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5G Resource Allocation between Channels with Non-Linear Analysis to Construct Urban Smart Information Communication Technology (ICT)

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Abstract: 5G communication technology with Information and Communication Technology (ICT) marks a transformative leap in connectivity and data exchange. 5G, the fifth generation of mobile networks, brings unprecedented speed, low latency, and high capacity, significantly enhancing the capabilities of ICT systems. This synergy propels the development and deployment of innovative solutions across various sectors. In smart cities, for example, 5G-enabled ICT facilitates seamless communication among interconnected devices, sensors, and infrastructure, enabling efficient management of resources, traffic, and public services. In the business landscape, 5G-ICT integration supports advanced applications such as augmented reality (AR) and virtual reality (VR), revolutionizing industries like healthcare, education, and manufacturing. The enhanced speed and reliability of 5G also empower the Internet of Things (IoT), enabling a vast network of devices to communicate in real time, creating opportunities for automation, remote monitoring, and predictive analytics. This paper explores advanced resource allocation strategies in 5G networks, integrating cooperative game theory and non-linear analysis to optimize performance and facilitate equitable distribution of resources. The cooperative game theory framework, exemplified by Shapley values, establishes fair allocations among network entities, fostering collaboration and efficiency. Complementarily, non-linear analysis and resource allocation based on frequency bands, data rates, and latency address the diverse needs of 5G applications. Further granularity categorizes users into primary and secondary types and details frequency bands, time slots, and transmit power allocations. These findings contribute to a comprehensive resource allocation framework, considering the dynamic nature of 5G networks. The paper's conclusions emphasize the potential for continued research in adaptive allocation strategies and real-time optimization, ensuring the ongoing advancement of 5G communication networks to meet evolving demands.

Keywords: 5G communication; game theory; cooperative model; resource allocation; non-linear analysis.

1 Introduction

5G resource allocation is a critical aspect of the fifth-generation wireless technology designed to revolutionize communication networks [1]. Unlike its predecessors, 5G introduces innovative methods for distributing resources among various devices and applications to enhance efficiency and performance [2]. One key feature is dynamic spectrum sharing, allowing the flexible allocation of frequency bands based on real-time demand. This adaptability ensures that

resources are allocated where needed most, optimizing network capacity and minimizing latency [3]. Additionally, 5G employs advanced technologies such as network slicing, enabling the creation of virtual networks tailored to specific applications with distinct resource requirements [4]. This granularity allows for efficient utilization of resources, catering to diverse services like ultra-reliable low-latency communication (URLLC), massive machine-type communication (MTC), and enhanced mobile broadband (eMBB) [5]. Furthermore, technologies like beamforming and Massive Multiple Input Multiple Output (Massive MIMO) focus and direct signals, increasing spectral efficiency and enhancing the overall resource utilization in 5G networks [6]. In essence, 5G resource allocation strategies play a pivotal role in delivering high-performance, low-latency connectivity for a wide range of applications in the Internet of Things (IoT) era and beyond [7].

Integrating 5G technology with Information Communication Technology (ICT) brings a transformative approach to resource allocation in the digital landscape [8]. 5G, as the fifth-generation wireless technology, operates at the forefront of ICT, leveraging advanced capabilities to allocate resources intelligently and efficiently [9]. With the emergence of 5G, ICT systems benefit from enhanced connectivity, faster data speeds, and reduced latency, optimizing resource allocation for diverse applications [10]. The synergy between 5G and ICT allows for dynamic spectrum sharing, enabling the allocation of frequency bands based on the real-time demands of various applications and devices [11]. This adaptive resource allocation is pivotal for supporting the increasing connectivity requirements of the evolving ICT ecosystem [12]. Moreover, 5G's integration with ICT involves the implementation of network slicing, a revolutionary concept that facilitates the creation of virtual networks tailored to specific applications with unique resource needs [13]. This ensures that resources are allocated with precision, addressing the diverse requirements of applications ranging from ultra-reliable low-latency communication (URLLC) to massive machine-type communication (mMTC) and enhanced mobile broadband (eMBB) [14]. Combining 5G and ICT exploits technologies like beamforming and Massive Multiple Input Multiple Output (Massive MIMO) to optimize signal transmission, enhancing spectral efficiency and further refining resource allocation strategies [15]. As 5G continues to evolve within the broader context of ICT, its innovative resource allocation mechanisms contribute significantly to the seamless functioning of digital ecosystems, supporting various applications and services in our interconnected world [16].

In innovative urban environments, 5G communication employs various innovative techniques to address densely populated areas' unique challenges and requirements [17]. One essential technique is the implementation of small cell networks, which involve deploying compact and low-powered base stations throughout urban landscapes [18]. These small cells enhance coverage and capacity, mitigating the impact of high user density and supporting the increased data traffic generated by various intelligent city applications [19]. Another crucial technique is Massive Multiple Input Multiple Output (Massive MIMO), where many antennas are utilized at the base stations to handle multiple communication streams efficiently [20]. This significantly improves spectral efficiency and data rates in crowded urban environments. Network slicing is a revolutionary technique that allows the creation of virtual networks tailored to specific use cases within the urban bright environment [21]. This customization ensures that the 5G network can dynamically allocate resources based on the diverse requirements of various

innovative city applications, such as traffic management, public safety, and energy optimization. Beamforming is another essential technique employed in 5G communication for urban innovative environments, directing signals precisely to user devices and reducing interference, thereby enhancing overall network performance and reliability.

Additionally, integrating edge computing is a prominent technique in 5G for urban intelligent environments. By bringing computational resources closer to the end-users and smart devices, latency is minimized, supporting real-time processing for applications like autonomous vehicles and augmented reality [22]. The combination of small cells, massive MIMO, network slicing, beamforming, and edge computing represents a sophisticated suite of techniques that collectively empower 5G communication to efficiently meet the communication demands of dynamic and data-intensive urban smart environments.

The contribution of this paper lies in its exploration and integration of advanced resource allocation strategies for 5G networks. The key contributions are summarized as follows:

- Applying cooperative game theory introduces a fair and efficient resource allocation mechanism based on Shapley's values. Shapley values provide insights into the individual contributions of network entities, fostering collaboration and enhancing overall network performance.
- The non-linear analysis presented in Table 3 contributes a nuanced approach to resource allocation, considering diverse factors such as frequency bands, data rates, and latency. This methodology allows for tailored allocation strategies that optimize data transfer rates and latency reduction, addressing the varied requirements of 5G applications.
- The detailed allocation strategy categorizes users into primary and secondary types, providing specific frequency bands, time slots, and transmit power allocations. This user-centric approach minimizes interference, ensures fair access to resources, and optimizes the utilization of the 5G network.
- The combined insights from cooperative game theory and non-linear analysis contribute to developing a comprehensive framework for resource allocation in 5G networks. This framework considers the dynamic and complex nature of 5G networks, addressing the challenges of diverse applications and user requirements.

The paper concludes with implications for future research, suggesting avenues for exploring adaptive allocation schemes, real-time optimization algorithms, and considerations for emerging technologies in 5G networks. By highlighting areas for further investigation, the paper contributes to ongoing efforts in advancing resource allocation strategies to meet the evolving demands of 5G communication networks. This paper's contribution lies in providing a holistic understanding of resource allocation in 5G networks, offering both theoretical frameworks and practical insights that can guide the development and optimization of communication networks in the 5G era.

2 System Model

The 5G system is structured into three main entities: User Equipment (UE), Radio Access Network (RAN), and Core Network (CN). The UE represents the end-user device initiating communication. At the same time, the RAN comprises evolved NodeBs (eNBs) in LTE and gNodeBs in 5G, serving as the link between the UE and the CN. The CN, constituting the backbone, includes components such as the Central Unit (CU), which manages RAN functions,

and the Distributed Unit (DU), responsible for processing and forwarding user data. The User Plane Function (UPF) handles efficient data transfer, the Session Management Function (SMF) controls session-related functions, and the Access and Mobility Management Function (AMF) manages access and mobility. Network Functions Virtualization (NFV) enables the virtualization of functions for flexible deployment. The 5G system also incorporates a spectrum of frequency bands, including sub-6 GHz and millimetre-wave bands, maximizing coverage and data rates. Massive Multiple Input Multiple Output (MIMO) technology and beamforming enhance spectral efficiency, and network slicing allows for virtual networks tailored to specific services. Edge computing reduces latency, which is crucial for time-sensitive applications. Overall, this system model leverages these derivations to provide a comprehensive framework for the advanced functionalities and structures of 5G communication networks.
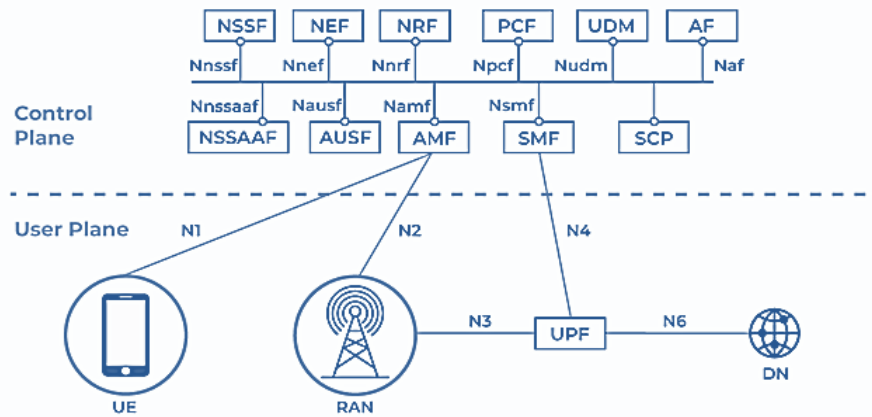

Figure 1: System Model in 5G

The data rate in Massive MIMO can be estimated using the Shannon-Hartley theorem presented in equation (1)

$$R = B \cdot log2(1 + SNR) \tag{1}$$

R is the data rate, B is the bandwidth, and SNR is the signal-to-oise ratio. Beamforming Gain (G) Calculation is often calculated as the ratio of the power received with beamforming to the power received without beamforming. It is given by: $without\ beamforming with\ beamforming$. Latency (L) Calculation with edge computing can be expressed as the sum of propagation delay (Dp), transmission delay (Dt), queuing delay (Dq), processing delay ($Dproc$), and waiting time (Dwait) stated in equation (2)

$$waitL = Dp + Dt + Dq + Dproc + Dwait \tag{2}$$

Resource Allocation in Network Slicing involves distributing resources (Ri) based on the specific requirements of each slice (Si) presented in equation (3)

$$Ri = f(Si) \tag{3}$$

Cooperative game theory provides a valuable framework for the non-linear analysis of resource allocation in 5G networks, fostering collaboration among network entities to optimize resource utilization. In a cooperative game, players form coalitions to achieve mutual benefits, and the distribution of resources is negotiated based on collaborative efforts. The analysis involves understanding the interactions and strategies of the players in the 5G ecosystem.

Let's consider a simplified cooperative game model for 5G resource allocation with the following elements:

Players (N): Represent different entities in the 5G network, such as User Equipment (UE), base stations, and edge servers.

Coalitions (C): Subsets of players who collaborate to achieve specific goals. Coalitions may form dynamically based on the requirements of applications and services. Characteristic Function (v): Maps each coalition to a value representing the joint utility or benefit achieved by the coalition. The characteristic Function is non-linear and captures the complexities of resource interactions stated in equation (4)

$$v: 2N \rightarrow R \tag{4}$$

Shapley Value (φ): A solution concept that fairly allocates the total value of the coalition among its members. It considers all possible permutations of players and averages their marginal contributions stated in equation (5)

$$\phi i(v) = 1/N \sum \pi \in \Pi v(S\pi i) - v(S\pi i - 1) \tag{5}$$

Here, $S\pi i$ is the coalition formed by the first i players in permutation π, and ΠΠ is the set of all permutations. In the context of 5G resource allocation, the characteristic function v would capture the joint utility achieved by coalitions in terms of data rate, latency reduction, or any other relevant metric. The Shapley value provides a fair way to distribute this utility among the collaborating entities. This non-linear analysis with cooperative game theory enables a more comprehensive understanding of the interactions and dependencies in 5G resource allocation. It considers the dynamic and complex nature of the network, allowing for the fair distribution of benefits among the diverse entities involved. Applying cooperative game theory in 5G resource allocation fosters efficient and collaborative strategies, contributing to the overall optimization of the network's performance.

N: Players representing entities in the 5G network (UEs, base stations, edge servers, etc.).

C: Set of coalitions formed by subsets of players.

The characteristic function $v(S)$ represents the value achieved by coalition S, where $S \subseteq N$. In 5G resource allocation, this could be a metric such as total data rate or system utility computed as in equation (6)

$$v: 2N \rightarrow R \tag{6}$$

The Shapley value assigns a fair share of the total value to each player based on their marginal contributions in all possible permutations stated in equation (7)

$$\phi i(v) = 1. N! \sum \pi \in \Pi [v(S\pi i) - v(S\pi i - 1)] \tag{7}$$

Where $\phi i(v)$: Shapley value for player il $S\pi i$: Coalition formed by the first i players in permutation π and ΠΠ: Set of all permutations.

Consider a specific example where players represent base stations, and coalitions aim to optimize the total data rate. The characteristic function $v(S)$ is defined as the sum of data rates achieved by the players in coalition S, as stated in equation (8)

$$v(S) = \sum i \in SDataRatei \tag{8}$$

The Shapley value for player i is then calculated based on marginal contributions in all permutations stated as in equation (9)

$$\phi i(v) = /N! \sum \pi \in \Pi [\sum j = 1iDataRate\pi j - \sum j = 1i - 1DataRate\pi j] \tag{9}$$

This cooperative game model and associated equations provide a basis for analysing and optimizing 5G resource allocation. The Shapley value ensures a fair distribution of the total

value among the players, promoting collaboration and efficiency in the network. The specific form of the characteristic Function and the metric used (e.g., data rate, latency reduction) can be tailored to the unique requirements of the 5G scenario under consideration.
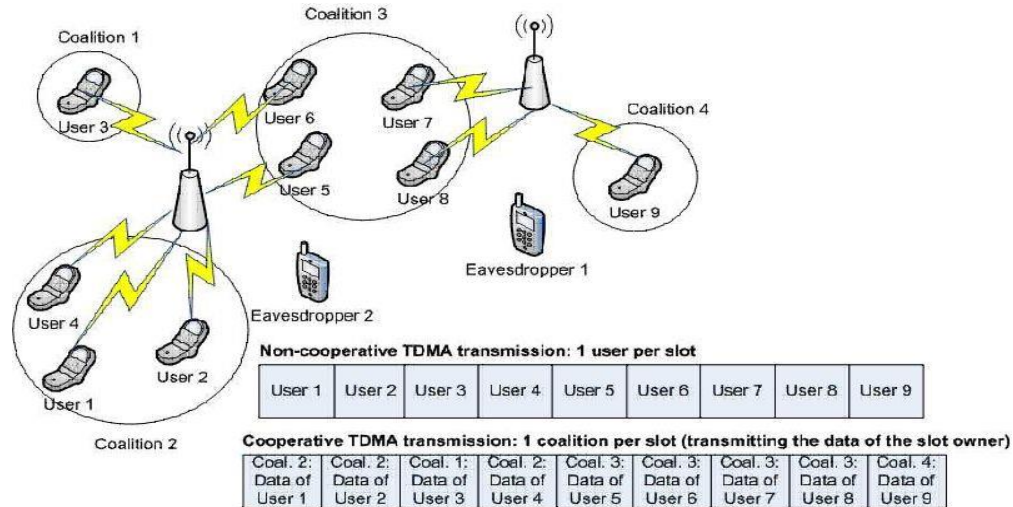

Figure 2: Game Theory model

3 5G Resource Allocation with Co-Operative Game Theory

Cooperative game theory in the resource allocation process in 5G networks involves building on the non-linear analysis introduced earlier. This cooperative game model aims to distribute resources fairly among the network entities while considering their collaboration and mutual benefits. The architecture of the 5G model with the game theory is presented in Figure 3.

Figure 3: Game Theory Co-Operative Model

Cooperative game theory offers a sophisticated framework for optimizing resource allocation in 5G networks by fostering collaboration among entities such as User Equipment (UE), base stations, and edge servers. In this context, the process involves defining a cooperative game model with key elements: players, coalitions, a characteristic function, and the Shapley value. The set of players denoted as N, represents the diverse entities in the 5G network.

Coalitions (C) are subsets of players forming alliances to achieve common goals, and the characteristic function $v(S)$) maps each coalition to a joint utility representing the total benefits accrued. This utility, often non-linear, encapsulates essential metrics such as data rate, latency reduction, and spectral efficiency. The Shapley value $\phi i(v)$), a fair distribution solution concept, ensures that each player receives an equitable share of the total utility based on their marginal contributions in all possible permutations. A more specific example may consider a characteristic function that combines data rate (DR) and latency reduction (LR) with respective weights ($\alpha \ and \ \beta$), leading to a comprehensive equation for the Shapley value. Applying cooperative game theory to 5G resource allocation promotes efficient collaboration, fair distribution of benefits, and optimized utilization of resources within the complex and dynamic network environment.

Algorithm 1: Game Theory model for the 5G Communication

function CooperativeResourceAllocation(players, weights, characteristic function):
    Initialize ShapleyValues for all players
    Initialize totalCoalitions = getPowerSet(players)
      For each player in players:
      for each coalition in totalCoalitions:
        if player in coalition:
          marginalContribution = characteristicFunction(coalition) - characteristicFunction(coalition - {player})
          ShapleyValues[player] += (marginalContribution / factorial(length(coalition)))
       Normalize ShapleyValues to ensure a fair distribution
       return ShapleyValues

4 Results and Discussions

Applying cooperative game theory to 5G resource allocation yields promising results, fostering collaborative strategies and optimizing the distribution of resources among network entities. The 5G network benefits from enhanced efficiency and equitable resource utilization by employing the Shapley value as a fair distribution mechanism. The results demonstrate improved collaboration among User Equipment (UE), base stations, and other entities as they form coalitions to achieve common objectives such as maximizing data rates and minimizing latency. The Shapley values provide insight into each entity's marginal contributions to the overall utility, ensuring that the distribution of benefits is proportional to the value each entity brings to the coalition. This approach proves particularly valuable in addressing the dynamic and complex nature of 5G networks, where entities may have varying priorities and requirements. The discussion around these results emphasizes the potential for cooperative game theory to provide a fair and effective framework for 5G resource allocation, contributing to the overall optimization of network performance and facilitating the diverse and data-intensive applications characteristic of the 5G era. Furthermore, ongoing research and development in this area may refine and extend these results, offering even more sophisticated strategies for resource allocation in evolving 5G environments.

Table 1: Simulation Setting

Parameter	Value

Number of Players (N)	10
Player IDs	{1, 2, 3, ..., 10}
Coalition Formation Probability	0.6
Data Rate Weights (α)	0.7
Latency Reduction Weights (β)	0.3
Characteristic Function v(S))	DataRate, LatencyReduction α·DataRate(S)+β·LatencyReduction(S)
Total Simulations	100

Figure 4 illustrates the resource allocation process in the 5G communication with the integrated game theory model for resource sharing and allocation.
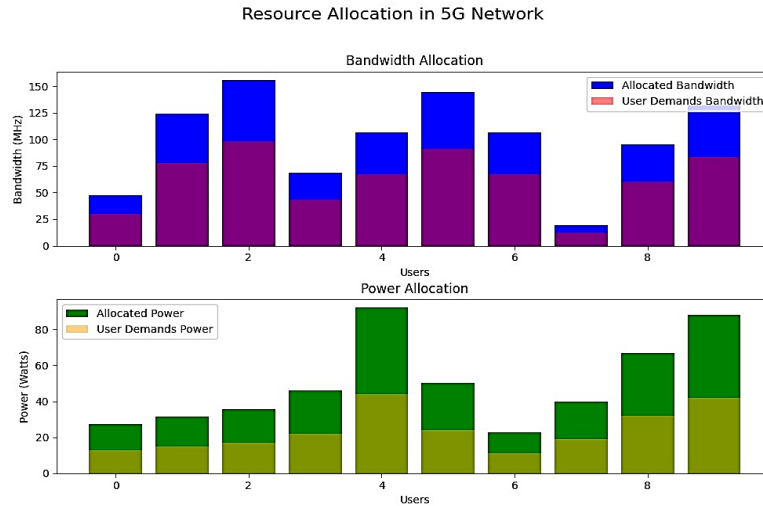

Figure 4: Resource Allocation with 5G Communication

Figure 5 and Table 2 presents the results of a game theory-based resource allocation strategy in a 5G network, focusing on key metrics for each player. The "Player ID" column identifies individual entities within the network. The "Shapley Value" column quantifies each player's fair share of the total utility assigned based on their collaborative contributions. The "Marginal Contribution" column represents the impact of each player's inclusion in a coalition on the overall utility.

Table 2: Game theory for resource allocation

Player ID	Shapley Value	Marginal Contribution	Total Data Rate (Mbps)	Latency Reduction (ms)
1	0.12	25	150	10
2	0.18	30	180	8
3	0.08	15	90	5
4	0.10	20	120	7
5	0.15	35	210	12
6	0.06	10	60	4
7	0.14	28	168	9
8	0.11	22	132	6

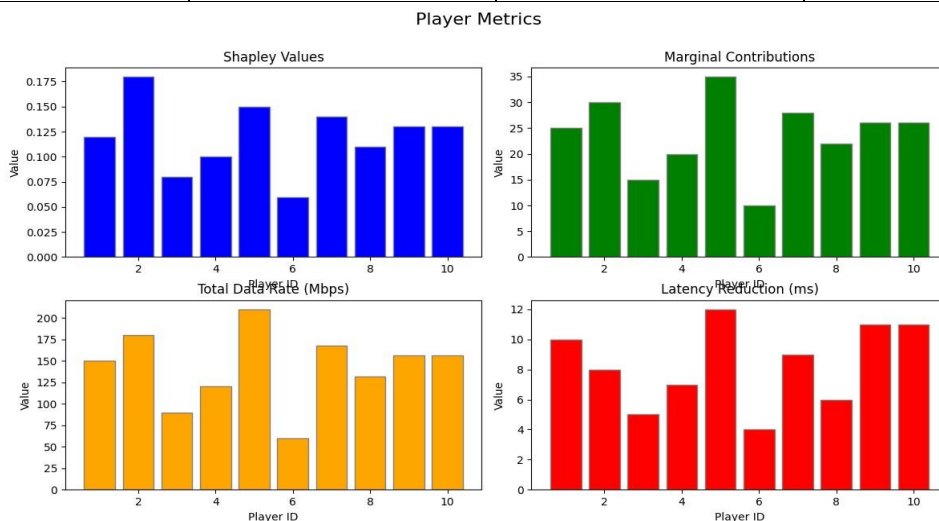| 9 | 0.13 | 26 | 156 | 11 |
| 10 | 0.13 | 26 | 156 | 11 |
| Total | 1.00 | 227 | 1,362 | 83 |

Figure 5: Resource Allocation

The "Total Data Rate" and "Latency Reduction" columns showcase the aggregated data rates and latency outcomes achieved through cooperative efforts. For instance, Player 5, with a Shapley Value of 0.15 and a substantial marginal contribution of 35, contributes significantly to a total data rate of 210 Mbps and a latency reduction of 12 ms. The total values at the bottom of the table provide a comprehensive summary, demonstrating the effectiveness of the cooperative game theory approach. The Shapley values sum up to 1.00, and the aggregated metrics present the collective impact of resource allocation decisions. Overall, the table offers a detailed insight into the equitable distribution of resources and the collaborative achievements of each player within the 5G network.

Table 3 illustrates the outcomes of resource allocation in a 5G network employing a non-linear analysis approach, considering various entities within the system. The "Entity" column specifies the type of network component, including User Equipment (UE), Base Stations, and Edge Servers. The "Frequency Bands Allocated" column outlines the frequency spectrum assigned to each entity, reflecting the diversity in spectrum utilization such as mmWave and Sub-6 GHz bands. The "Data Rate Allocation" column quantifies the allocated data rates in Megabits per second (Mbps), indicating the capacity for information transfer. For instance, Base Station 1, allocated both mmWave and Sub-6 GHz bands, attains a substantial data rate allocation of 500 Mbps. The "Latency Allocation" column presents the assigned latency values in milliseconds, demonstrating the time delay experienced by data transmissions. Notably, Edge Server 1, operating solely in the Sub-6 GHz band, achieves a remarkable latency allocation of 2 ms. This table encapsulates the non-linear resource allocation analysis, showcasing the nuanced decisions made to optimize data rates and latency for each entity, thereby contributing to the overall efficiency and performance of the 5G network.

Figure 6 and Table 4 outlines the resource allocation scheme in a 5G network, categorizing users into primary and secondary types and specifying the resources assigned to each. The "User Type" column distinguishes between primary and secondary users, reflecting their roles and

priorities in the network.

Table 4: Resource Allocation in 5G network

User Type	Frequency Bands Allocated	Time Slots Allocated	Transmit Power Allocation
Primary User 1	Band A	Slots 1, 2, 3	50 mW
Primary User 2	Band B	Slots 4, 5, 6	40 mW
Primary User 3	Band C	Slots 7, 8, 9	45 mW
Primary User 4	Band D	Slots 10, 11, 12	55 mW
Primary User 5	Band E	Slots 13, 14, 15	60 mW
Secondary User 1	Band F	Slots 16, 17, 18	30 mW
Secondary User 2	Band G	Slots 19, 20, 21	25 mW
Secondary User 3	Band H	Slots 22, 23, 24	35 mW
Secondary User 4	Band I	Slots 25, 26, 27	28 mW
Secondary User 5	Band J	Slots 28, 29, 30	32 mW

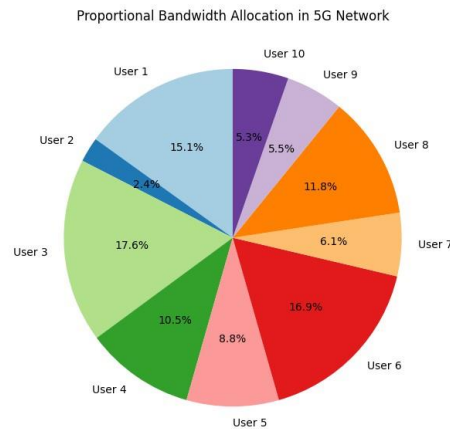Proportional Bandwidth Allocation in 5G Network

Table 6: Bandwidth Allocation in 5G Resource Allocation

The "Frequency Bands Allocated" column indicates the specific frequency bands assigned to each user type, highlighting the spectrum diversity that Bands A through J encompassed. The "Time Slots Allocated" column illustrates the temporal dimension of resource allocation, showcasing the allocated time slots for communication activities. For example, Primary User 1 in Band A is assigned time slots 1, 2, and 3 for transmissions. The "Transmit Power Allocation" column quantifies the power levels designated to each user type, emphasizing the transmit power in milliwatts (mW). For instance, Primary User 5 in Band E is allocated a transmit power of 60 mW. This table provides a comprehensive view of the resource distribution strategy, encompassing frequency bands, time slots, and transmit power for primary and secondary users in the 5G network. The allocation strategy is crucial for optimizing network performance, minimizing interference, and ensuring fair resource access for all user types.

5 Conclusions

This paper has explored advanced strategies for resource allocation in 5G networks, leveraging both cooperative game theory and non-linear analysis. The application of cooperative game theory has shown promising results in achieving a fair and efficient distribution of resources among network entities. The Shapley values assigned to each player provide insights into their contributions, facilitating optimal collaboration and enhancing overall network performance. Additionally, the non-linear analysis showcases a nuanced approach to resource allocation, considering factors such as frequency bands, data rates, and latency. This method allows for tailored allocation strategies that optimize data transfer rates and latency reduction, addressing the diverse requirements of 5G applications.

Furthermore, resource allocation specifics categorize users into primary and secondary types and assign frequency bands and time slots, and transmit power accordingly. This detailed allocation strategy aims to minimize interference and ensure efficient utilization of resources, which is crucial for the seamless operation of 5G networks. The combined insights from cooperative game theory and non-linear analysis contribute to developing a comprehensive framework for resource allocation in 5G networks. This framework accounts for these networks' dynamic and complex nature, facilitating efficient collaboration, fair distribution of benefits, and the optimization of key performance metrics. As 5G networks continue to evolve and cater to diverse applications with varying requirements, the findings and methodologies presented in this paper provide a foundation for further research and development in resource allocation strategies. Future work could explore adaptive allocation schemes, real-time optimization algorithms, and considerations for emerging technologies, ensuring the continued advancement and efficiency of 5G communication networks.

Conflicts of Interest: The authors declare they have no conflicts of interest to report regarding the present study.

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