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Resource Allocation in Air Base Station-Enabled Wireless Network: Survey

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Problem statement. *Due to their mobility, flexibility, ease of deployment, and low cost, Autonomous Aerial Vehicle (AAV) play an important role in future wireless networks. However, their pratical implementation faces challenges, including energy constraints, dynamic channel variations, interference management, and the need for efficient resource allocation to ensure seamless connectivity for ground users. Traditional optimization methods often fail to adapt to these complexities in real-time, limiting the effectiveness of AAV-assisted wireless networks.* ***The aim of the work*** *provides a comprehensive review of resource allocation in AAV-assisted wireless networks, focusing on power and bandwidth optimization strategies, as well as the key challenges in ensuring efficient and reliable communication.* ***Methods:*** *used in this study include a systematic review of existing literature, analyzing optimization approaches such as Game Theory, Artificial Intelligence for efficient resource allocation in AAV-assisted wireless networks.* ***Novelty:*** *this study analyzes resource allocation challenges in AAV-assisted network, focusing on the interdependence of power and bandwidth allocation. It explores optimization techniques like Game Theory, and Artificial Intelligence.* ***Results.*** *The analysis in this paper demonstrates that Game Theory and Artificial Intelligence based approaches significantly improve resource allocation efficiency. Additionally, the study identifies key challenges, including heterogeneous density network, security concerns, and complex channel modeling, providing insights for future research.* ***Practical / Theoretical Relevance:*** *This study advences the theoretical understanding of resource allocation in AAV-assisted wireless networks by integrating optimization strategies from Game Theory and Artificial Intelligence. Pratically, it provides insight into enhancing network efficiency, adaptability and security, making AAV-based communication more viable for real-world applications, such as disaster recovery, remote areas coverage, and IoT data collection.*

Key words: *AAV, Power Allocation, Bandwidth Allocation, Game Theory, Artificial Intelligence*

I. Introduction

While 5G networks are being deployed from major cities to rural areas, researchers have begun to envision 6G networks to meet all future network and application requirements [1]. Future generations of networks will provide full space-air ground coverage, as well as remote and highly mobile communications with low latency. To achieve ubiquitous global coverage, satellite, aerial, and maritime networks will be integrated into existing terrestrial networks to provide seamless wireless connectivity [2].

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Autonomous Aerial Vehicle (AAV), also known as AAVs or drones, are an indispensable component in the aerial network system, a basic component in the overall network system in the future. Compared to satellite networks, the cost of deploying AAVs is much cheaper, so they can be used in large numbers to improve performance, and can be implemented in many different fields such as military, civil [3, 4]. In addition, AAVs are very easy to recover after use. Satellite networks have expensive operating costs and require the use of special equipment at high costs to withstand the harsh environment in outer space. In traditional terrestrial networks, ground base stations are typically located in a fixed location, often in densely populated areas. In addition, the resource supply is abundant and easy to replace. However, coverage is limited due to the height of ground base stations and unpredictable user demands, which can overload the ground network system as the number of users increases. In addition, ground base stations are susceptible to destruction by natural disasters. Although the ground network infrastructure is capable of providing high data rates to end users, it is limited by the limited of network coverage in rural and remote areas, highlighting the significant challenge of achieving ubiquitous connectivity. Due to their mobility, AAVs can act as flying base stations to provide wireless networks to users in disaster-stricken areas, or in remote areas and farmers. In addition, AAV can collect data from Internet of Things (IoT) devices, which are scattered in places where terrestrial networks cannot be deployed, such as deserts and volcanoes [5]. Although AAV-enabled wireless networks have many advantages, as mentioned above, they still have many disadvantages, such as limited energy and limited capacity. Therefore, in recent years, researchers have always focused on optimization of energy, transmission channels, and trajectory has always been a focus of researchers in recent years. In this article, we consider an overview of resource allocation in AAV-assisted wireless networks. More specifically, we give an overview of power and bandwidth allocation, which are always the criteria (metrics) for resource allocation problems for AAVs.

II. Resource Allocation in AAV-Assisted Wireless Network

With the ever increasing demand for data rates and connectivity, future networks require new technology trends, such as AAV-enabled wireless networks. These aerial networks have a number of challenges that need to be addressed in order to be used effectively. One of these challenges is resource management in AAV networks. Some resource allocation problems in communication networks that are of interest to researchers are Power and Bandwidth Allocations.

A. Power Allocation

Despite advances in battery technology in recent years, AAVs enabled wireless power transfer to provide a sustain able energy supply for widely distributed low-power ground devices [6], the energy issue remains a challenge for AAVs. The data transmission time depends on the maximization of the average data rate of the AAV. However, the total transmission power of the AAV is limited, depending on the original design, and power allocation is necessary for AAVs to improve energy efficiency. With the objective of maximizing the average AAV data rate, Chen et al. [7] consider the deployment of multiple AAVs to provide wireless connections for ground devices with different quality of service (QoS) requirements based on power allocation and 3D placement of AAVs. The authors in [8] proposed power allocation for non orthogonal multiple access (NOMA) – AAV network to maximize the total data rate of the network system. The external AAV acts as a flying base station or a data collector from remote sensors. The AAV can act as relaying devices, where the AAV provides wireless connectivity to remote users without a reliable direct connection. Thus, [9] has considered AAVs as flying relays to support data transmission, when a direct connection between the source node and the destination node is not possible. By jointly optimizing the trajectory and power allocation of the source node and AAV, the problem of maximizing the end-to-end throughput of the system is solved.

B. Bandwidth Allocation

The configuration of the AAV can be changed depending on the purpose of use. Installing additional devices to increase the bandwidth for the AAV-assisted wireless network is necessary. However, the design of the AAV is almost impossible to change while it is being deployed to perform the mission. Meanwhile, in many cases, the requirements of the users and the number of users are not precisely determined. In addition, when additional devices are integrated, the payload of the AAV increases, which leads to a decrease in the deployment time of the AAV. Therefore, optimizing the bandwidth of the AAV-assisted wireless network during deployment is a very important issue. Optimize AAVs placement and bandwidth al location for wireless access and backhaul links by considering different configurations of line-of-sight (LoS) and non line of sight (NLoS) connections [10]. Using AAV as relay device to improve QoS for multi-user video streaming. Chen et al. [11] studied the management of band width and transmission power with objective of maximizing the total long-term QoS of user, which are determined by the freezing time and the bit rate, utilizing Lyapunov optimization theory and ascending clock auction. In future communication networks, to meet the demand for data rates that can reach 100+ Gb/s with latency requirements of less than 1 ms, THz communication promises to meet these requirements [12]. Xu et al. studied the combination of ultra-wide bandwidth of THz communications and mobility of the AAV in [13]. However, the stability of THz communication is not high and the position of AAV may change, which reduces the stability of the transmission channel. Therefore, in [13], the authors studied (discovered/designed) to reduce the total delay of the uplink and downlink in AAV-THz wireless systems by jointly optimizing the 3D deployment of the AAV, the transmit power and bandwidth of each user.

III. Solution to Resource Allocation in AAV-Assisted Wireless Network

In general, solving resource allocation problems while still satisfying QoS is relatively difficult. The complexity of the problem is directly proportional to the number of devices in the system and the degree of heterogeneity of the network. Therefore, finding suitable mathematical tools to solve many problems when allocating resources to terminals becomes extremely urgent. To solve these difficulties, in this paper, we will highlight some methods to solve resource allocation problems, including Game Theory and Artificial Intelligence.

A. Game Theory

Game theory is a branch of applied mathematics that describes, analyzes situations, and gives actions according to the direction of the player. In game theory, there are 3 main components: players, strategies, and rewards represented by different constraints of the network system. These constraints often involve factors such as power, bandwidth and user demands, which can significantly affect the optimal outcomes of a game. Depending on the main strategy of the game, two main strategies are widely applied in AAV wireless networks: non-cooperative games and cooperative games.

Non-cooperative games are the most basic type of game theory, where each player independently develops a strategy to maximize their reward through rational actions [14, 15]. In this context, players do not share information and aim to optimize their own benefit, often leading to competitive behaviors. These games are particularly relevant in wireless networks where individual devices, such as AAV or users, operate independently to achieve specific objectives like maximizing throughput or minimizing latency.

In constrast, cooperative games allow players to from agreements or coalition that influence their strategy choices and the resulting payoffs [16, 17]. This form of game theory is particularly useful in AAV-assisted wireless networks when players need to work together to achieve a common goal, such as maximizing overall network capacity. The goal of cooperative games is often to predict which coalitions will form, how the players will coordinate their actions, and how to distribute the collective rewards among all participants.

B. Artificial Intelligence

Recent breakthroughs in artificial intelligence (AI), especially advances in machine learning, offer promissing solutions for complex resouce allocation and bandwidth offloading in AAV-assisted wireless netoworks. Reinforcement learning (RL), a key branch of machine learning, enables agents to iteract with their environment through trial-and-error, learning from feedback to optimzie their actions. This ability to adapt and learn from experience is particularly valuable in AAV networks, where conditions like mobility and resource availability change rapidly.

Q-learning, a popular RL algorithm, has been applied to optimize AAV trajectory and resource allocation. Aiming to maximize the system's secrecy rate [18]. It works by approximating the optimial action-value function, helping agents determine the best actions withouts requiring a model of the environment. This makes Q-learning suitable for dynamic environments like AAV-assisted wireless networks, where network conditions are highly variable. By leveraging such techniques, AAV network can optimize resource management, ensuring more efficient and secure communication.

IV. Challenges and Open Research Direction

A. Heterogeneous Density Network

In the current context, wireless networks can be divided into different layers, such as satellite networks, airborne networks, and terrestrial networks. Within the same layer, different types of cell structures (e.g. femto, macro, micro, etc.) can be considered. In addition, the number of networked devices is increasing rapidly, and these devices operate on different frequencies. Different applications will require different levels of data traffic and different speed requirements for each user. Therefore, it is a challenge to allocate resources efficiently, i.e., to meet the needs of different types of users and in different cells in the network. Essentially, resource allocation in a wireless AAV-enabled network depends heavily on the data rate requirements of the users, which are highly variable in nature and therefore need to be predicted.

B. Channel Models

Due to its low cost and high mobility, AAVs have great potential in the near future for deployment in remote areas, stadiums and other public areas. Modelling the airborne channel characteristics for the above realistic scenarios along with different weather conditions is an important research direction in the future to increase the reliability of wireless communication. Using high frequency communication is considered to increase the transmission speed of the communication network system, however, the effects such as small-scale fading, Doppler effect, and multipath fading due to the mobility of AAVs [19].

C. Security

AAV-enabled wireless networks are always vulnerable to attacks due to the lack of manual control. Attackers can easily steal AAV data and reprogram it. Currently, researchers are working on incorporating artificial intelligence to avoid such situations. However, there is still a lot of room for improvement in security and privacy techniques for AAV enabled communication links to avoid such malicious attacks.

V. Conclusion

The number of devices requiring connectivity and high data rates is increasing at a very fast pace, creating a significant challenge for traditional terrestrial wireless networks. In addition, the difficulty in building and designing terrestrial wireless networks in remote areas or areas that are easily destroyed by natural disasters. Therefore, in this paper, we present the use of AAV-supported wireless networks for some scenarios. However, the problems of power and bandwidth are always challenges that AAV-supported wireless networks need to solve. Recent research works on the resource allocation problem of AAV-supported networks and some solutions to solve the problem are presented. Finally, we have presented some open research problems that need to be improved for AAV-supported wireless networks are discussed.

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Распределение ресурсов в беспроводной сети связи с базовой станцией на воздушной платформе: Обзор

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Постановка задачи. *Благодаря своей мобильности, гибкости, простоте развертывания и низкой стоимости, автономные воздушные аппараты (AAV) играют важную роль в будущих беспроводных сетях. Однако их практическая реализация сталкивается с проблемами, такими как ограничения по энергии, динамические изменения каналов, управление помехами и необходимость эффективного распределения ресурсов для обеспечения бесперебойного соединения с наземными пользователями. Традиционные методы оптимизации часто не могут адаптироваться к этим сложностям в реальном времени, что ограничивает эффективность беспроводных сетей с поддержкой AAV.* ***Цель работы*** *– предоставить всесторонний обзор распределения ресурсов в беспроводных сетях с поддержкой AAV, сосредоточив внимание на стратегиях оптимизации мощности и пропускной способности, а также на ключевых проблемах, связанных с обеспечением эффективной и надежной связи.* ***Методы****. В данном исследовании используется систематический обзор существующей литературы, анализ оптимизационных подходов, таких как теория игр и искусственный интеллект для эффективного распределения ресурсов в беспроводных сетях с поддержкой AAV.* ***Новизна****. В данной работе анализируются проблемы распределения ресурсов в сетях с поддержкой AAV, с акцентом на взаимозависимость распределения мощности и пропускной способности. Рассматриваются такие методы оптимизации, как теория игр и искусственный интеллект.* ***Результаты.*** *Анализ, проведенный в данной статье, демонстрирует, что подходы, основанные на теории игр и искусственном интеллекте, значительно улучшают эффективность распределения ресурсов. Кроме того, в работе выявлены ключевые проблемы, такие как неоднородная плотность сети, проблемы безопасности и сложное моделирование каналов, что предоставляет направления для будущих исследований.* ***Практическая / теоретическая значимость.*** *Это исследование развивает теоретическое понимание распределения ресурсов в беспроводных сетях с поддержкой AAV, интегрируя стратегии оптимизации из теории игр и искусственного интеллекта. На практике оно позволяет лучше понять, как повысить эффективность, адаптируемость и безопасность сети, делая связь на основе AAV более жизнеспособной для реальных приложений, таких как восстановление после сбоев, покрытие удаленных районов и сбор данных для Интернета вещей.*

Ключевые слова: *AAV, распределение мощности, распределение полосы пропускания, теория игр, искусственный интеллект*

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