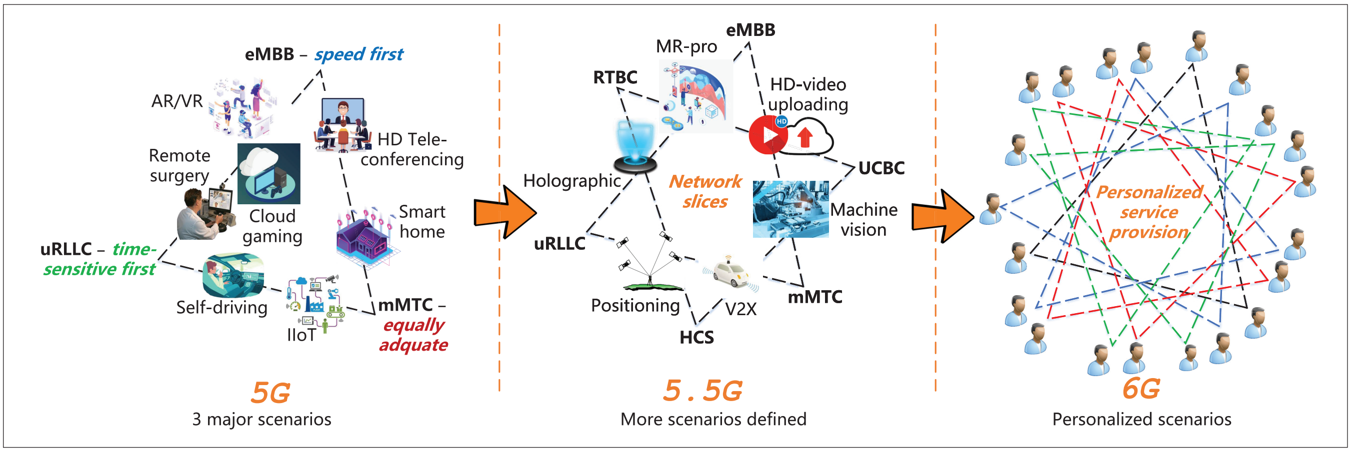

FIGURE 1. Dilemma of resource allocation faced by 5G toward the era of personalized service provisioning in 6G.

poor signal strength, but is because the user does not value the services more than others. In economics, it is said that such allocation of resources achieves efficiency, which is the most widely acknowledged criterion.

In order to realize user-centric resource allocation (UCRA), first of all, we need a way to reflect the user's value. It is very difficult to model the user's value directly, due to its subjectivity and complexity. Complexity means that evaluation of value is usually concerned with various aspects, such as QoS and the importance of services transmitted to the user. From economics, we know that price can concisely reflect the scarcity of resources. A user can explicitly show his subjective value on service by either offering a price or accepting a price, regardless of the type of service. Hence, UCRA should take resource prices into account. Also, a fine-grained dynamic resource charing policy should be adopted such that users' personalized services can be charged with differential costs. Actually, the paradigm of resource allocation changes from centralized planning from a third-party view by the scheduler to a resource market, in which all users participate. However, it is impractical to let users directly interact with the resource market since both transaction costs and overheads of wireless communications incurred by the interactions will be too high. To this end, we utilize the Cybertwin concept proposed by Yu *et al.* [3]. Cybertwin provides a general edge-based intelligent agent service to users. Specifically, Cybertwin can participate in the resource market in real-time on behalf of the user. Under the market rules, Cybertwin will determine how much resource the user can acquire and how much the user should pay for the resource. Thus, Cybertwin essentially performs management of user's network access. To summarize, the main contributions of this article are listed as follows:

- We propose the user-centric criterion for realizing personalized resource allocation for 6G. The core idea is to consider users' subjective values on services in resource allocation, such that the overall values conveyed by the network can be maximized. We take price as the value indicator of users' services.
- We develop practical user-centric resource allocation by utilizing Cybertwin as a user's agent and realize a resource market with negligible transaction costs and communication overheads.
- We develop appropriate market rules from auction theory and demonstrate the effectiveness of user-centric resource allocation through comparisons with four other scheduling algorithms in simulation.

In the remainder of this article, we first explain the rationale of UCRA in detail and outline its difference with other related works. Then, we introduce the Cybertwin-assisted core network and implementation of the resource market. Afterwards, we analyze the feasibility of three classical auction formats and provide studies on different UCRA algorithms through simulation. We conclude the whole article and point out future works at the end of the article.

Rationale of User-Centric Resource Allocation

In this part, we first explain the rationale of UCRA by discussing its benefits and emphasizing its distinct design goals. Then, we briefly summarize related works and highlight our differences with them.

Benefits

The Equilibrium Between Demand and Supply Can Be Achieved in the Resource Market Given a Proper Price: The state of equilibrium indicates the state that both resources are fully utilized and users' demands under the current price are satisfied. Currently, most cellular networks adopt the flat-rate charging policy, which means the resource prices are irrelevant of the actual relationship between demand and supply. Also, resource allocation methods are basically centralized planning, without any information on which users desire services most. Consequently, the imbalance between demand and supply will occur very often, since users' demands can vary arbitrarily. However, if dynamic pricing of resources is adopted, then price can reflect the real-time state of network resources utilization. Since each user has a value on his service, he will evaluate whether it is worth using the network resources to satisfy his demand based on the current resource price. In other words, the payoff for requesting a service becomes small so that the user's demand diminishes. Meanwhile, due to the reduction of total demands, other users' demands can be satisfied and positive payoffs can be gained for these users.

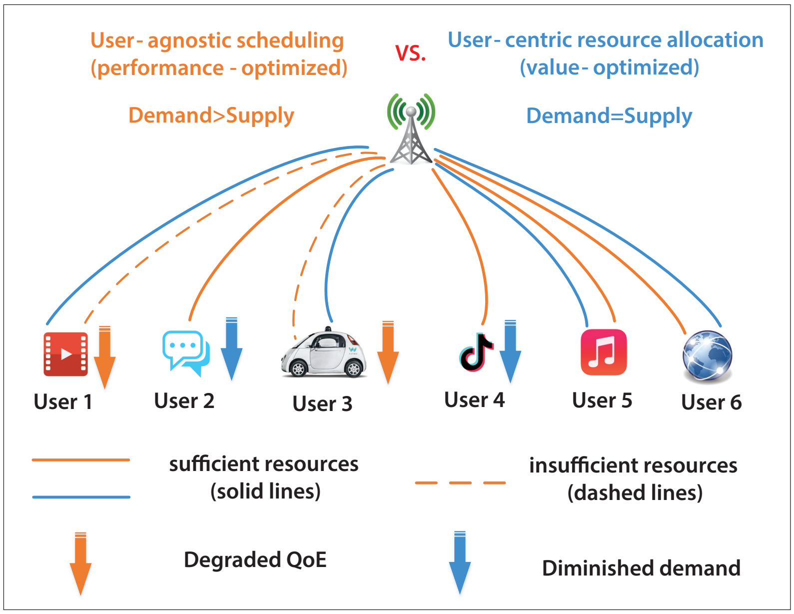

FIGURE 2. Comparison between user-agnostic scheduling (orange lines) and user-centric resource allocation (blue lines).

Figure 2 gives the comparison between user-agnostic scheduling (orange lines) and user-centric resource allocation (blue lines). In user-agnostic scheduling, all users have demands on services, and the scheduler allocates resources so as to optimize overall network performance. However, the QoE of user 1 and user 3 is degraded due to insufficient resources. From the perspective of network, the total demands of all users are larger than the supply, that is, the throughput it can provide. In user-centric resource allocation, since price is leveraged to flatten the total demand, user 2 and user 4 either reduce their demands or migrate to other time/space. On the one hand, their QoE will not be degraded since they do not feel worthy using the resources at the current price. On the other hand, user 1 and user 3's high-value demands can be satisfied with the saved resources. Meanwhile, the total demands can meet supply.

UCRA Can Be as Simple and Scalable as the Current Resource Allocation Methods Such as Proportional Fair Scheduling, and Is Much Easier to Implement Than Optimization-Based Centralized Allocation and Network Slicing: Price essentially aggregates all the knowledge (regardless of what it is) concerned with a user's intention on the requested service. Therefore, it is an indicator of a user's value, and can be directly utilized as a parameter in existing resource allocation methods. Also, different from centralized optimization, each user has his own value and makes decision on offering or accepting the price on his own, so resource allocation can work in a distributed manner. Network slicing can be regarded as allocation of resources based on the type of services. Hence, it requires classification of various kinds of services. However, a fine-grained classification requires a large number of slices and is impractical to implement, while a coarse-grained classification cannot strictly distinguish different services and is less useful. With a price attached to a user's service as the value indicator, the network can easily become aware of the priority of service, regardless of its types, and resources can be allocated accordingly.

UCRA is Economically Efficient: In economics, an efficient allocation means to allocate resources to those who have the highest values and can make the best of resources. Users who offer or accept higher prices believe they can create more values through utilizing the resources, thus they should be allocated resources so that more values can be created for the whole society. Note that it does not necessarily mean that rich users are more likely to acquire resources than poor users. Also, when users have to compete for resources, the price will become higher and users have to pay more for acquiring the resources. Since the same resources cannot be allocated to different users simultaneously, the winning users actually pay for the additional social costs, that is, the costs that other users cannot utilize the resources. In this way, users pay the costs they deserve to pay for occupying the resources.

The Network Itself Can Benefit From Applying the User-Centric Criterion in Three-Fold: To begin with, the additional profits gained from higher prices can be used for investment on network infrastructures so as to further increase the resource supply. In this way, all users eventually gains benefits from the users who pay social costs.

Then, operators can adopt cell-based dynamic pricing scheme in a natural way based on users' demands. A cell with lower resource price can attract more users while a cell with higher resource price can incentivize users with lower values to reduce their demands or move to other cells. Hence, resource utilization can be balanced among different cells. Also, a user's payment depends on his serving cell, and operators can avoid applying a unified data plan for different regions with different network operating costs and user incomes. The cell-based dynamic pricing scheme can not only yield more profits from users with high values, but also benefit users in less developed regions.

Last, the value of services provided on the network can be gradually improved. With the user-centric criterion for resource allocation, users tend to satisfy their most desired demands, especially when the resource price is high. It is also easier for users to acquire resources when they are willing to pay more for the high-value services. As a result, services with higher values are more likely to be transmitted, and the demand for such services will increase. As per the law of supply and demand, supply of high-value services will also be increased. Hence, service providers will endeavor to improve the value of their services.

Design Goals

The design goals of UCRA are distinct and are emphasized in this subsection.

On Operator's Profit: Since operators are running business instead of public welfare for providing the network to users, and especially considering the surging costs of current 5G, we think it is acceptable for operators to gain more profits from those users who are willing to pay more for their high values of services. UCRA essentially achieves this goal by allocating resources based on users' subjective values on services. In the long term, operators can keep providing better network services to users, for example, through investing on network infrastructure or new technologies. Also, a profitable market can attract new operators to come in such that the market can become more competitive.

On Value-Orientated Allocation: The main objective of user-centric criterion is to achieve economic efficiency in that the total value conveyed by the network can be maximized. In other words, the value of each transmitted byte is different, and it is not worthy using the limited resources for low-value services from the global view, regardless of the total throughput, which may decrease since resource allocation is not throughput-optimized. However, we think that fairness in terms of users' total transmitted data during a certain period can still be taken into account in order to avoid starvation of users. Compromise can also be made by taking into account users' signal strength in resource allocation. The user-centric version of proportional fair allocation is such a compromised solution and will be examined in the article. Besides, a user's demand on low-value service can be migrated to other time or space with lower total demands, for example, at late night, or at certain cells where there are few users, and the overall network throughput may actually become larger due to more sufficient utilization of idle resources.

On User-Friendly Interface: In order to make the dynamic prices of resources user-friendly, as well as to allow price changes frequently, we address this practical challenge by introducing the Cybertwin agent for each user. As to be introduced later, Cybertwin will provide a simple interface for users to use the network with negligible transaction costs.

On User's Costs: We introduce more flexibility for users to manage their monetary costs on using the network. On the one hand, the overall costs of a user are not necessarily higher, since the price will be lower when resources are not fully utilized. On the other hand, it is totally dependent on each user's desire to spend more or less, and dynamic pricing can offer more flexibility to users. A user may spend more for acquiring better quality of services and higher values, or he may decrease his demands during peak hours so as to save costs.

On Network Neutrality: We leave the controversy of network neutrality to users. Network neutrality advocates that all services should be treated equally with respect to utilizing the network resources. In UCRA, the network still treats different services the same, and it is the users' choices that influence which services are more likely to be transmitted on the network.

Related Works

The key idea of user-centric criterion is to consider users' subjective values on services in resource allocation through utilizing price as the value indicator. Note that it is different with user-centric network (UCN), which refers to an access network architecture that uses more than one nearby APs to serve each user. In this subsection, we briefly examine related works on resource allocation concerned with economic and pricing models and highlight our differences with them.

Difference With Respect to Objective: In [4], Zhang et al. present a survey on auction approaches for resource allocation in wireless systems. The

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authors mention how radio resources are defined as auction commodities, such as subchannel and time slot. The quality of these commodities is determined by their capability to carry data. [5] is another recent survey on economic and pricing models for resource management in 5G. Luong et al., summarize the objectives of different applications (Fig. 1 in [5]), including throughput/data rate maximization, revenue maximization, system utility maximization, and so on. Even if a utility or valuation function is defined for a user, it is still based on network performance metrics, such as instantaneous spectral usage (bit/s/Hz) [6]. Therefore, although economic and pricing models have been extensively exploited, users' subjectivity is not considered, and the objective is not concerned with the overall value to users.

Difference With Respect to Scenario and Method: Dynamic pricing has been successfully applied in other scenarios. For example, in [7], Abdalrahman and Zhuang study dynamic pricing for PEV charging with deep reinforcement learning (DRL). The DRL approach is also used in other dynamic pricing problems such as demand response in smart grid [8], and express lane tolls [9]. In [10], Qian *et al.*, adopt Stackelberg pricing game for spectrum sharing in VANET. Economic model is also utilized for privacy preserved mobile crowd sensing [11]. Dynamic pricing has also been investigated to alleviate Internet congestion [12]. The authors suggest to modify the Internet protocol by adding a bid field in each packet. Another approach is given by partitioning a network into different channels with different prices [13]. In [14], Sen *et al*., introduce time-dependent pricing for cellular data. Different prices are applied at different times of the day, and users are notified a day ahead so as to make a plan on data usage. Unlike existing works, in this article, we are the first to develop a practical Cybertwin-assisted approach for realizing fine-grained user-centric resource allocation in cellular networks.

Cybertwin-Assisted Implementation Framework

To realize UCRA, users need a practical way to show how much they desire the requested services, or their altitude toward resource price. Generally, dynamic pricing can be implemented through either posted price or price discovery. In posted price, price is determined by the seller. Posted price can be used as a tool for coarse-grained demand control [14], since it is difficult to decide an appropriate price in real-time. In price discovery, price is discovered from buyers' bids. Price discovery can be used for resource allocation with an appropriately designed auction format. However, several challenges still need to be addressed [4]. First, dynamic resource price implies that users need to intensively react to the price changes by passively adjusting their demands or actively submitting different bids. Hence, substantial transaction costs are incurred when the price changes rapidly. Second, users' communications with the market face security and reliability problems in the wireless environ-

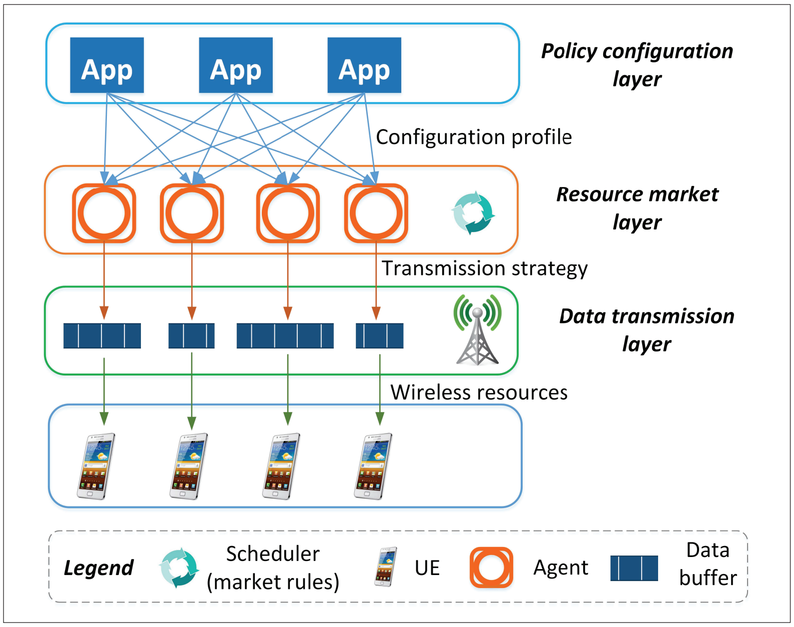

FIGURE 3. The architecture of Cybertwin-assisted core network.

ment, and also cost wireless resources. Last, a user-friendly interface for interacting with the market is required.

In this article, we introduce a framework for UCRA by utilizing Cybertwin as a user's always-online agent and implementing a price discovery based resource market. As introduced in [3], Cybertwin has the following functionalities. First, it serves as a user's entry point to the Internet and authenticates the user. Second, it proxies a user's communications and manages different access networks that the user connects with. Last, it can also act as user's personal assistant and behave on behalf of the user. Thus, for now, it can be deployed as a network function (NF) within the 3GPP 5G service-oriented architecture in the 5G core network (5GCN) at the edge. The benefits that Cybertwin brings are three-fold:

- Cybertwin reduces the communication overheads on wireless links by communicating with the resource market on the edge cloud within the core network, with enhanced security, high reliability.
- Cybertwin reduces the transaction costs of users by participating in the resource market on behalf of users.
- As user's assistant for communication, Cybertwin provides a simple interface to the user through a configuration profile with only four parameters and intelligently determines how data is transmitted to the user and the corresponding costs, both under the user's control.

The architecture of Cybertwin-assisted core network is illustrated in Fig. 3. On the top lays the policy configuration layer, in which each user can configure policies for each App. The generated configuration profiles are loaded by the user's Cybertwin, which competes on the resource market layer for resources, based on the market rules enforced by the scheduler. At the data transmission layer, each user's data in the buffer is transmitted according to the transmission strategy and resource allocation results, and wireless resources are allocated to each user. The transmission strategy allows users to customize their requirements on how services should be transmitted. The process of resource allocation is as follows. In each scheduling period, Cybertwin submits a bid to the scheduler. It also informs scheduler the expected data to be transmitted. Scheduler then calculates the resource allocation results based on market rules.

For users' convenience, we adopt the declarative interaction paradigm between a user and Cybertwin. Specifically, a user can manage Cybertwin's behavior through a configuration profile that includes the following parameters:

- *Unit price cap:* the most money a user is willing to pay for a resource unit
- *Budget:* the total money a user is willing to spend during a longer period, for example, a month
- *Bidding strategy:* determining the bid for a resource unit in each scheduling period
- *Transmission strategy:* determining the data expected to transmit in each scheduling period.

Except for a default profile, each App can have an App-specific profile for its own traffic, such that users can customize their preferences on different services. For machine-type users, Cybertwin can be configured by their owners.

In current cellular network, resource block (RB) is the basic unit for scheduling, thus a resource unit is defined as an RB in this article. In other words, the highest price that a user is willing to pay for an RB is used as the value indicator of the user's requested service. Investigation on using other value indicators is not discussed for now. Note that although current cellular network charges users by the amount of transmitted bytes, it is more reasonable to charge users by used RBs, since users actually consume RBs to transmit data. Also, the costs of RBs for transmitting the same bytes are usually different due to channel state variety, which means that the corresponding social costs are different. Moreover, cost-sensitive users may prefer moving to places where signal strength is strong, so as to consume fewer RBs and thereby pay less. This is beneficial for improving the resource utilization efficiency.

Auction-Based Allocation Methods: Analysis and Evaluation

Analysis

Formally, market rules can be characterized by mechanism design theory [15]. A mechanism, also known as an auction format, is comprised of: a set of bids from all users, an allocation rule determining the probability that a user gets an item based on the bids, and a payment rule deciding his expected payment. Although arbitrary mechanisms can be adopted, for the UCRA, the mechanism should be economically efficient, such that the total value of the network is maximized. Besides, users only need to pay the reserve price if resources are sufficient.

From the perspective of auction, resource allocation has the following properties. In each period, it is a sealed-bid multiunit auction, which means users submit their bids without knowing others', and units are allocated solely based on the submitted bids. Separate auctions are conducted sequentially in consecutive periods. A user usually demands many RBs in a period, and his total demand is usually satisfied in many periods.

We briefly introduce three practical auction formats: discriminatory auction (D), uniform-price auction (U) and Vickrey auction (V) [15]. The three auctions are all standard in that units are allocated to the highest bids, but differ in payment rules. In D, a user pays his winning bids, namely "pay-as-bid." In U, all users pay the highest losing bid (clearing price) for their winning units. In V, a user pays the highest losing bids of his competing bids (the bids except his own).

Equilibrium analyses for the three auctions are given under private value, risk neutrality and symmetry settings. Specifically, each user has an identically and independently distributed value vector containing values for all units, aims to maximize his expected payoff characterized by a linear function, and adopts the same bidding strategy as others. In V, it is a weakly dominant strategy to bid truthfully, that is, bid as the value vector. It also directly implies that V allocates efficiently. In fact, an efficient equilibrium requires any value be mapped into bid by the same increasing function. Unfortunately, it is generally intractable to derive closed form equilibrium strategies for the other two auctions, yet some structural features can be derived. In U, it is known that bid on the first unit is equal to value. Also, payoff can be increased by shading the other values, since one of these bids may become the clearing price and thereby influence the payment on all units. U is inefficient since the above requirement fails. However, if user has single-unit demand, then U becomes efficient and truthful. Actually, inefficiency stems from user's demand of multiple units. In D, it can be demonstrated that different units are also bid differently, thus D is also inefficient. However, same as U, it is efficient under single-unit demand condition, and symmetric strategy can be derived.

We now check applicability of the three auction formats. V has the most desirable features, but the payment rule is relatively complicated. U has the same properties as V under single-unit demand condition. Since the scale of an RB is very small, it is reasonable to assume flat demand of units, that is, marginal values of additional RBs are equal. Then, the item to be sold can be regarded as a "transmission opportunity." Thus, each user only has single-unit demand, and U becomes an appropriate mechanism. Basically, with U, the overall utility of all users is maximized, as given by

$$Util_{\mathbf{U}} = \sum_{i:v_i - p_i > 0} (v_i - p_i), \tag{1}$$

where v_i and p_i are the value and paid price of user *i*, respectively. Equation 1 also indicates that a user will only use the services when his utility is positive. Although D is also efficient with single-unit demand, its equilibrium strategy is related with the number of total users, which varies frequently. The strategy also requires calculation of order statistics, which is very complex when the number of total units is large. Moreover, equilibrium of D is *ex ante*, while equilibria of both V and U are *ex post*. Since resource allocation consists of sequential auctions, users have incentives to deviate from *ex ante* equilibrium in the next auction after payments of the current auction have been revealed. Therefore, D is not suitable when static strategies are adopted in each period. However, if dynamic strategies are adopted in the sequential resource allocation process, D becomes suitable due to the pay-as-bid mechanism, which means users are responsible for their bids and will be more cautious on submitting higher bids.

> Separate auctions are conducted sequentially in consecutive periods. A user usually demands many RBs in a period, and his total demand is usually satisfied in many periods.

Simulations Results

Some simulations results are presented to show the differences between traditional and UCRA methods. We adopt the numerology of LTE, which is also compatible with the 5G NR flexible numerology. We use a 20MHz frequency band, and the total number of RBs in one period (1ms) is 200. There are 20 users, each requesting a single service of ~ 3000kb/s. Without loss of generality, we randomly assign MCS for each user, reflecting users' different locations, channel states, and so on. We set 15 steps of *unit price cap*, with each user randomly choosing one of them, representing users' different values on services. The reserve price is set to 0. We simulate 100 periods, so budget is not considered. Also, we adopt the best-effort transmission strategy that attempts to transmit all the data coming from core network in each period. We use U (denoted as price) as the auction format, and compare it with traditional max C/I (denoted as maxCI) and proportional fair (denoted as pf) scheduling methods. Considering users' value may not be the only objective in practice, we also examine user-centric version of proportional fair scheduling. Specifically, *unit price cap* is used as the value indicator. Hence, considering fairness, user-centric proportional fair (denoted as pf-price) scheduling is developed by using value indicator as the weight variable. Furthermore, considering throughput, transmission rate is included in pf-price (denoted as pf-price2).

We compare the above five methods from the perspectives of throughput and value, respectively. Figure 4 shows the cumulative distribution function (CDF) curve of average transmitted data in a period of all users, and the subfigure on the top-left gives the average of all users. We can find that maxCI has the largest average transmitted data, yet pf allows all users to transmit. Although price transmits less data, pf-price2 makes a comprise toward transmitting more data. Figure 5 shows the CDF curve of average value in a period of all users, and the subfigure on the bottom-right gives the average of all users. Here, value is represented via the value indicator, namely *unit price cap*, multiplied by the number of allocated RBs. It is obvious that price has the highest value, indicating that resources are allocated to those who have higher values. Also, pf-price and pf-price2 make a compromise toward fairness and throughput, respectively.

Conclusion and Future Directions

In this article, we have presented a user-centric resource allocation solution, namely UCRA, from the perspective of economics so as to accommodate users' personalized scenarios for 6G. UCRA

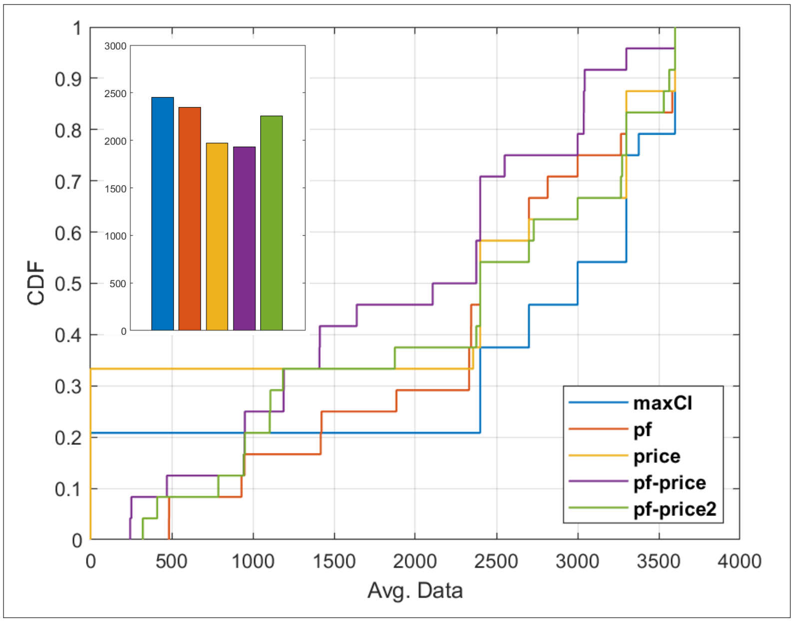

FIGURE 4. Average transmitted data in a period of all users.

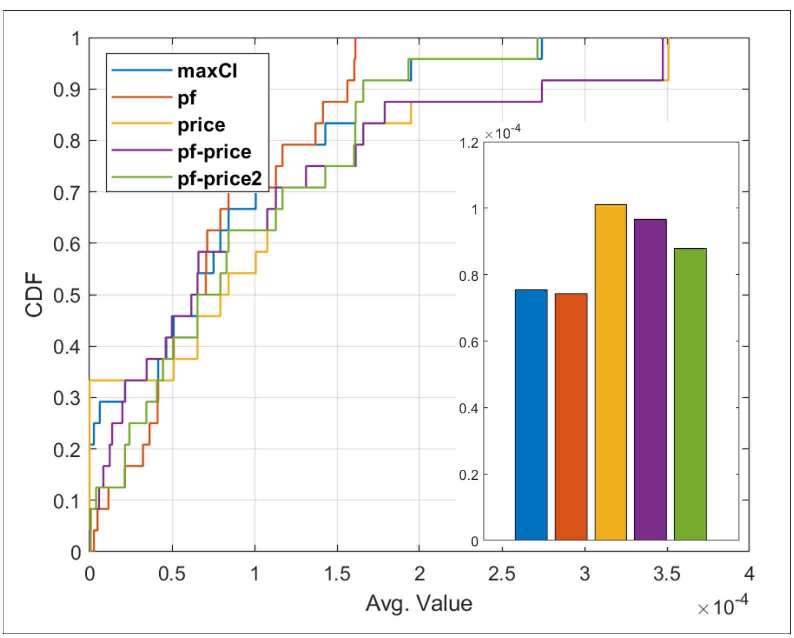

FIGURE 5. Average value in a period of all users.

can serve as a candidate proposal for 6G since it differs from current resource allocation methods mainly in that the overall value of transmitted services is prioritized. We have developed a feasible implementation framework with low transaction costs, in which users' subjective values on services are represented by price and are incorporated into the resource allocation process, and Cybertwin is used as users' agent for participating the resource market. Rules of the resource market are developed from auction theory so as to guarantee the QoE of users' high-value services. Other variants of UCRA including the user-centric proportional fair scheduling are also given as potential methods when compromise is needed.

There are several research directions on the topic:

- The UCRA framework can be further developed. By adopting intelligent transmission strategies, users' personalized requirements on quality of service (QoS) can be realized, or users' costs can be reduced. Also, other value indicators can be designed and utilized, so as to reflect users' subjectivity more accurately and comprehensively.
- The "definition" of resources can also be extended beyond resource blocks. On the one side, more types of resources can be jointly considered, such as power, computing, and caching resources. On the other side, resources can come from a larger scope. For example, in cooperative transmission scenarios such as user-centric cell-free access, all resources from different transmission points near the user can be utilized. Also, in heterogeneous access network scenario, resources from WiFi, 5G, 4G and so on. can be aggregated to serve the user. As the manager of user's network access, Cybertwin will play an important role in realizing such cross-network resource allocation. Essentially, on the input side are users' personalized scenarios, and on the output side are the resources that users require to satisfy their demands, and the corresponding costs that users should pay.
- Experiments should be conducted so as to obtain more valuable results in terms of user experience, network performance, costs of users, and revenue of operators. The environment of the experiment could be partly simulated or emulated, for example, through an open-source 5G software radio suite, but real users should participate the experiment, since users' behaviors cannot be simulated. The results are useful to demonstrate the logical inference on implications of UCRA.

Besides the topic, we further discuss some other open problems regarding what could be changed in future 6G from the economic perspective. 6G should be able to satisfy the long-tail demands and scenarios at very low marginal costs. This requires a very flexible architecture (e.g., a fully-decoupled radio access network) and mechanism for quick aggregation of resources. The ecosystem of 6G should also be open so as to allow more players joining the market. This can be achieved with the development of open-source access and core network functions running on general servers and hardware. The ownership and management of resources could also be separated for improving liquidity of resources. Financial instruments can also be developed for resource transactions. For instance, asset-based security (ABS) backed by spectrum leases can be sold to users. Also, the right to use resources can be traded as futures.

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