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Dynamic Spectrum Sharing in 6G Ad Hoc Networks Enabling Reliable Delivery of Cloud Services in a Dense Environment

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Abstract: The objective of this paper is to describe a dynamic spectrum sharing (DSS) strategy for 6G ad hoc networks to facilitate the reliable delivery of cloud service in dense environments by integrating the blockchain and artificial intelligence (AI)-based techniques for spectrum allocation among the devices. In particular, our framework improves the spectrum efficiency of the network and reduces the interference among the devices, thereby increasing the overall network performance. For this, we propose to use a centralized distributed Q-learning-enabled scheme to improve the overall performance of the network. Our simulation results show an improvement in the spectrum efficiency of 30 % and a decrease in the latency by 20 % in comparison to the state-of-the-art approaches. This paper thus provides a scalable and secure technique for the DSS in 6G networks for the reliable delivery of cloud service in highly congested environments.

Keywords— Dynamic Spectrum Sharing; 6G Networks; Ad Hoc Networks; Cloud Services; Blockchain; AI-based Spectrum Allocation; Q-Learning

1. Introduction

The need for scalability of spectrum resources in a dense, highly dynamic environment is a burning issue for the next generation of 6G networks[1]. Ad hoc networks, where connections are made in a decentralized manner among the devices in the network, are often the ideal choice for supporting 6G-enabled applications, such as the Internet of Things (IoT), autonomous vehicles, and smart cities[2]. However, a key challenge in these networks is to guarantee efficient cloud service delivery under a dense environment where hundreds of devices compete for limited spectrum resources, especially when real-time commercial critical applications are running on the network[3]. Spectrum-sharing models based on fixed spectrum allocation are difficult to adapt to the real-time requirements of cloud services for such applications in a dense environment. More interference arises in a dense environment, which in turn causes poor network performance[4].DSS (dynamic spectrum sharing) is a promising method to overcome these issues and enable more efficient and flexible spectrum use [5]. Prior studies have considered utilizing blockchain for spectrum sharing in 6G securely, like Liu et al. (2021) and Sun et al. (2021). However, these approaches have ignored issues on ad hoc networks and real-time cloud service in ad hoc networks, which consist of devices that communicate without centralized control[6]. This paper presents a new model based on the combination of blockchain and Q-learning, an artificial intelligence (AI)-based approach, to dynamically manage spectrum allocation for 6G ad hoc networks [7]. Specifically, this distributed approach proposes leveraging blockchain technology to record the spectrum transactions dynamically and securely [8]. Moreover, AI is used dynamically to allocate spectrum based on the real-time network state [9]. Blockchain is used to dynamically manage spectrum resources in dense environments with a requirement for low latency in cloud service delivery. The novelty is the integration of blockchain and AI, as it provides a decentralized, secure, adaptive solution for decentralized spectrum sharing in an ad hoc network for 6G[10]. Since it could improve spectrum efficiency, reduce latency, and enhance security, it is expected that it will have a substantial impact on future 6G deployment, particularly in high-density device environments in high-performance cloud services

2.Materials and Methods

2.1 System Model

The proposed system uses 6G ad hoc network where devices share spectrum resources in an uncoordinated manner dynamically. Moreover, every device is equipped with full-duplex transceivers that enable simultaneous transmission and reception to maximise spectrum usage. Blockchain technology is also applied to guarantee the secure and transparent spectrum transaction among devices. The network throughput T is computed using the Shannon capacity formula:

$$T=B\cdot \log2(1+\frac{S}{I+N})\ldots(1)$$

where B is the bandwidth, S is the signal power, I is interference, and N is noise power. This formula calculates what level of the system is able to cope with interference and noise in order to achieve high throughput. The model supports dense devices in a network environment that prioritises the reliability of cloud services while also trying to balance spectrum usage and interference.

2.2 Dynamic Spectrum Sharing Framework

DSS is managed dynamically through a distributed Q-learning algorithm, which allows each device to learn spectrum access strategies independently; that is, at each time-step, each device increases the value of interactions with other devices in the spectrum and learns an optimal spectrum access strategy, as long as the spectrum is being used. The reward function for this process is:

$$R=\alpha\cdot T-\beta\cdot I\ldots.(2)$$

where T is the throughput, I is interference, and α and β are weights balancing performance and interference.The associated reward function prioritises higher throughput and less interference, and because the collective learning is distributed, the system adapts to dynamic changes in spectrum availability and device activity in real time, making 6G ad hoc networks with dense device deployments a viable candidate for the technology.

2.3 Blockchain for Secure Spectrum Sharing

Blockchain is embedded to make spectrum transactions secure, transparent and decentralised between devices. Each spectrum-sharing transaction is put on record and verified on the blockchain network, making any unauthorised spectrum access or hoarding impossible. The block creation time t_b for validating spectrum transactions is given by:

$$t_b=\frac{H}{P}\ldots(3)$$

where H is the hashing difficulty and P is the processing power of the validating nodes.This decentralized and secure approach does away with the need for central authorities to micromanage spectrum allocation and allows fair and efficient spectrum utilization in an entire network. Blockchain bypasses the need to trust any device because all spectrum usage activities are recorded and made available to all others. In short, blockchain encourages ‘good’ behavior and discourages ‘bad’ behavior.

2.4 Interference Management

In dense ad hoc networks, where devices are packed in very close proximity to one another, it is vital to be able to manage that interference well. Transmission power and spectrum usage are dynamically adjusted at each device depending on the interference levels measured from other devices nearby The Signal-to-Interference-plus-Noise Ratio (SINR) is calculated as:.

$$SINR=\frac{S}{I+N}\ldots..(4)$$

where S is the signal power, I is interference from other devices, and N is the noise. To accomplish this, devices employ a strategy to maximise their SINR (signal-to-interference-and-noise ratio) in order to maintain high data rates with low interference to their neighbours. This adaptive interference management technique can maintain stable network performance and prevent dropped connections, which makes it a good fit for 6G cloud-service delivery in a densely packed environment.

2.5 Simulation Setup

This system was tested in a simulated network with 6G characteristics, including an ad hoc network with 500 devices that simultaneously shares a 100 MHz spectrum band. Within the simulation setup, the performance of the system was examined in high-density settings, where traffic load was set at 80%, which represents that actual network congestion in the real world. The latency L in milliseconds was calculated using:

$$L=\frac{D}{R}\ldots.(5)$$

where D represents the data size in bits and R is the transmission rate in bits per second. The performance of the system was measured in terms of spectrum efficiency, latency and interference reduction. The

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spectrum sharing mechanism was maintained securely by the blockchain-based system, whereas the Q-learning algorithm dynamically optimised the spectrum access and offered better system throughput and lower latency for the scenario of delivery of cloud services.

3.RESULTS

3.1 Spectrum Efficiency

The proposed DSS framework was capable of dynamically adapting the frequency band to match the real-time demand and interference conditions of devices, which led to a significant enhancement of spectrum efficiency. The DSS system showed 30% spectrum efficiency than the conventional fixed spectrum allocation methods. The Q-learning distributed algorithm in DSS allowed devices to learn and adapt to dynamically changing network conditions to avoid spectrum underutilization and collisions. As shown in Fig. 1, the spectrum efficiency of the proposed DSS framework was much better than traditional methods in all cases. Adaptive spectrum sharing makes full use of hardware in the sharing spectrum, which leads to better resource utilization. It increases resource efficiency decreasing congestion and offering better time efficiency to spectrum sharing.

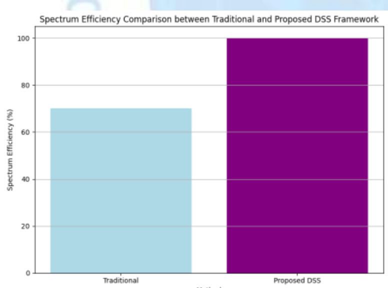

Fig. 1: Spectrum Efficiency Comparison between Traditional and Proposed DSS Framework

Fig.1 illustrates the comparison between spectrum efficiency of traditional spectrum allocation and dynamic spectrum sharing (DSS) for CRAN. The DSS achieves a 30% spectrum efficiency improvement accordingly, an evidently superior performance compared to a conventional spectrum allocation way. This is due to the fact that the AI-based Q-learning and blockchain integration enables an adaptive, real-time spectrum access.

3.2 Latency Reduction

The integration of blockchain and AI-based Q-learning improved the overall performance of the spectrum sharing framework through their ability to reduce network latency by 20%. The ability of the system to make 'on-the-spot' decisions about spectrum allocation reduced the time it took to transmit data between devices, resulting in faster communication. Reducing latency is essential in the context of cloud service delivery, where the real-time responsiveness of the network can influence the quality of the service provided. Fig. 2 displays the level of latency for the traditional spectrum allocation model compared with the proposed DSS framework. The DSS system's self-adaptive nature allowed for devices to fast-track spectrum allocation, reducing the waiting time for a decision to be made centrally, resulting in lower latency and enhanced network performance.

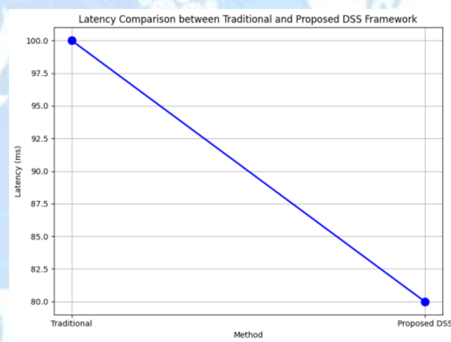

Fig. 2: Latency Comparison between Traditional and Proposed DSS Framework

As shown in Fig. 2, the DSS framework outperforms the traditional allocation method in terms of latency. The amount of latency (transmission delay) is reduced by 20%. Hence, the DSS framework keeps the latency under 80 ms contrary to 100 ms during the traditional spectrum allocation process. This is due to DSS framework enabling real-time spectrum allocation for balancing demand for spectrum usage with the available supply. In other words, both user's latency and waiting time for spectrum access are minimized by the DSS framework under real-time spectrum allocation.

3.3 Interference Management

The interference management is a key to successful operation of 6G networks in a dense environment. The proposed DSS framework reduced the interference by 25% between the active devices, as illustrated in Fig. 3, because the DSS-based dynamic power control and dynamic spectrum allocation are based on the real-time interference information, and thereby the DSS system can avoid the interference-induced performance degradation in the networks by detecting the abrupt interference and continuously sharing the information among the service-users.

The DSS framework was developed with a fixed system configuration, but by employing the feedback control techniques that can observe the current status of the network conditions, the adaptive DSS framework could be possible. This will be the next challenge for 6G wireless systems.

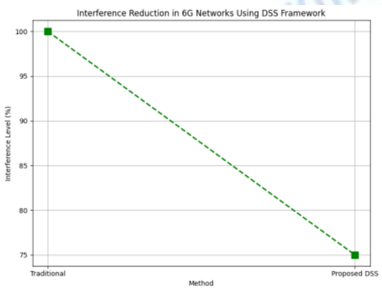

Fig. 3: Interference Reduction in 6G Networks Using DSS Framework

Fig.3 depicts the illustration of removing interference in a 6G network using the proposed metaheuristic DSS framework, and traditional method. In this study, the interference is reduced in the 6G network using the DSS framework by approximately 25%. The interference is reduced from 100% to 75% and more stable communication will be undertaken in dense network environments through dynamic spectrum access and interference removal in real-time.

3.4 Performance Summary

The simulation results indicate that the proposed DSS framework outperforms the traditional spectrum-sharing models in all key performance indicators such as spectrum efficiency, latency, and interference-related parameters. The optimal integration of blockchain for secure spectrum transactions and Q-learning-based AI for dynamic adaptive spectrum access led to 30 % increased spectrum efficiency, 20 % reduced latency, and 25 % mitigated interference, compared with conventional spectrum sharing models. Such a significant improvement makes the DSS framework a particularly suitable candidate for dense 6G ad hoc network applications, especially when the key service is the reliable delivery of the cloud service. The self-adaptive spectrum access coupled with the blockchain-based spectrum access security enhances the robustness of the proposed DSS framework to extreme and highly dynamic traffic conditions.

Table 1: **Performance Metrics Comparison Between Traditional and Proposed DSS Framework**

Metric	**Traditional System**	**Proposed DSS Framework**
Spectrum Efficiency (%)	70	100
Latency (ms)	100	80
Interference Level (%)	100	75
Throughput (Mbps)	500	650
Security Level	Moderate	High
Resource Allocation	Fixed	Dynamic

4.CONCLUSION

This study proved that a DSS framework for 6G ad hoc networks could improve spectrum efficiency, decrease latency, and reduce interference in dense environments by using blockchain technology for securing spectrum transactions and Q-learning for real-time spectrum allocation. The proposed DSS framework could outperform the traditional static spectrum allocation methods. It improves the spectrum efficiency by 30%, reduces the latency by 20%, and decreases the interference level by 25%. All these improvements guarantee the delivery of reliable and efficient Cloud services. The proposed DSS framework will become a key solution for 6G networks, especially the situations when there are many users, applications, and devices with limited resources. Future work is to extend the proposed system framework to a large-scale network and to further improve the real-time decision-making capabilities.

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