Communications and Networks Resources Sharing in 6G: Challenges, Architecture, and Opportunities

Kun Yan, *Graduate Student Member, IEEE*, Wenping Ma, *Member, IEEE*, Shaohui Sun, *Member, IEEE*

***Abstract*—To realize unprecedented applications and individualized services, dynamic and efficient Communications and Networks Resources (CNRs) sharing is crucial in the 6G era. While exploring novel CNRs undoubtedly enhances comprehensive performance in 6G networks, improving the effective utilization of existing resources can balance the burden on communication networks and increase the quality of service. This article systematically investigates the challenges associated with future CNRs sharing in 6G networks and clarifies the potential of blockchain and evolutionary algorithms in CNRs sharing. Meanwhile, we propose a generalized architecture for CNRs sharing in 6G networks, which can support various types of CNRs sharing single or hybrid. Specifically, a blockchain embedded with an adjustable consensus mechanism is employed to ensure the security and efficiency of resource trading. Furthermore, evolutionary algorithms are utilized to achieve customizable and flexible resource matching. The simulation result indicates that the proposed architecture not only facilitates efficient resource trading but also effectively improves resource utilization, thereby demonstrating the feasibility of the proposed architecture. Finally, we outline open issues for future work related to the proposed architecture.**

***Index Terms*—6G networks, resources sharing, blockchain, evolutionary algorithms, resource trading, resource matching.**

I. Introduction

UNDOUBTEDLY, the trajectory of our lives and society is inexorably steering toward increased automation, digitization, intelligence, and interconnectivity. The widespread commercialization of 5G networks offers an initial glimpse into these characteristics. Envisioned for the 6G era is a deep entanglement of the digital and physical worlds, featuring edge intelligence-besed distributed scenarios including Ubiquitous Internet of Things (UIoT), Holographic Integrated Sensing and Communication (HISC), Extended Reality (XR), and Artificial General Intelligence (AGI), permeating every facet of our daily existence [1]. Communications and Networks Resources (CNRs), including spectrum, infrastructure, computing, caching, data, and storage, etc., will play a pivotal role in supporting the requirements of these ambitious services. Nevertheless, the Terahertz frequency bands, the multitude of ultra-small cells, and diverse computing centers will expedite the evolution of 6G networks to being more distributed and heterogeneous. The Space-Air-Ground Integrated Network aims to achieve worldwide connectivity, a goal that may increase the complexity of CNRs allocation and management, while potentially impeding effective utilization. Consequently, 6G networks must continuously improve the efficiency of CNRs utilization while expanding new CNRs [2].

Wireless communication networks is transitioning to distributed or multi-center management. Namely, 6G networks will be composed of numerous micro mobile operators with flexible business models [3]. Therefore, blockchain is expected to be one of the most promising 6G technologies for enhancing distributed network management. This shift has spurred the trend towards integrating blockchain with CNRs sharing in 6G networks [2]. Specifically, blockchain utilizes the consensus mechanism to establish trusted interactions between unfamiliar sharing entities. As a distributed ledger, blockchain can provide tamper-proof resource status updates for CNRs. Furthermore, due to blockchain's inherent transactional properties and the automated execution of smart contracts, it has potential to significantly improve CNRs sharing efficiency [3–6].

Spectrum sharing, considered the foundation of CNRs sharing, is deemed an integral improvement in 6G networks. It facilitates task offloading in wireless communication and enables the transmission of signaling information during energy changes [4]. Spectrum sharing has led to considerable existing research. Maksymyuk *et al.* [3] integrated blockchain into 6G networks, proposing flexible and dynamic spectrum sharing strategies through smart contract in a transaction-oriented way. Zhang *et al.* [5] proposed a user-autonomous spectrum sharing model leveraging blockchain and swarm intelligence to reduce costs incurred by centralized management through the coordination of individual decisions and global policies. Moreover, AI will permeate almost the entire field of 6G networks, further accelerating the sharing of resources such as data, computation, and caching. Chen *et al.* [7] proposed a resource allocation scheme based on the Lagrangian dual and Kuhn-Munkres algorithm to obtain the optimal power allocation and channel allocation. Miao *et al.* [8] utilized deep reinforcement learning (DRL) to enhance the quality and efficiency of data sharing.

In this article, we integrate **B**lockchain and **E**volutionary algorithms to propose a novel **D**ynamic **C**NRs **S**haring architecture, BEDCS. This architecture is designed to achieve multi-dimensional and fine-grained secure sharing. The distinct contributions of this article are listed as follows:

- The proposed BEDCS is a generalized architecture designed to accommodate the diverse attributes and requirements of different resources in 6G networks, enabling more dynamic and efficient CNRs sharing.

Manuscript received February 3, 2024. This work was supported in part by the Key Industry Innovation Chain Project of Shaanxi Provincial Science and the Technology Department, China under Grant 2022ZDLGY03-08.

Kun Yan and Wenping Ma (corresponding author) are with the School of Telecommunications Engineering, Xidian University, China; Shaohui Sun is with the State Key Laboratory of Wireless Mobile Communication, Datang Mobile Communications Equipment Co., Ltd, China.

- We propose a novel consensus mechanism endorsed by trust, referred to as Proof of Trust and Adjustment (PoTA), which dynamically adjusts based on different resources, integrating blockchain with CNRs sharing.
- We model CNRs sharing as a multi-objective optimization problem (MOOP) and utilize evolutionary algorithms to encode and analyze it, providing more comprehensive solutions for resource providers and requesters.

The remainder of this article is structured as follows. We next present the challenges and potentials in CNRs sharing. Following that we introduce the proposed BEDCS. Then we present blockchain-based resource trading and evolutionary algorithms-based resource matching, respectively. The following section completes the experimental verification and discussion. The final section gives the conclusion.

II. Challenges and Potentials in CNRs Sharing

A. Challenges in CNRs Sharing

Although spectrum sharing has received tremendous attention from researchers, the sharing of data, computing, and storage has also yielded significant research results. However, three challenges in CNRs sharing still need to be emphasized.

Generalized CNRs Sharing Scheme: Complex application scenarios in 6G will impose stricter requirements on CNRs, likely necessitating support from hybrid resource sharing. Existing schemes realize the sharing of spectrum, data, and other resources to enhance service reliability through AI [8]. However, this approach is not applicable to hybrid CNRs sharing, as models trained solely on one resource sharing cannot be generalized to other resources. Therefore, building a generalized resource sharing platform to support various types of CNRs sharing single or hybrid is an important challenge to address.

Multi-Perspective CNRs Sharing Strategy: Green is considered as one of the metrics for 6G networks design [9]. This implies that network management cannot be implemented from a single perspective. Existing resource sharing schemes mainly consider only one or two factors, such as utilization or revenue [3], which may undermine the concept of green 6G. Thus, it is imperative to consider CNRs sharing in 6G networks from multiple perspectives.

Applicability of Blockchain in 6G: Distributed network management in 6G will fully unlock the potential of blockchain. This implies that blockchain will need to be adapted to the requirements of the services. Despite existing schemes focusing on utilizing blockchain to construct distributed scenarios, the actual applicability of blockchain is often overlooked. For example, blockchain utilizing directed acyclic graph reduces the burden of Proof of Work on the system but may make the consistency of the model uncontrollable [2, 3]. Therefore, the applicable blockchain and consensus mechanisms built for CNRs sharing in 6G networks is also a challenge.

B. Potentials of Blockchain in CNRs Sharing

As an open, encrypted, and distributed ledger, blockchain functions without centralized institutions, and the consensus mechanism is employed to effectively support the security and trustworthiness of the system. The potential of blockchain in CNRs sharing is as follows:

Distributed Resource Management: Traditional centralized management solutions aim to ensure absolute control over resources without considering the flexible reuse of resources. Simultaneously, the potential risk of a single point of failure may lead to widespread system paralysis. Through the allocation of management authority to multiple entities facilitated by blockchain, it can effectively avoid the impact of a single point of failure. Furthermore, multi-entity management can enhance the regional circulation of resources, thereby improving utilization efficiency.

Tamper-Proof Resource Update: In traditional solutions, the resource occupancy status is updated by providers in a central database, but it is not mandatory. Consequently, the resource utilization status in the system may not be promptly synchronized, leading to restrictions on the circulation of resources. By utilizing blockchain, resource providers and requesters can jointly maintain an immutable and secure distributed ledger. The resource utilization status will be automatically updated through smart contracts, further facilitating the circulation of resources.

Efficient Resource Trading: Traditionally, resource trading relies on a centralized organization, losing transparency of transaction information and monopolizing the pricing right of resources. In the 6G era, increased frequency of CNRs sharing transactions will lead to rising costs for the centralized organization [2]. In contrast, blockchain facilitates the efficient automation of transactions through smart contracts, allowing for associative updates to the status of resources. The global broadcasting of blocks ensures the non-repudiation of information.

C. Potentials of Evolutionary Algorithms in CNRs Sharing

The evolutionary algorithms, based on optimization algorithms derived from natural selection and genetic mechanisms in biological evolution, demonstrate excellent performance in addressing complex, nonlinear, and highly optimized problems [10]. The potential of evolutionary algorithms in CNRs sharing is as follows:

Highly Flexible Resource Allocation: Traditional approaches that utilize convex optimization for solving resource allocation problems often exhibit inefficiency. Although AI approaches can provide optimal decision-making, the associated privacy and computational issues cannot be ignored. Evolutionary algorithms can map resource allocation to a MOOP, allowing for flexible configuration of resource types, sizes, attributes, and so on. It can dynamically adjust the population evolution direction adaptively to explore optimal solutions. Moreover, it is insensitive to initial data, ensuring user privacy [10].

Customizable Resource Matching: Currently, the majority of resource matching approaches are profit-oriented, aiming to encourage more resource providers to share their resources. While this increases the enthusiasm of resource providers, resource requesters can only passively accept all terms. In the

TABLE I
COMPARISON OF BLOCKCHAIN AND EVOLUTIONARY ALGORITHMS WITH TRADITIONAL SOLUTIONS FOR ACHIEVING CNRS SHARING

Functionalities	**Traditional solutions**	**Blockchain solutions**	**Advantages**
Management	Resource provider; centralized control	Multiple entities; distributed control	Decentralization; automation; transparency
Record	Centralized database	Distributed ledger; smart contract	Tamper-proof; integrity
Trading	Centralized institution	Distributed ledger; smart contract	Automation; efficiently; non-repudiation
Functionalities	**Traditional solutions**	**Evolutionary algorithms solutions**	**Advantages**
Allocation	Convex optimization-based; AI-based	Resource code; population evolution	Flexibility; universality
Match	Profit-oriented	Multi-objective optimization-based	Customization; on-demand computing

evolutionary algorithms-based approach, resource providers can differentiate pricing for the resources they own. Meanwhile, resource requesters can compute different sizes and types of resources according to their own needs to achieve customized resource matching.

The potential of blockchain and evolutionary algorithms for CNRs sharing is summarized in Table I, demonstrating their advantages compared to traditional methods.

III. DESIGN OF PROPOSED BEDCS

A. System Model

BEDCS is a generalized solution that integrates blockchain extensively into the CNRs sharing of 6G networks, as illustrated in Fig. 1. It supports rich advanced applications in the application layer by flexibly managing and scheduling various resource types in the CNRs layer. Meanwhile, evolutionary algorithms is implemented to match resource providers with requesters, measure the deep reuse of resources from multiple perspectives, and realize fine-grained dynamic resource allocation. The proposed architecture consists of four main part:

CNRs Providers: Generally, they are large primary network operators, computing centers, and other entities that serve as the main constructors of 6G networks, owning the majority of CNRs. Once they have fulfilled the requirements of the services they support, they share the free resources.

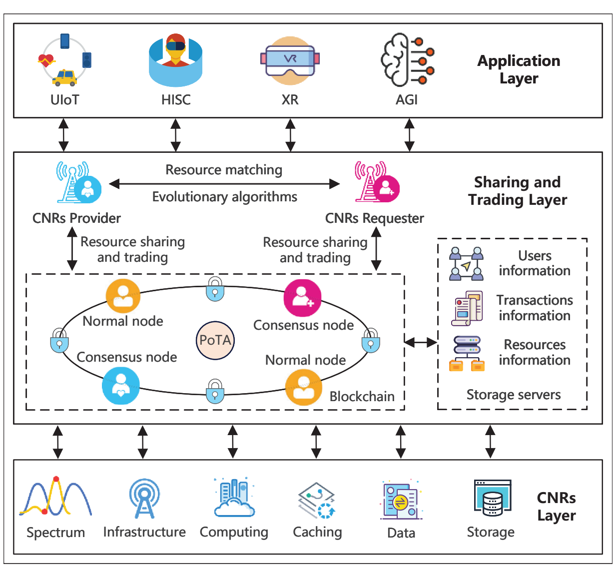

Fig. 1. BEDCS architecture for CNRS sharing in 6G networks.

CNRs Requesters: Generally, they are virtual network operators, edge service providers, and other entities with limited resources. They request more resources for further optimization to provide more refined services or meet their own resource requirements.

Consensus Nodes: All resource providers in BEDCS can serve as consensus nodes and engage in consensus work. However, participation in the consensus for sharing specific types of resources is limited to members possessing the same resource type.

Storage Servers: As one of the important components of the blockchain, in BEDCS, Inter Planetary File System (IPFS) is employed to fulfill the security requirements for storing and updating the information of users, transactions, resources, etc. in the system.

B. Generalized Architecture

As the core of BEDCS, the sharing and trading layer in Fig. 1 establishes a generalized mechanism for CNRs matching and trading. This mechanism is designed to accommodate the sharing of single or hybrid CNRs, utilizing blockchain and evolutionary algorithms. Blockchain provides a distributed platform where resource providers can broadcast free resources, and resource requesters can choose suitable providers based on their needs. Automated deal-making, as well as resource occupancy updates can be realized using smart contracts.

More importantly, resource matching is formulated as a MOOP relying on the evolutionary algorithms. This implies that resource providers can set the appropriate selling price based on the evolutionary result. Moreover, the dominant right of the trading will not be monopolized by the provider. Resource requesters can perform evolutionary computation on the required resource to determine the matching with the appropriate provider, thus achieving a fairer trading. Owing to the advantages of multi-objective optimization, during the process of resource evolutionary computation, not only the financial attributes of the resources are considered, but also other attributes, such as throughput, transmit power, area, delay, energy efficiency, etc. in spectrum resources sharing; time consumption, energy consumption, distance, load balance, etc. in computing resources sharing.

Therefore, in BEDCS, large-scale CNRs sharing among operators is attainable, while small-scale CNRs sharing among devices is fulfilled.

IV. Blockchain-Based Resource Trading

A. Trust Model

In general, trust between entities is established through mutual interactions. In BEDCS, local trust is established through mutual ratings among entities in CNRs sharing, and global trust is achieved using the EigenTrust algorithm [11]. This trust model is implemented as follows:

Local Trust: To achieve fine-grained classification of rating similarity and to distinguish between honest and malicious ratings, the 7-pointed rating scale is employed. Specifically, trust scores of {-3, -2, -1, 0, 1, 2, 3} represent worst, bad, poor, unknown, fair, good, to excellent ratings, respectively. The rating is mandatory; otherwise, entities will not be allowed to participate in the next sharing. Assuming entity e is the CNRs provider, it will collect ratings from various entities within a specific period, forming its local trust.

Global Trust: For entity e, the rating set of each entity can only be provided to itself for reference and cannot serve as the basis trust of entity e. Thus, the EigenTrust algorithm is employed to aggregate the local trust of each entity. By computing the rating sets provided by all entities to entity e within a specific period, the trust level of the whole system towards entity e in this phase can be quantified, forming its global trust.

B. PoTA Consensus Mechanism

As the core of blockchain, the consensus mechanism establishes the security foundation of the distributed system. PoTA, as the consensus mechanism of the blockchain in BEDCS, is endorsed by global trust. Simultaneously, the factors of CNRs (e.g., band size, number of sub-bands, coverage area in spectrum resources; number of computing devices, average computing power in computing resources) are utilized as the basis for selecting bookkeeping nodes, thereby comprehensively integrating the blockchain into CNRs sharing. This procedure is considered a multi-attribute decision-making problem, with the main process of the n-th consensus outlined as follows:

Parameters Positivization: Positivization is required as some parameters may have a negative relationship with the results in multi-attribute problems, and the reciprocal of these parameters are utilized to achieve positivization.

Parameters Aggregation: Different weights are assigned to adjust the influence of parameters on the results, and the weighted sum of many parameters and global trust is the final result, which is denoted as $S(n)$.

Time Mapping: The $S(n)$ of each entity is mapped to the waiting time $T(n)$ using the exponential distribution to achieve distributed consensus. $T(n)$ is adjusted by preset parameter to reduce it by an order of magnitude compared to the overall algorithmic runtime, minimizing the impact on PoTA's efficiency.

Bookkeeping node Generation: In the proof-based consensus mechanism, the bookkeeping nodes are typically nodes with relatively high capabilities in the system. Therefore, nodes with the largest $S(n)$ in PoTA, namely, the candidate whose waiting time $T(n)$ ends first, will be more likely to obtain the right to pack the block.

The types of CNRs and their associated factors involved in sharing are pre-recorded in PoTA, and the above algorithm is embedded into the blockchain wallet of each entity. During the consensus process, the system can adaptively adjust the bookkeeping node generation mechanism associated with each type of CNRs.

C. Block Generation

The sharing and state updates of a large number of CNRs in 6G networks are inevitable. Once relevant information is

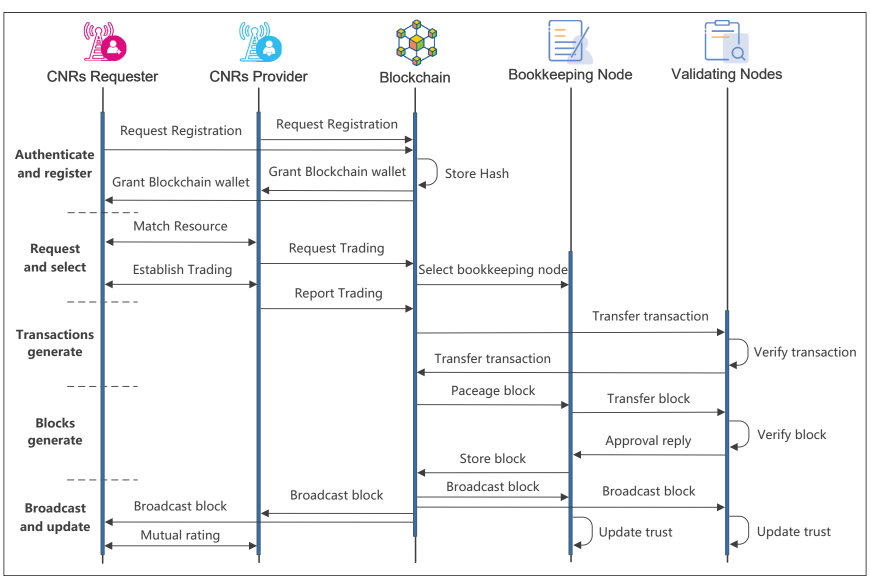

Fig. 2. Blocks generation process of blockchain in BEDCS.

generated, it will be recorded in the blockchain and simultaneously broadcasted, as illustrated in Fig. 2. The detailed steps of block generation are as follows:

Step 1 (Authenticate and register): Each entity participating in CNRs sharing needs to utilize its real identity information to obtain the necessary public key, private key, and wallet address for communication. The information is not stored; instead, only its hash value is retained. This approach ensures the security and privacy of the information and effectively preventing sybil attacks.

Step 2 (Request and select): Upon mutual matching of CNRs providers and requesters, the CNRs provider initiates a transaction request. Subsequently, entities with same resource in the system compete for the bookkeeping node through PoTA. Once the trading between CNRs provider and requester is completed, the trading and resource updates are reported to the blockchain.

Step 3 (Transactions generate): Once receiving the relevant information, the system proceeds to package it into a transaction, incorporating signatures from both parties using their private keys. Subsequently, the transaction is transferred to validating nodes to verify its accuracy. If the verification result is correct, the transaction is added to the transaction pool; otherwise, it is invalidated.

Step 4 (Blocks generate): Transactions in the transaction pool are periodically packaged into a new block by the bookkeeping node. Subsequently, validating nodes conduct thorough checks on the received block, including verifying signatures, timestamps, and the legitimacy of the bookkeeping node. The result is then returned, and the new block is stored in the blockchain.

Step 5 (Broadcast and update): After the block is stored, transaction and resource update information will be broadcasted across the system. Both parties involved in the trade will provide mutual ratings, and nodes participating in the consensus work will receive incentives for trust updates.

PoTA facilitates high-trust entities in the system to acquire bookkeeping rights, and the inclusion of resource factors introduces greater randomness in the selection of bookkeeping nodes, preventing collusion attacks. Furthermore, to prevent the monopoly of bookkeeping rights, after completing a consensus task, the bookkeeping node is restricted from participating in bookkeeping for a predefined time period.

V. Evolutionary Algorithms-Based Resource Matching

A. Problem Descriptions

Establishing an accurate matching mechanism is the most significant driving force to improve CNRs sharing. In BEDCS, resource matching is formulated into a MOOP by abstracting certain resource attributes. However, these attributes are diverse and intertwined, and a change in one attribute directly impacts changes in others. In this subsection, the Non-dominated Sorting Genetic Algorithm III (NSGA-III) [12], a many-objective evolutionary algorithm, is employed to address the aforementioned MOOP and construct a generalized resource matching mechanism that supports various types of CNRs.

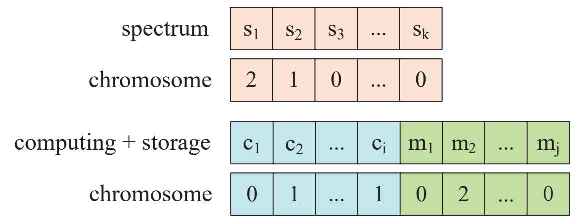

Fig. 3. Encoding of CNRs.

To illustrate, an example of spectrum resources is considered. In pre-planned communication networks, the quantifiable Signal-to-Interference-plus-Noise Ratio (SINR) is significantly influenced by user density. Utilizing Shannon theorem, the data rate in the subband can be determined based on SINR. Bandwidth and data rate assist in quantifying transmit power. The logarithmic utility function measures revenue based on data rate and the desired leasing time. In spectrum sharing, the uncontrolled increase in subbands utilization leads to a decrease in SINR, data rate, and revenue, coupled with increased transmit power. However, it is instructive to note that if SINR falls below the required threshold for data transmission, the entire communication networks becomes paralyzed. Hence, it is crucial to examine the trade-offs among these conflicting objectives. With the constraints of meeting 6G networks metrics [13], the optimization objectives of this MOOP is to maximize throughput and subband occupancy, ensure revenue through spectrum sharing, and meet the requirement of minimizing transmit power, all at the same time.

The abstraction of other resources as MOOP follows a similar principle as described above. In combinatorial CNRs sharing, the underlying principles remain consistent, with the condition that CNRs providers must possess these resources simultaneously. This establishes a dynamic and customized scheme for resource matching.

B. CNRs Encoding

Evolutionary algorithms utilize the concept of population evolution to tackle practical problems. Here, each individual in the population is represented as a string of numbers that map to potential solutions through a given encoding. Thus, the encoding of a practical problem serves as a crucial element for population evolution. In BEDCS, the occupancy status of sub-resources is encoded into genes, while the resource segments involved in sharing are encoded as chromosomes, constituting the entire CNRs providers for evolution. Since the occupancy status of resources is independent of resource types, this encoding approach enables BEDCS to achieve generalized CNRs sharing.

In BEDCS, a gene value of 0 indicates that the sub-resource is free, while values of 1 and 2 signify occupation by the CNRs provider and the CNRs requester, respectively. Fig. 3 visualizes the encoding of spectrum resources containing k sub-bands and hybrid computing and storage resources containing i and j sub-resources, respectively. Taking spectrum resources as an example, the 1st sub-band is occupied by CNRs requesters, while CNRs providers occupy the 2nd and

3rd sub-bands, and the k-th sub-band is free. The encoding for hybrid computing and storage resources follows a comparable pattern. Since genes and chromosomes in the population directly correspond to the resource allocation strategies, there is a mutual mapping between them. The chromosomes consistently represent the unique outcomes of each iteration during the evolutionary process.

C. Population Evolution

Simulating the strategy of biological evolution, a completely new chromosome (resource allocation strategy) can be generated through mutual crossover and mutation operations between parental chromosomes in NSGA-III. Under the constraints of MOOP, the crossover operation enhances the diversity of offspring chromosomes, while the mutation operation, within defined conditions, modifies individual genes to seek chromosomes with higher fitness. Following the principles of NSGA-III [12], the population generated after crossover and mutation operations is combined with the initial population, forming a merged population, and non-dominated sorting is executed on this population. Subsequently, reference points on the hyper-plane are determined, and chromosomes are associated with points. Finally, the Niche-Preservation Operation is conducted to obtain a population after one iteration of evolution. By performing several iterations of evolution, a population containing the optimal chromosomes (resource allocation strategies) can be obtained.

Typically, the final population contains a set of optimal solutions for resource allocation, known as Pareto solutions. However, in resource matching, a deterministic recommendation is required. Therefore, the Technique for Order Preference by Similarity to Ideal Solution (TOPSIS), in conjunction with entropy weighting, is utilized to evaluate the most optimal solution among various Pareto solutions. Specifically, this represents the optimal resource allocation scheme.

VI. Experimentation and Discussion

A. Experiments and Results

To validate the feasibility of the proposed BEDCS, we evaluate the performance of the PoTA algorithm using Golang language 1.19.2. Additionally, we assess the improvement of sub-resource utilization rate under the metrics of data rate (10-100 Gb/s), transmit power (20-80 dbm), computing power (100-1000 TOPS), and storage size (1-10000 GB) in 6G networks [13] with Matlab 2023b.

First, we test the number of transactions per second (TPS) of three algorithms: PoTA (in spectrum sharing), Proof of Stake (PoS) and Delegated Proof of Stake (DPoS). The tests are carried out 10 times, and the average is calculated to minimize errors. As shown in Fig. 4, the TPS of the three algorithms exhibits a negative correlation with the number of nodes. Notably, PoTA has the highest improvement of 62.43 percent and 18.97 percent compared to PoS and DPoS, respectively. This can be attributed to PoTA's utilization of weight evaluation to entirely replace hash competition and voting elections in PoS and DPoS. As a result, it saves consensus time and improves transaction throughput.

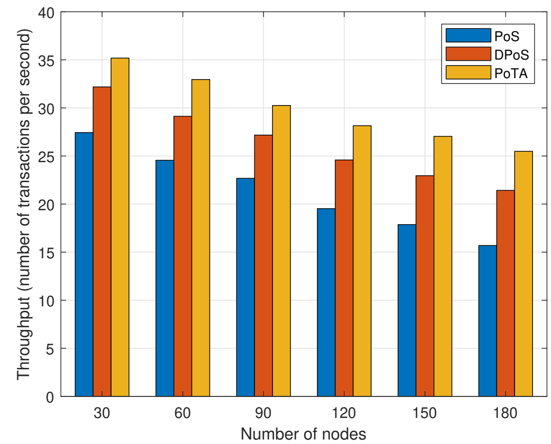

Fig. 4. Throughput comparison.

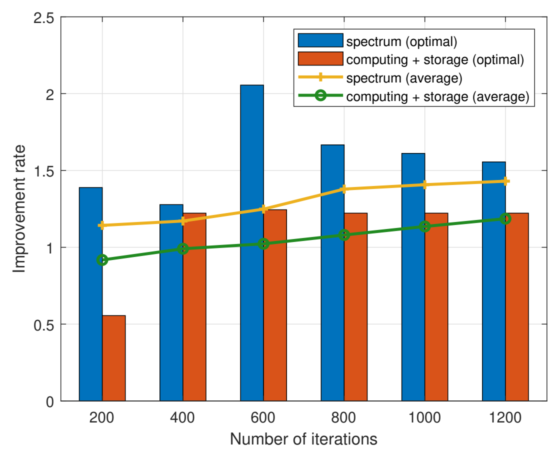

Fig. 5. The improvement rate of sub-resources occupancy.

Next, we abstract spectrum resources with 100 sub-bands from four objectives: subband occupancy, data rate, transmit power, and revenue. Additionally, we abstract hybrid computing and storage resources, each with 100 sub-resources, from six objectives: sub-resource occupancy, computing power, energy consumption, storage size, read/write speed, and revenue. Since diverse evolutionary resulting from crossover and mutation operations in NSGA-III, both the optimal solution and the average of all solutions in these two MOOPs are considered. The improvement rates in sub-resource occupancy before and after evolution are shown in Fig. 5. Overall, the improvement rate in sub-resource occupancy shows a positive correlation with the number of iterations in the average case. This implies that maximizing the number of iterations is essential to achieve optimal resource allocation. In the optimal case, the irregular variations in improvement rate result from the diversity of the final evolved population, with TOPSIS selecting the best within the current population. However, the minimum improvement rates still reach 127.78 percent and 55.56 percent.

B. Advantage of BEDCS

BEDCS constructs a generalized architecture for 6G that facilitates the sharing of various types of CNRs, whether single or hybrid. It adopts a strategy of minimizing sub-resource management for customizable fine-grained resource matching. Additionally, PoTA deeply integrates blockchain into CNRs sharing, ensuring security while enhancing the randomness of the consensus.

Since NSGA-III has a relatively good convergence and always selects the optimal solution within the final evolved population, it provides superior QoS and QoE for resource allocation [14] compared to DRL-based solutions [8]. Meanwhile, under the condition of N optimization objective functions and M population sizes, the computational complexity of NSGA-III-based CNRs matching is $O(NM^2)$, outperforming the computational complexity of resource matching mechanisms in [5, 7]. In addition, while preserving the same computational complexity, BEDCS can support more optimization objectives compared to [15], thereby paving the way for a more comprehensive resource allocation strategy in 6G networks.

C. Future Opportunities and Open Issues

BEDCS addresses the CNRs sharing problem through the utilization of blockchain and evolutionary algorithms. Considering the diverse directions in the planning and development of 6G networks, additional research topics related to BEDCS can be further explored.

Promote User Participation in Sharing: BEDCS employs blockchain to bridge resource providers and requesters for sharing, incorporating a trust model to tackle trading concerns. While price is a factor considered by BEDCS, it may not be sufficient to motivate all resource providers to participate in sharing. Therefore, in conjunction with BEDCS, designing a suitable incentive mechanism is crucial. Providing incentives beyond financial rewards to participants in the sharing can enhance the system's activity.

Fine-Grained Privacy Protection: Although the blockchain in BEDCS can provide pseudonymous communication for users with blockchain wallet addresses, the privacy protection measures may be somewhat inadequate for complex 6G networks and diverse application scenarios. Moreover, various CNRs may have distinct privacy protection requirements. Therefore, establishing a fine-grained privacy protection architecture for BEDCS to facilitate comprehensive privacy protection for users and information.

Explore combinations of CNRs: To provide advanced 6G applications, service optimization at the resource level becomes indispensable, making it essential to explore CNRs combinations for different applications. This exploration can offer more detailed CNRs optimization solutions for both application providers and resource providers. Hence, researching CNRs combinations accross diverse application scenarios and effectively utilizing BEDCS can effectively drive the development of a rich variety of 6G applications.

VII. Conclusion

This article explores the challenges, potential, and advantages of utilizing blockchain and evolutionary algorithms in CNRs sharing within 6G networks. BEDCS, a novel generalized architecture is proposed to meet the dynamic and fine-grained requirements of CNRs sharing in 6G networks. Leveraging the introduced PoTA, blockchain is integrated fully with CNRs sharing, facilitating efficient and secure resource trading based on a trust model. Diverging from other solutions, evolutionary algorithms pave the way for a generalized CNRs sharing architecture, catering to diverse resource matching. We hope this article sheds light on CNRs sharing and contributes to the advancement and development of 6G networks.

References

[1] X. Li *et al.*, "Blockchain-Enabled Applications in Next-Generation Wireless Systems: Challenges and Opportunities," *IEEE Wireless Commun.*, vol. 28, no. 2, pp. 86–95, 2021.

[2] S. Hu *et al.*, "Blockchain and Artificial Intelligence for Dynamic Resource Sharing in 6G and Beyond," *IEEE Wireless Commun.*, vol. 28, no. 4, pp. 145–151, 2021.

[3] T. Maksymyuk *et al.*, "Blockchain-Empowered Framework for Decentralized Network Management in 6G," *IEEE Commun. Mag.*, vol. 58, no. 9, pp. 86–92, 2020.

[4] J. Xie *et al.*, "Resource-Efficient DAG Blockchain with Sharding for 6G Networks," *IEEE Network*, vol. 36, no. 1, pp. 189–196, 2022.

[5] H. Zhang *et al.*, "A DAG Blockchain-Enhanced User-Autonomy Spectrum Sharing Framework for 6G-Enabled IoT," *IEEE Internet Things J.*, vol. 9, no. 11, pp. 8012–8023, 2022.

[6] S. T. Muntaha *et al.*, "Blockchain for Dynamic Spectrum Access and Network Slicing: A Review," *IEEE Access*, vol. 11, pp. 17 922–17 944, 2023.

[7] P. Chen *et al.*, "Energy-Efficient Resource Allocation for Secure D2D Communications Underlaying UAV-Enabled Networks," *IEEE Trans. Veh. Technol.*, vol. 71, no. 7, pp. 7519–7531, 2022.

[8] Q. Miao *et al.*, "Federated deep reinforcement learning based secure data sharing for internet of things," *Computer Networks*, vol. 197, p. 108327, 2021.

[9] C.-X. Wang *et al.*, "On the Road to 6G: Visions, Requirements, Key Technologies, and Testbeds," *IEEE Commun. Surv. Tutorials*, vol. 25, no. 2, pp. 905–974, 2023.

[10] T. Bäck, D. B. Fogel, and Z. Michalewicz, "Handbook of Evolutionary Computation," *Release*, vol. 97, no. 1, p. B1, 1997.

[11] S. D. Kamvar, M. T. Schlosser, and H. Garcia-Molina, "The Eigentrust algorithm for reputation management in P2P networks," in *Proc. 12th Int. Conf. World Wide Web (WWW)*, New York, USA, 2003, p. 640–651.

[12] K. Deb and H. Jain, "An Evolutionary Many-Objective Optimization Algorithm Using Reference-Point-Based Nondominated Sorting Approach, Part I: Solving Problems With Box Constraints," *IEEE Trans. Evol. Comput.*, vol. 18, no. 4, pp. 577–601, 2014.

[13] S. Chen *et al.*, "Vision, Requirements, and Technology Trend of 6G: How to Tackle the Challenges of System Coverage, Capacity, User Data-Rate and Movement

Speed," *IEEE Wireless Commun.*, vol. 27, no. 2, pp. 218–228, 2020.

[14] M. M. Damaneh *et al.*, "Power Allocation in CRNs based on QoS and QoE," in *Proc. 9th Iranian Joint Congr. Fuzzy and Intell. Syst. (CFIS)*, 2022, pp. 1–7.

[15] A. Martínez-Vargas *et al.*, "Application of NSGA-II algorithm to the spectrum assignment problem in spectrum sharing networks," *Appl. Soft Comput.*, vol. 39, pp. 188–198, 2016.

VIII. Biography Section

Kun Yan (kyan@stu.xidian.edu.cn) received a B.S. degree in internet of things engineering from Xi'an University of Technology, Xi'an, China, in 2019, He is currently working toward a Ph.D. degree in the School of Telecommunications Engineering, Xidian University. His research interests include blockchain, 6G networks, and internet of things.

Wenping Ma (wp_ma@mail.xidian.edu.cn) received his Ph.D. degree in communication and information system from Xidian University, Xi'an, in 1999, where he is currently a Full Professor with the School of Telecommunications Engineering. His current research interests include information theory, communication theory, blockchain, and 6G networks security.

Shaohui Sun (sunshaohui@catt.cn) received his Ph.D. from Xidian University, Xi'an, China, in 2003. Since January 2011, he has been the Chief Technical Officer with Datang Wireless Mobile Innovation Center of the Datang Telecom Technology and Industry group, where he has been deeply involved in the development and standardization of the Third-Generation Partnership Project Long-Term Evolution (3GPP LTE). His current research interest includes advanced technologies related to B5G/6G.