RIS as a Network Resource: User Multiplexing and Pricing Algorithms

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***Abstract*—Reconfigurable Intelligent Surfaces (RIS) have the ability to actively control wave propagation through space, enabling the creation of Programmable Wireless Environments (PWEs). This capability allows for the utilization and control of previously unexploited resources. However, there is a notable gap in allocating these resources to network users in a way that aligns with the pricing policies of telecommunications stakeholders. This paper considers RIS elements as network resources and describes a pricing policy that links the PWE efficiency of individual users to an optimal method for sharing RIS elements. A specialized policy tailored to this purpose, is designed with a focus on robustness, ensuring its applicability across various RIS functionalities and frequency bands. Its computational efficiency further underscores its viability for deployment in practical scenarios.**

***Index Terms*—RIS, resource allocation, multiplexing, pricing, codebook, RAN**

I. Introduction

The advent of new technologies towards Beyond-5G (B5G) and 6G wireless communications has fundamentally changed our perception of the communication environment. The propagation environment has been always considered as an uncontrollable factor while now it can be seen as a set of programmable resources, transforming existing wireless networks into Programmable Wireless Environments (PWE) [1].

Reconfigurable Intelligent Surfaces (RIS) play a crucial role in this transformation through the real-time optimal interaction with electromagnetic (EM) propagation [2]. This interaction allows for the effective utilization of resources that were previously underused, aiming to significantly improve the Quality of Service (QoS) for users. Despite these advancements, the issue of allocating these resources among multiple users, while also aligning with the pricing policies of existing telecommunications stakeholders, remains open.

At the system level, PWEs are created by coating all planar surfaces within an area with RISs. In this context, it becomes feasible to dynamically manage the existing EM waves within the communication network, optimizing their behavior in real-time [1]. A characteristic feature of PWEs is their ability to create new pathways for signals between base stations and end-users, overcoming Non-Line-of-Sight (NLoS) issues by rerouting signals around obstacles toward the desired directions. However, PWEs can address even more complex challenges, such as creating quiet zones for an enhanced physical security layer and mitigating the impact of the Doppler effect [3], especially in vehicular networks.

Within a PWE, each RIS unit is able to concurrently serve multiple end-users and depending on the optimization criteria and the policy in effect efficiently allocate its resources. Past experience in resource allocation strategies from other network domains [4], [5] like also the newly introduced concept of virtual programmable metasurfaces [6], can provide a strong foundation for addressing resource allocation challenges in PWEs. Additionally, frameworks dedicated to the simultaneous serving of multiple users from one RIS unit have also been proposed [7]. Nonetheless, there exists a notable gap in the research literature regarding pricing policies related to the use of shared RIS network resources.

In this context, our research contributions are as follows:

- We describe the end-to-end QoS problem in the mobile network considering RIS operations.
- We handle RIS as network resources and we propose an algorithm dedicated to the RIS resource al-

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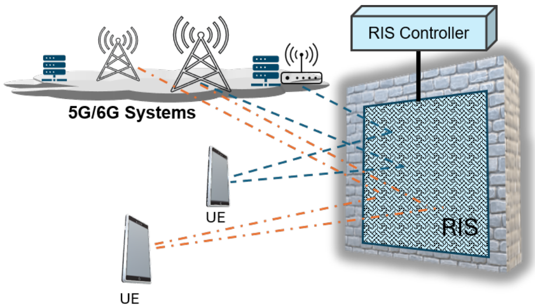

Fig. 1: A workflow of the RIS-assisted RAN concept

location based on pricing modeling. The algorithm is robust in terms of RIS functionality and physical layer characteristics like the operating frequency band. Furthermore, it can be adapted to any pricing policy.

- We conduct a comprehensive analysis of the proposed algorithm, focusing on its effectiveness concerning user pricing levels and its computational complexity.

The rest of this paper is organized as follows: Section II introduces the motivation of our paper and Section III the prerequisite knowledge and a proposed resource allocation scheme. Section IV presents the related studies. Section V defines the notion of RIS as a network resource, while Section VI elaborates on the resource allocation algorithm proposed in this paper. The evaluation of the algorithm is presented in Section VII. Section VIII offers conclusions and discusses potential research challenges.

II. Motivation

In end-to-end communication scenarios in 5G, QoS management requires a multifaceted and highly complex analysis. Below, we summarize the main factors that impact the expected QoS for user traffic considering the 5G system. Additionally, RIS operations introduce an additional control point that must be considered since they are capable to manipulate the propagation environment in a software- defined manner. This analysis is based on 3GPP related specifications like TS38.300, TS38.212, TS23.501 etc., see also [8], [9].

In Figure 1, an end-to-end communication scenario can be seen where traffic originating from a data network (DN) traverses the 5G network user plane, then through the Radio Access Network, traffic is destined to a RIS-based PWE and then finally RAN reaches the User Equipment (UE).

A. End-to-end QoS management model in 5G

In 5G in the Radio Access Network (RAN), Layer 1 describes the Physical Layer (PHY), while Layer 2 consists of the Medium Access Control (MAC), Radio Link Control (RLC), Packet Data Convergence Protocol (PDCP), and Service Data Adaptation Protocol (SDAP) sublayers [10]. The process of applying QoS before packets depart from the RAN involves several steps. First, packets arrive from the data network to the User Plane Function (UPF), which functions similarly to a router. At this point, the first step of packet buffering is performed. Packets are marked with a QoS Flow Identifier (QFI) and are tagged based on the QoS Enforcement Rules (QERs). Each QFI is associated with characteristics such as priority level, Packet Error Rate (PER), and maximum data burst size, which inform scheduling decisions.

Next, packets arrive at the RAN's SDAP sublayer, where a second buffering stage takes place. The SDAP sublayer is responsible for mapping the QFIs assigned by the UPF into Data Radio Bearers (DRBs). Following this, packets are passed to the PDCP sublayer and then to the RLC one. The main operations performed by the RLC are buffering and segmentation. Finally, the RLC sublayer provides the last actual queue where packets wait until a notification from the MAC prompts them to be forwarded.

A Resource Block (RB) is the fundamental unit for allocating radio resources in both the time and frequency domains. Each RB spans one slot in time and frequency subcarriers. The allocation of resource blocks is dynamic, changing from one slot to another based on network conditions, user demand, and QoS requirements. The scheduler in the base station (gNodeB) is responsible for allocating resource blocks to different users and services. It optimizes for factors such as throughput, latency, and fairness. The modulation and coding scheme (MCS) determines how data bits are mapped to radio symbols. The gNodeB base station determines the appropriate MCS index based on the Channel Quality Indicator (CQI) index.

A stronger signal typically results in a higher Signal-to-Noise Ratio (SNR), which enables higher data rates. This means more data can be transmitted and received in a given time period, improving the speed and efficiency of communication. Additionally, a stronger signal reduces the likelihood of errors during data transmission, resulting in fewer re-transmissions and less packet loss, thereby enhancing the QoS.

B. RIS as a component extending the Radio Access Network

As it is known, different factors can affect the final QoS received by the UE. The integration of RIS technology with the RAN can significantly enhance the PHY quality of 5G communication links. Using RIS can address the limitations of higher frequency bands, like millimeter waves (mmWave), which provide higher data rates but suffer from shorter ranges and are easily obstructed, disrupting the LoS between the base station and the UE. Furthermore, RIS technology can support the demand for smaller and denser cells, ensuring that QoS is maintained or even enhanced, thereby improving overall coverage. It also mitigates the impact of environmental factors, such as interference from other signals within the same or different frequency bands.

Apart from the benefits, new challenges also arise. The installation of RIS in B5G/6G networks requires efficient resource allocation schemes for serving multiple users simultaneously which can be also aligned with corresponding pricing policies in respect of the expected QoS. This is our primary motivation and the core of the proposed method.

III. Prerequisites and resource allocation

RIS technology is based on the principles of metamaterials, which are artificially engineered structures created by connecting basic units known as unit cells. Viewed from a macroscopic perspective, a RIS manifests as a thin, planar, and rectangular device, resembling a tile, made up of an array of these unit cells. The incorporation of embedded active elements within the tiles, such as PIN diodes [10] or MEMS [11], [12], endows RIS with the ability to modulate the propagation of EM waves across its surface in a software-defined manner.

When an EM wave impinges on a RIS, the state of its active elements, i.e., their values and interconnections, namely the RIS configuration, results in specific current distributions. By the proper determination of the RIS configuration, the incident EM wave can be effectively manipulated leading to various macroscopic responses. These include beam steering, beam splitting, perfect absorption, and the modulation of the wavefront's phase, amplitude, and/or polarization, as well as wavefront sensing [13]. The mentioned capabilities are collectively known as RIS functionalities.

The definition of the optimal RIS configuration for a specific functionality and network topology, i.e., the positions of receivers and transmitters, is a complex optimization task [14]. The only practical approach to enabling real-time operation of RISs relies on the creation of a codebook [1]. The codebook is a data structure designed to map the desired macroscopic RIS functionality to the respective microscopic configuration of RIS elements.

The lifecycle of RIS comprises two main phases: manufacturing and operation. During the manufacturing phase, the codebook is created. The functionalities supported by the RIS unit concerning transmitter and receiver positions are analyzed to compute the optimal RIS configuration for each case. This process is known as codebook compilation. Once the optimal configurations are determined through a dedicated optimization procedure, they are stored as entries in the codebook. This information is accessible via a dedicated database for use during the operation phase.

During the operation phase, the system is informed about the real-time topology of the network and it can retrieve the corresponding entry from the codebook to configure the RIS optimally. This eliminates the need for additional computation time for RIS configuration, making real-time operation feasible.

As mentioned previously, each RIS unit should have the capability to simultaneously serve multiple users with diverse requirements. The most effective approach to achieve this task is the development of specific algorithms that can multiplex various codebook entries [15]. A such an algorithm is Codebook Multiplexing Algorithm (COMMON) whose workflow is detailed in Alg. 1.

COMMON is used as a baseline for the pricing modeling that will follow in subsequent sections and is designed to serve a dynamic number of users, denoted as K, simultaneously. It requires as input the dimensions of the RIS, M, N. Additionally, the discretization parameter, N_d, needs to be predetermined. The algorithm accesses the Codebook Database to obtain the relevant entries, labeled as CE. The common RIS configuration, referred to as CC, is established by selecting the most common value among the discretized ones for each RIS element.

IV. Related Work

In the research bibliography, numerous proposals exist for the dynamic allocation of resources in previous generation networks. The primary challenge faced by proposed algorithms -named as schedulers- was to balance the task of ensuring the satisfaction of a dynamically changing number of users' performance with the imperative of minimizing decision time [4]. Additionally, within the same network, there may be diverse user groups with different pricing levels. These pricing differences should be considered in the performance results to ensure fairness [16].

The topic of RAN has been proposed as the central focus in the new B5G/6G networks [17], [18]. The resource slicing to enhance QoS remains an open issue [18]. Additionally, the collaboration between various base station units and the management of energy consumption are also important considerations [17]. Although RIS technology has the potential to address these challenges, to the best of our knowledge, there has not yet been a dedicated analysis of its integration into RAN technology.

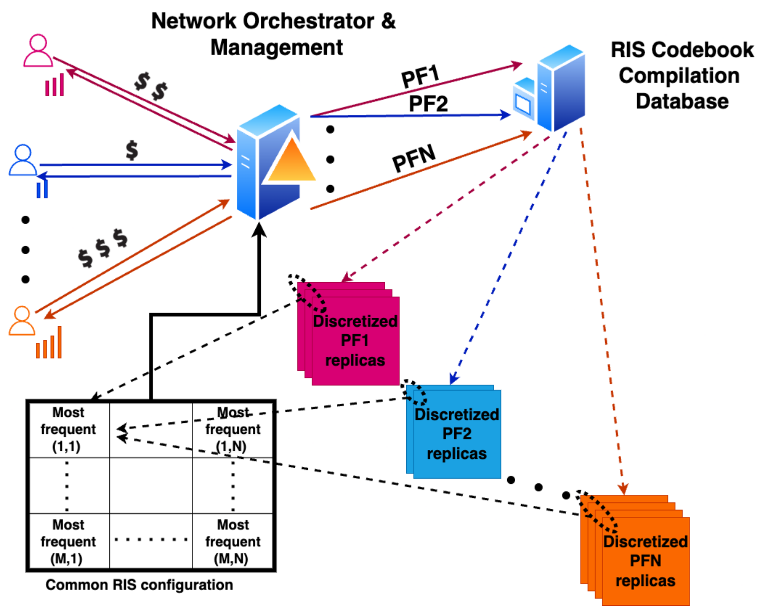

Fig. 2: Workflow of the PRIME algorithm

Algorithm 1: Codebook Multiplexing Algorithm (COMMON)

Input: Dimensions of RIS (M, N), Number of users K, discretization parameter N_d, Codebook Entries CE_k

Output: Common RIS configuration $CC(M, N)$

Initialization: Discrete Entries DE_k

Discretization function $f_{dis}(N_d)$*:*

for $k = 1$ to K **do**

  $DE_k \leftarrow f_{dis}(CE_k, N_d)$

end for

Initialize $CC(M, N)$ to store the final RIS configuration

for each element (m, n) in CC **do**

  Initialize an empty list $values$

  for $k = 1$ to K **do**

    Append $DE_k(m, n)$ to $values$

  end for

  Determine each element value with the most frequent one

  $CC(m, n) \leftarrow$ ComputeMostFrequent$(values)$

end for

return CC

Leveraging knowledge from well-established techniques is crucial for optimizing RIS network resource allocation. In [6], the concept of a Virtual Programmable Metasurface (VPM) is introduced, an idea closely aligned with the widely known Virtual Machine concept. VPMs are designed as software entities that encapsulate a specific subset of RIS resources, simplifying their management and control.

Addressing PWE specifically, the suggested frameworks are notably limited, particularly in relevance to the potential of RIS technology and the associated advantages in B5G/6G networks. One of the few proposals, as detailed in [7], introduces a resource sharing model for PWE. The primary concept involves the concurrent provision of multiple functionalities through the segmentation of the RIS. Each RIS tile or a group of tiles is assigned to specific tasks. The proposed algorithm then assigns competing user requests based on weighted policies, ensuring Time-Division-Multiple-Access (TDMA) style of resource sharing in the PWE.

An alternative approach to RIS multi-tasking involves the use of time duty-cycling, where each user is allocated specific time slots during which they are served by the RIS unit [19]. In contrast, in our previous work [15], we proposed a more ambitious strategy of sharing the entire RIS surface to meet the demands of multiple users simultaneously.

Building on this, we propose the first algorithm for RIS resource allocation, as depicted in Fig. 2. Users participate in the network based on the pricing policy predetermined by telecommunication stakeholders. As a first step, the Network Orchestrator and Management component assigns a payment factor to each user. In our algorithm, the payment factor (PF) is an integer value that aligns the discrete levels of pricing with the corresponding performance that each user expects, as described by the stakeholders' pricing policy. The assignment of the PF is an internal procedure that needs to be defined only once according to the given policy or each time stakeholders decide to update it.

Having assigned PFs to the users, the sharing of the RIS is achieved via the pricing-based multiplexing of RIS codebook entries, and they receive efficiency proportional to their contribution. This algorithm is easily applicable to any RIS design, in any frequency band and functionality, and in any already existing pricing policy.

V. MODELING AND HANDLING RIS AS A NETWORK RESOURCE

The forthcoming integration of RIS into existing communication networks transforms them into additional resource that also requires involvement in the allocation process. The key distinction, however, is that in the case of RIS, the allocation pertains not directly to the RIS' hardware elements but to the communication efficiency gained by the proper manipulation of EM waves.

With this in mind, simply mapping RIS elements to specific users' requirements cannot directly lead to the desired resource allocation, as might be the case with other components, such as dividing a physical CPU into virtual ones. Instead, the resource allocation refers to a well-defined method by which users *share* the RIS elements, benefiting from the control of the EM energy in accordance with the pricing policy of the stakeholders.

A. User efficiency and metrics

In this study, we define a metric used to evaluate the performance of users in respect of stakeholders' pricing policy. We propose a metric whose main principle is that the user efficiency can be gauged by the deviation in the RIS elements' values between two key points: (i) the content of a codebook entry, where the user is served exclusively by a RIS unit with optimal performance, and (ii) the common RIS configuration, designed to compromise the needs of multiple users in respect of the given pricing. Specifically, after the determination of the common RIS configuration, the deviation for each user is calculated as:

$$D_k(i,j) = CE_k(i,j) - CC(i,j) \quad (1)$$

It has been proven that specific groups of RIS unit cells can significantly influence their macroscopic response [14]. Therefore, deviations in the values of these cells should impact RIS behavior more than others. In the proposed metric, this physical insight is also included, taking into account the contribution of each unit cell to the RIS response. Therefore, the calculated deviation by Eq. 1 is then multiplied by an M $\times$ N matrix, Con,

Acronym	Definition
PF	Payment Factor
GPFU	Gain per PF Unit
MEL	Minimum Efficiency Level
RIS-NET	RIS as a Network Resource

TABLE I: List of Acronyms

which represents the contribution of each specific unit cell to the RIS response.

$$AD_k(i,j) = D_k(i,j) \times Con(i,j) \quad (2)$$

The final efficiency per user is computed by subtracting 1 (the optimal case) from the sum of the resulting products of Eq. 2, as:

$$eff_k = 1 - Loss_k = 1 - \sum_{i,j} AD_k(i,j) \quad (3)$$

The users' PWE performance is mainly determined by the pricing with which they participate in the communication network, that can be represented quantitatively by an assigned PF. It is also affected by the total number of users that have to be served. It is helpful to define the following parameters.

Gain per PF unit (GPFU): GPFU denotes the efficiency enhancement achieved with the addition of each PF unit, as defined by telecommunication providers. There is a notable correlation between GPFU and the total number of users.

Minimum Efficiency Level (MEL): MEL stands for the efficiency threshold set by each telecommunication provider for all users. The product of GPFU and each user's PF, when added to MEL, determines the efficiency level of individual users. Similarly to the GPFU, MEL is strongly connected to the total number of users.

B. RIS as a Network Resource

Management of RIS as a Network Resource involves establishing a procedure $F(\cdot)$ that connects the efficiency of each user to the sharing strategy of RIS elements. As previously examined, the user efficiency depends on factors such as the GPFU, the MEL, and the PFs. Similarly, the sharing strategy is influenced by the PFs of the participating users and their total number, K. The mathematical formulation of the RIS as a Network Resource (RIS-NET) definition is as follows:

$$\boxed{\begin{aligned} \text{RIS-NET} &= F(\text{efficiency}, \text{sharing}), \\ \text{where efficiency} &= f(GPFU, MEL, PFs), \\ GPFU &= g(K), \\ MEL &= h(K), \\ \text{and sharing} &= k(K, PFs). \end{aligned}} \quad (4)$$

VI. PRICING

While COMMON effectively handles the multiplexing of different codebook entries, it lacks the resource allocation procedure based on the pricing with which each user participates in the network. To address this, we propose PRIcing-based Multiplexing of codebook Entries (PRIME) that is described in Alg. 2. The primary difference between these two algorithms is that the PRIME assigns a PF value to every user. As mentioned previously, PF represents an integer that influences the algorithm's operations to ensure that the resource allocation is established properly.

The PRIME algorithm primarily composes a proposal for the procedure $F(\cdot)$ described in Equation 4, aligning the method of RIS elements sharing with users' efficiency. It mirrors COMMON through the discretization of the CE elements. After this step, and before defining the common RIS configuration, CC, it creates a proportional number of configuration replicas for each user, based on the user's PF. The CC is then derived from these replicas, meaning users with higher PFs exert more influence on the common configuration.

The relationship between the efficiency of each user and their assigned PF is linear and can be expressed by Eq. 5. This relationship holds significant importance for telecommunication stakeholders' policies, as it ensures the existence of discrete and multi-level user servicing that can be aligned with respective pricing models.

$$eff_k = GPFU(K) \times PF + MEL(K) \qquad (5)$$

As concerns the applicability of PRIME, it is also directly linked to the computational time that it requires in real operation scenario. It should be underlined that the resource allocation -via the multiplexing of RIS configurations in a common one- is an additional task within the RIS-assisted environment among others such as the localization of the users, the determination of the desired for each user functionality, the retrieving of the respective codebook entries from the dedicated database, and the final alignment of the elements values with the computed ones in the hardware level. Therefore, the algorithm should impose the minimum computational time. Thus, the respective complexity has to be examined.

Observing its workflow in Alg. 2, it becomes evident that the computational complexity is function of three key parameters (i) the PF values, (ii) the dimensions of the RIS and (iii) the total number of users.

Firstly, the algorithm discretizes the codebook entries for each user across the RIS elements, resulting in a computational complexity of $O(KMN)$. Subsequently, the algorithm generates configuration replicas based on the PFs associated with each user, adding another layer of complexity. These replicas are then combined, resulting in a computational complexity proportional to the number of users and their respective PFs. Thus, this part of the algorithm incurs a complexity equivalent to the sum of all PF values, denoted as $O(\sum PF)$. Therefore, the overall computational complexity of the PRIME algorithm is expressed as $O(KMN + \sum PF)$.

Algorithm 2: PRIcing-based Multiplexing of codebook Entries (PRIME)

Input: Dimensions of RIS (M, N), Number of users K, discretization parameter N_d, Codebook Entries CE_k, Payment Factors PF_k
Output: Common RIS configuration $CC(M, N)$
Initialization: Discretize CE_k to DE_k
Discretization function $f_{dis}(N_d)$*:*
for $k = 1$ to K **do**
  $DE_k \leftarrow f_{dis}(CE_k, N_d)$
end for
Replica Creation based on Payment Factors:
Initialize an empty list $replicas$
for $k = 1$ to K **do**
  Append DE_k to PF_k $replicas$
end for
Initialize $CC(M, N)$ to store the final RIS configuration
Determine each element value with the most frequent one
for each element (m, n) in CC **do**
  $CC(m, n) \leftarrow$ ComputeMostFrequent$(replicas)$
end for
return CC

VII. EVALUATION

First, we conduct a comparative analysis for efficiency performance of the COMMON and PRIME algorithms. Then, we explore the relationship between efficiency and pricing, as it is expressed through PFs. Lastly, we confirm the computational complexity of the PRIME algorithm using numerical simulations. All the required measurements are obtained through simulations conducted in MATLAB environment. As previously mentioned, the algorithm does not involve the creation of the codebook entries and assumes them as given. Moreover, the codebook entries represent the optimal RIS active elements values. Therefore, they can be simulated as an RIS dimension $M \times N$ matrix.

A. COMMON & PRIME comparison

For the evaluation of the algorithms, we use a 100x100 RIS unit tasked with serving 10 users simultaneously.

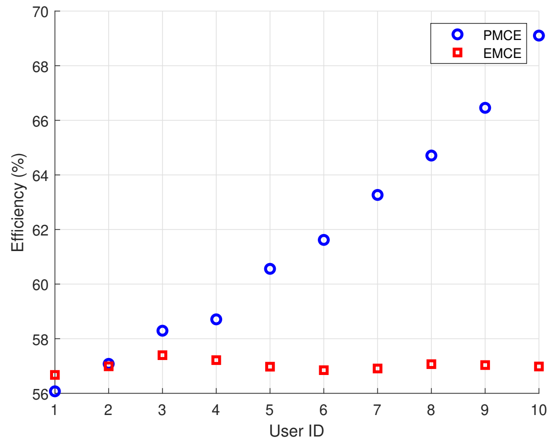

Fig. 3: User efficiency for PRIME and COMMON algorithms

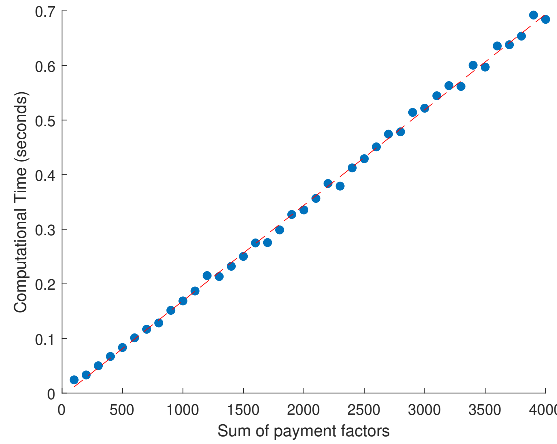

Fig. 5: Time complexity of the proposed algorithm with respect to sum of users' PF values.

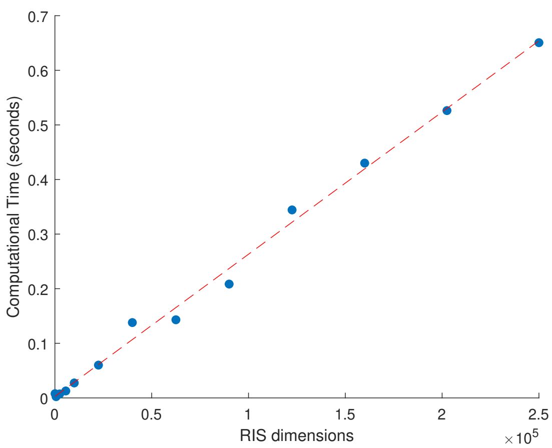

Fig. 4: Time complexity of the proposed algorithm with respect to RIS dimensions.

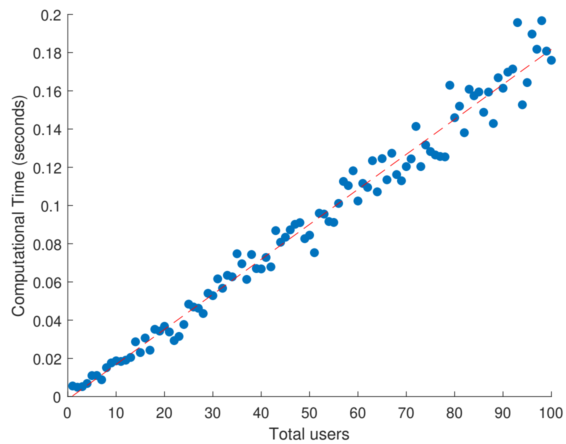

Fig. 6: Time complexity of the proposed algorithm with respect to the total number of users.

The COMMON algorithm can be viewed as a special case of PRIME, where the PF for all users is uniformly set to 1. In the PRIME scenario, PFs are assigned incrementally to each user, starting from 1 and increasing to 10 (with User ID=1 assigned PF=1, User ID=2 assigned PF=2 and so on). The efficiency for each user is depicted in Fig. 3.

Regarding COMMON, it serves as a direct approach for multiplexing RIS codebook entries, resulting in an approximate efficiency rate of 57% for each user. In the context of PRIME, user priorities are determined based on their pricing. The linear relationship between efficiency and PF is characterized by an MEL value of 57 and a $GPFU$ close to 1.25. Another notable observation is that the MEL equals the efficiency of all users in the COMMON scenario. This suggests that through PRIME, the improved efficiency of users with higher PFs is not achieved at the expense of those with lower PFs, ensuring the network neutrality. Users with higher PFs can experience an efficiency improvement of approximately 25%.

B. *Efficiency & Pricing Relationship*

The PRIME algorithm offers a linear relationship between a user's pricing level and their received efficiency, as illustrated in Eq. 5. However, the MEL and GPFU factors demonstrate a strong connection with the network parameters, specifically the RIS dimensions and the total number of users. To further investigate this connection, we conducted various numerical simulations.

We explored different combinations of network parameters, employing RIS with dimensions such as $M =$

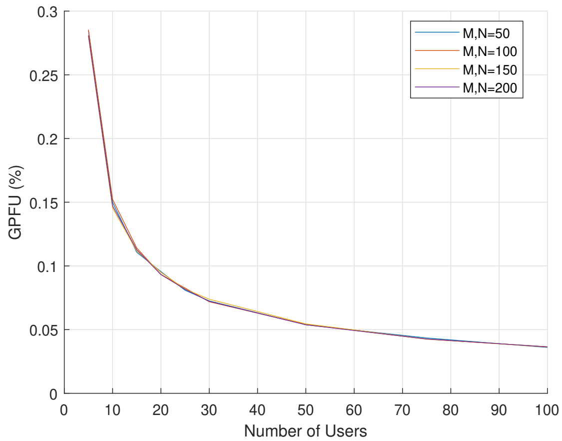

Fig. 7: User efficiency for PRIME and COMMON algorithms

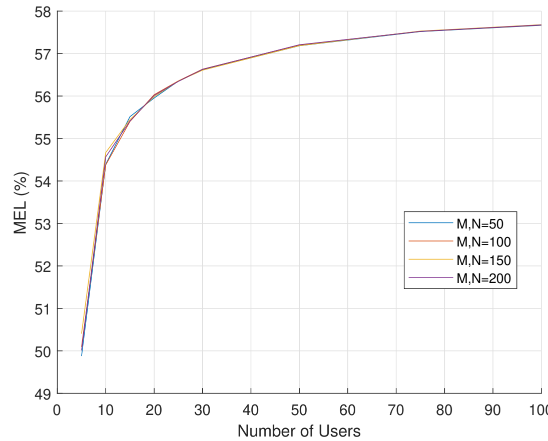

Fig. 8: User efficiency for PRIME and COMMON algorithms

$N = 50, 100, 150, 200$ to accommodate different user counts ($K = 5, 10, 15, 20, 25, 50, 75, 100$). PF values were varied from 1 to 100. Each configuration of M and K was tested 100 times, and statistical analyses were performed to derive meaningful and accurate insights. In Figs. 7 and 8, the mean values for each network parameter combination are illustrated.

From observing the results, we conclude that PRIME is robust across different RIS dimensions, as they have minimal impact on both the MEL and GPFU parameters. The MEL ranges from 50, exhibiting logarithmic behavior with respect to the total number of users, and converges to a value of 57.8. Conversely, the GPFU follows an exponential function relative to the total number of users, converging to a value of 0.05.

The findings indicate that in denser communication networks with higher MEL values, users with lower PFs experience greater benefits. On the other hand, GPFU shows an inverse trend. Initially, GPFU values start at 0.28 for scenarios involving 5-20 users served by a single RIS unit, decreasing to 0.04 when there are 100 or more users. This suggests that in scenarios with up to 20 users, those with higher PFs can achieve an efficiency of about 80%.

C. Numerical simulations for PRIME Complexity

In this part, we validate with numerical simulations that the computational complexity of PRIME is $O(KMN + \sum PF)$, as it is shown in Section VI. For the computational complexity of RIS dimensions ($M \times N$), the total number of users is kept constant at 20, the maximum value of the PF is set at 20, and the total RIS elements are varied from 100 to 250,000, as it is illustrated in Fig. 4. Examining the relationship between computational complexity and PF in Fig. 5, the RIS dimensions are 100x100, and the total number of users is 20. The maximum PF value ranges from 5 to 200, with all users having the same PF value in each run. Lastly, Fig. 6 investigates the computational complexity's relationship with the number of users, where the RIS dimensions are 100x100, and the maximum PF value is set at 20. The user count varies from 1 to 100.

The numerical simulations verified the linear computational complexity with respect to RIS dimensions, total users and sum of PFs. Particularly concerning the latter, this accounts for a minor deviation from perfect linearity observed in the parameters depicted in Fig. 4 and Fig. 6. In these cases, only the maximum value of the PF is defined, while the PF for each user is determined within the acceptable range, a fact that is likely to be the case in general.

VIII. Conclusion and Future Work

In this paper, we manage RIS as a network resource through a procedure that links each user's expectations by means of QoS, with the sharing method of RIS elements, considering a pricing policy. The algorithm proposed guarantees a linear relationship between the PWE efficiency per user and their pricing. Lastly, we present the computational complexity of the algorithm, which operates at the millisecond level, confirming its practical applicability in real-world scenarios. Numerical simulations and results are also presented.

The proposed algorithm represents a first solution for RIS resource allocation through the multiplexing of RIS codebook entries in respect of a pricing policy. Our future plans include the development of more sophisticated algorithms in this direction, focusing on (i) the control of the acceptable variance between the individual user codebook entries and the common RIS configuration, using the available metaheuristic tools [20], (ii) the further minimization of the computational time to maintain practicality in real-world implementation and (iii) the resource allocation of multi-hop communication links where multiple RISs serve multiple users, such as AVs in V2X networks. Additionally, the utility of these algorithms extends beyond just resource allocation, allowing for more sophisticated functionalities within RIS. A prime example of this is beam splitting, which can be viewed as a fusion of multiple beam steering RIS configurations.

ACKNOWLEDGMENT

This work was funded by the German Federal Ministry of Education and Research (BMBF), grant 16KISK020K (6G-RIC), 2021-2025, the WISAR project for theoretical design and NATWORK project under Grant Agreement No. 101139285, for practical design.

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