Received: 1 November 2022 | Revised: 23 December 2022 | Accepted: 23 January 2023

IET Networks

DOI: 10.1049/ntw2.12102

The Institution of Engineering and Technology WILEY

CASE STUDY

NGMA-based intergrated communication and computing for 6G-enabled cognitive radio networks

Wei Liang[1] | Jiankang Zhang[2] | Dawei Wang[1] | Lixin Li[1] | Soon Xin Ng[3]

[1]School of Electronic and Information Collage, Northwestern Polytechnical University, Xi'an, China

[2]School of Electronics and Computer Science, Bournemouth University, Poole, UK

[3]School of Electronics and Computer Science, University of Southampton, Southampton, UK

Correspondence

Jiankang Zhang, Wallisdown Rd, Poole, BH12 5BB, UK.

Email: jzhang3@bournemouth.ac.uk

Funding information

National Nature Science Foundation of China, Grant/Award Number: 62101450; Xidian University, Grant/Award Number: ISN22-03; Shenzhen Science and Technology program, Grant/Award Number: JCYJ20210324121006017

Abstract

According to the urgent low latency and the heavy computation tasks demands required for sixth-generation (6G) wireless networks, the authors introduce the conventional resource allocation algorithms, including the game theory, artificial-intelligence (AI) methods, and matching theory enabled framework, in which the multi-access edge computing (MEC) scheme collaborative with the cloud platform to serve the primary users (PUs) and cognitive users (CUs) for next generation multiple access (NGMA). The proposed framework allows both the PUs and CUs to offload their computation tasks in a 6G-enabled cognitive radio (CR) networks, so called cloud-assisted CR-MEC networks. In particular, the fundamentals of this conceived networks based on NGMA are first introduced. Hence, a number of methods based on the resource allocation algorithms are proposed in order to improve the quality of service for the mobile users, and reduce their transmission latency as well as the energy consumptions. Moreover, the motivations, challenges, and representative models for these conventional algorithms are described for integrated-intelligent communication and computing aided NGMA networks. Furthermore, the open issues and future research directions for this conceived networks are summarised.

KEYWORDS

cloud computing, cognitive radio

1 | INTRODUCTION

In future sixth-generation (6G) networks, delay-sensitive tasks and context-aware applications are expected to explosively increase, thus causing huge burden on MEC offloading transmissions. In certain spectrum-hungry environment, such as IoT scene, the above problem will be further deteriorated, which might cause severe and large amount of outdated computing tasks. Therefore, the future 6G networks are recommended to use the CR technique to overcome the spectrum shortage problem as well as to employ the edge computing and also cloud technology for proximity computing services [1]. Therefore, multiple access edge computing (MEC) is an estimable technique that allows the mobile applications to process their own computation services [1]. Additionally, one of the ambitious issues in current MEC networks is to limit the computation task's storage. However, the edge server have the restricted capacity by comparing with the data centre of the cloud server. So that, it is not impractical to run a large applications on a particular MEC server. An efficient way to solve this concerned problem is to allow mobile users to process the component of their computation tasks with the cloud assisted. In ref. [2], a MEC with cloud collaborative scheme was conceived aim to reduce the energy consumption as well as latency during the process of a specific offloading terminal selections. In particular, the proposed architecture of ref. [2] integrates the entire process, including the data collection, data transmission, and service orchestration to service access, aiming to achieve lower energy consumption and latency for the entire network. Additionally, a joint optimisation problem of the computation resource management and offloading decision was proposed for cooperation of the cloud and MEC-based vehicular networks [3], in which the system's utility can be enhanced by reducing the tasks' latency. Specifically, a closed-form computation resource allocation algorithm was developed to decide whether a task is processed only at the edge node, or the collaborative cloud-MEC node [3]. However, the papers relate to the collaborative cloud-MEC scheme was investigated by refs. [2–4], and their corresponding performance of latency and energy consumption might be reduced.

Moreover, in certain spectrum-shortage environment, one of the significant argument in cloud-assisted MEC networks is the resource management problem. As a holistic fashion, CR technique is still an attractive option for the future 6G network to resolve the spectrum shortage. CR technique is able to utilise or share the occupied spectrum between the primary users (PUs) and cognitive users (CUs) in an appropriate way [5]. Hence, with the increasing demands over the future wireless networks, the key technology as well as the efficient methods is still an open issue for the integration of the artificial intelligence and CR technology.

Against the above background, in this article, we conceive a holistic design of blending CR capabilities with cloud-assisted MEC concepts, referred to as the cloud-assisted CR-MEC network, thereby developing a novel paradigm of communication-computing fusion for the 6G application. Moreover, we investigate the efficient algorithms including the game theory, AI-enable methods and matching theory in the considered cloud-assisted CR-MEC networks, aim to discover the trade-off between the latency and the computation storage of the networks. Additionally, the main contributions are summarised as following:

- An in-depth overview of the cloud-assisted CR-MEC framework based on next generation multiple access (NGMA) is provided, in the context of its state of the art, fundamental functionalities, and the key techniques of this network are highlighted.
- We develop the conventional algorithm-based game theory in order to resolve the computation-communication resource allocation issue of the conceived networks, for addressing the trade-off between spectrum- and energy-efficiency. More explicitly, we analyse how the resource management affect the MEC offloading transmission by implementing the AI-based methods.
- We build a joint resource allocation framework for the cloud-assisted CR-MEC networks based on the three-side matching theory, and carry out the corresponding performance evaluation in terms of energy consumptions.
- As a nascent stage of studying the cloud-assisted CR-MEC, we conclude the future research directions and challenges from the view of both theoretical study and practical implementation.

The paper is organised as below. We have reviewed the architectures of the CR-MEC in Section 2, and the rationales of cloud-assisted CR-MEC networks are outlined. Additionally, the design of efficient algorithms for considering offloading decision and resource management in cloud-assisted CR-MEC networks has been considered in Section 3. Moreover, a joint resource scheduling algorithm of cloud-assisted CR-MEC networks has been developed in Section 4. Furthermore, the relative future research directions have been detailed in Section 5. Finally, the conclusions are described in Section 6.

2 | FRAMEWORK OF CLOUD-ASSISTED CR-MEC NETWORKS

As shown in Figure 1, the cloud-assisted CR-MEC networks based on NGMA constitute of three main components to process their computation tasks, it includes the mobile users, MEC server, and the cloud platform in order to ensure the system's latency can be guaranteed. Additionally, by comparing with the current cloud-assisted based MEC networks [3], the considered network allows localised organisations, in which the tasks that require more mobile services to be offloaded and also the availability of spectrum can be widely advertised. In particular, multiple PUs and CUs could compute their tasks on MEC server and cloud platform depend on the storage of these two servers [6]. However, in the considered networks, the mobile devices would decide to use the distributed way to do the comprehensive resource allocation consisting of the communication resource allocation as well as the computation resource allocation, by suffering from the limited power supply, limited storage and the processing ability. The challenge problem occurs in this considered network is that the MEC server could be the standard interface manoeuvrability, which may easy to assist the mobile users to connect with the local powerful devices. More specifically, there are two methods to process the data in the considered networks. One is to implement the data processing among the mobile devices without the server's participation [3]. Another is that the data upload to the server directly according to the limited storage, and then transfer to the destination. Hence, the mobile devices of the cloud-based CR-MEC networks could process the computation offloading tasks, albeit the data would be offloaded to the MEC server or the cloud by using the communication links depending on the storage of the MEC server. So that, the computation tasks of the mobile users in considered networks could be processed in

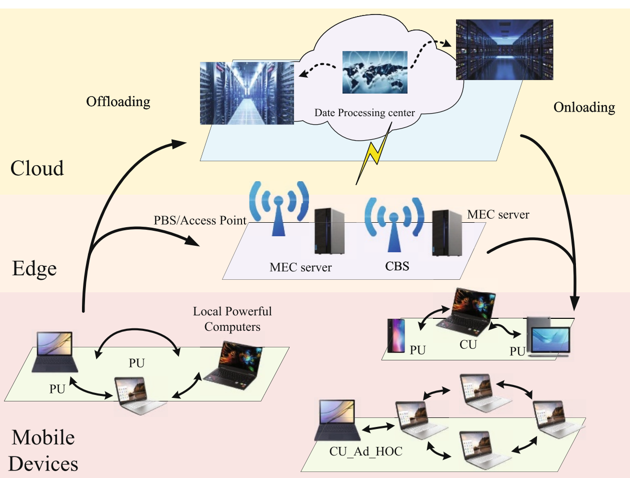

FIGURE 1 Architecture of the conceived networks.

three places, which are at the edge of the network, cloud platform, and local place of the mobile users.

2.1 | Edge-based scheme

Edge servers are usually the strong mobile devices that are deployed at the margin of the network. In particular, the edge servers which are close to the mobile devices could serve the main networks for mobile users' computation offloading. Additionally, the mobile users would decide to offload their intensive critical tasks to the edge servers due to the limited battery capacity as well as the computing power, for the sake of achieving the lower energy consumption. Nevertheless, the process of offloading decisions needs extra overhead and latency. Additionally, the offloading strategy could be affected by the resource allocations for the communication-computation decisions. Thus, the cooperation communication strategy was proposed for solving the joint optimisation problem of the offloading decision, MEC-cloud collaboration decision, and task computations in the multi-user wireless communication networks [6]. In particular, the mobile users execute the tasks either on local devices, MEC server or collaborative cloud-MEC device, aim to maximise the network's energy efficiency by considering the deadlines of the mobile users.

2.2 | Cloud-based scheme

Aforementioned research works mainly focus on the computation offloading on MEC server or cloud separately [6–8]. Cloud serves could extend the computing capacity, such as AliCloud servers, GoogleCloud servers, Amazon WebService cloud servers, and Microsoft Azure Cloud servers [3]. Thus, some potential problems occur due to the long distance data transmission, such as unstable connections and unacceptable latency, which is conflict to the low-latency demands for the future wireless communications. Additionally, there are not too much works focus on implementing the computing resources allocation on the MEC server as well as the cloud, simultaneously. In particular, the limited storage of edge servers which may not fully acquire all critical offloading demands. So that, with the increasing number of computation tasks, the capacity of edge server reach to its limit. Compare with the MEC computing, the cloud computing could provide a sufficient computing resources, although it may need long latency during the offloading processing. Nevertheless, to develop a heterogenous or hybrid networks to make sure the full usage of the computation resources is a promising research direction [2, 3].

2.3 | CR network

CR in the presence of the mobile communication network is considered as an emerging technology to carry out the spectrum access and spectrum sharing mechanism, in order to achieve high spectrum utilisation. Mobile devices refer to some smart devices with the limited computing and storage resources. A concept of cognitive radio cloud networks has been firstly proposed in ref. [9]. In particular, the mobility management service is provided based on the Microsoft's Windows Azure cloud platform for evaluating the time to perform CR's channel vacating, which requires sufficient long overall system response time. As a pioneer work, Wu et al. [9] gave a basic idea of the CR cloud network, including the functionality of edge computing, which however was lack of detailed network infrastructures. Moreover, a framework for MEC-based CR networks based on the AI methods was conceived in ref. [4]. More specifically, both partial offloading and local offloading scheme has been developed. However, there are no works relate to the investigating cloud-assisted CR-MEC networks.

However, it is significant to arrange the resources in the cloud-based CR-MEC network, with the considered performance on spectrum, latency and power, especially for large tasks' application. Both MEC-cloud collaboration and CR target to improve the spectrum utilisation, where the spectrum is allocated in an opportunistic manner. Improving the spectrum efficiency is still valuable to develop since the future wireless networks need to support high throughput with a low power consumption. However, the spectrum scarcity is still an important problem that needs to be solved for the 6G networks.

Although the traditional cloud-based technique can provide a powerful computing capacity, it leads to the additional latency because of the specific architecture and also long distances. On the other hand, computing offloading plays an important role in fulfilling the low latency requirements, especially while the storage of communication-computing resources are limited. Therefore, it is important to discover a trade-off between the latency and the computing storage in the cloud-assisted CR-MEC networks.

However, the previous works related to the edge-based CR networks mainly focus on maximising the throughput without meeting the low energy consumption requirement for task computation. Therefore, the novel exploration of task offloading in the cloud-assisted CR-MEC networks should fully address the energy cost as well as the service latency requirements. Hence, the novel cloud-assisted CR-MEC networks may be the key to fulfil the 6G requirements.

3 | CONVENTIONAL ALGORITHMS FOR OFFLOADING DECISION AND RESOURCE MANAGEMENT

The research on NGMA is in a very early stage. For the 6G networks, the NGMA is able to support massive mobile users in a much more overhead- and complexity-efficient manner than the current existing multiple access schemes. Additionally, the CR system in the presence of the NGMA assisted mobile communication network is considered as an emerging technology to carry out the spectrum access and spectrum sharing mechanism, in order to achieve high spectrum utilisation.

Additionally, we develop the advanced mathematical tools for facilitating the design of NOMA aided cloud-assisted CR-MEC communications, including the conventional game theory method, matching theory algorithms and novel machine learning approaches. Finally, several practical implementation challenges for NGMA are highlighted as the motivation for the 6G communications.

In the considered networks, both PUs and CUs have variety computation tasks need to be executed. However, each PU and CU could choose to execute their computation tasks locally, on the MEC server, or the cloud-MEC contractive. To elaborate further, the application of the game theory can effectively address the decision-making issues of the conceived networks among the multiple rational players, aim to obtain lower total cost of the system, including the energy consumptions, latency, and overhead. However, players may change their locations frequently and dynamically in the cloud-assisted CR-MEC networks, and hence the current patterns to the edge might not be the best choice due to the overheads. Due to the mobility of the mobile users, the usage of the resources and channel conditions would change accordingly. So that, the offloading decision-making problem becomes more complex to the edge nodes. Thus, the AI-enabled efficient methods would be the key technique to overcome the issue of the resource management. Regarding the demands for complex database and the complexity of the proposed networks, we develop a three side matching theory to solve the join consideration of the communication-computation resource scheduling in order to attain a significant improvement of the system performance with low complexity and overhead.

Game theory is a key method which is beneficially employed for resolving the resource management issue in CR networks [5]. In particular, a specific game can be classified as a set of players, a set of actions of individual player and the corresponding utilisation function for those players [5]. Each player selects an action and the corresponding strategy which is referred as the related entire plan of the action. However, the conventional stable game theory models based on the concept of the equilibrium concept, in order to make sure that a player could achieve either a fair or an optimal utility function under a given strategy by cooperating to the other players [10, 11]. The non-cooperative and cooperative games are two main types of the game theory. To elaborate further, the players make their decisions independently in the non-cooperative game and only consider to maximise their own reward. On the contrary, in the cooperative game, players cooperate with each other for the sake of maximising their system's overall rewards. Some game theoretic methods were developed in the MEC-based wireless networks are categories as communication resource allocation and computation resource allocation modes are summarised in Table 1.

3.1 | Game model for designing offloading decisions

According to the principle of game theory, three main elements should be explored in the cloud-assisted CR-MEC networks.

- **Player Setting**: in the cloud-assisted CR-MEC networks, the PUs and CUs could be treated as the players. Each user has their own computation tasks. There are two phases in the considered networks, which are communication and computing phases. In the communication phase, the CUs have to experience the interference from the PU because they would use the PU's spectrum band for the communication. Therefore, we have overlay CR scheme, underlay CR scheme and interware CR scheme to judgment the relationship between the PUs and CUs [5]. Additionally, in the computing phase, the base station (BS) schedules the PUs or CUs to completely offload their tasks. In particular, if the users offload their input data completely at their local place, then there is no offloading at the edge of the networks or local central processing unit. In the conventional assumptions, the users are assumed to complete their computational tasks within the given deadlines. Nevertheless, we consider a comprehensive computing-communication resource allocation scenario in the considered networks, aim to explore more resource utilisations as well as the task executions.
- **Utility Function**: In the non-cooperative game mode, both PUs and CUs are aim to maximise their own utility function. On the contrary, they should cooperate with each other in the cooperative game mode. The main concern of designing the utility function is about the comprehensive computation and communication resource allocation among the PUs and CUs. More specifically, the spectrum efficiency, offloading latency, energy consumption, and payoff could be designed as the utility function according to the system's goal.
- **Action based on normalisation factor**: Based on the principle of MEC and cloud computing, the PUs and CUs could process their own computation tasks by using their computation resources at the local processing place, where the users does not need to pay for the service. Moreover, the assumptions of setting up the utility of local execution of the users should be lower than that of the MEC/cloud servers, due to fact that the local processing latency is longer than the maximum tolerate limitation, and meanwhile the task processing delay of the MEC/cloud servers is lower than the maximum tolerable limitation. However, this normalisation factor is designed in order to change the offloading decision (action) of the players, whether the tasks are excused at their own access point, or on the MEC and cloud servers based on their utility functions.

Additionally, the definition of Nash equilibrium is important to a designed game.

To elaborate further, there is no player who has any intention to change its strategy for attaining a higher payoff in nash equilibrium, meanwhile the other players maintain their current strategies.

3.2 | Artificial intelligence (AI)-enabled resource management

The computational complexity of convolution methods is extremely high for real-time computation works, hence the

TABLE 1 Comparisons of current algorithms based on game theory to solve the computation and communication resource allocation problem in the wireless communication networks.

Resource allocation problem		Scheme	Application	Goal, reward and performance	Challenges
Communication resource allocation	Spectrum allocation	Matching game	• CR networks [5] • Relay selection and spectrum allocation	• Improving the throughput and reducing conflict probability • Interruption probability and blocking probability • Lower interruption probability and blocking probability	• Low energy consumption • Stability issue
	BS allocation	Hierarchical game	• MEC networks [6] • Wireless and cloud resource allocation	• Minimising the cost of mobile users (MU) and maximising the utility of MEC servers • MU: Combination of energy, latency and payment to server; MEC server: Combination of revenue from sharing resources and subtracting the operation cost • A pure-strategy nash equilibrium	• High achievable rate • Spectrum issue • Multiple users and low complexity
Computation resource allocation	Offloading decision	Potential game	• MEC-based vehicular networks [3] • V2X offloading and resource allocation	• Reducing the system overhead • Payoff function of vehicle • Nash equilibrium and finite improvement property	• High speed movement of users • High probability of service interruption • Vehicle location prediction issue
	Multiple MEC servers-selection	Coalition game	• MEC networks • Offloading selection of heterogeneous utility	• Maximising the reward of each user • Time-slotted rewards of computing offloading • Converging to a stable state	• Low energy consumption • High achievable rate • Spectrum issue
		Stochastic game	• MEC-based blockchains networks • Interactions of miners with MEC server	• Maximising the miners' expected long-term payoffs • Expected stage payoff of player • Converging to the stable states, and being perfect Bayesian equilibrium (PBE) and myopic PBE	• Partial offloading issue • Low energy consumption • Complexity issue
	Local and MEC servers-selection	Stackelberg game	• Coalition-based UAV MEC networks [10] • Computation offloading, channel allocation and position deployment	• Minimising the energy consumption • Individual utilities relating to the action profiles of leaders and users • Stackelberg equilibrium	• High speed movement of UAV • Complexity issue • Location issue

resource allocation would be a challenge for considering the latency-critical application tasks. For the sake of tackling this problem, algorithm in terms of AI method might be considered as the solutions. The advantage of implementing the AI algorithm is training a learning model for the sake of getting the complex connections between the future task mobility and past task mobilities [12]. In particular, AI method could learn online by interacting with the environment by comparing with the conventional algorithms, such as the convex optimisation as well as the game theory method.

In addition, MEC/cloud technology is an important technology promising to handle computationally intensive and latency-sensitive applications. In the cloud-assisted CR-MEC-related optimisation problems, the communication and computing resources are often limited due to the constriction of the computing platforms. In particular, the communication and computing resource allocation are often coupled with each other. Thus, the system model might be designed as a non-convex optimisation problem, which it is difficult to solve by using the conventional methods. Therefore, reinforcement learning (RL) algorithms are considered to be effective in these scenarios for jointly optimising resource management and task offloading based on their own characteristics, aim to maximise the obtained long-term rewards by balancing exploration and exploitation. However, the conventional RL algorithms cannot overcome the problems of the dimensional disaster and slow convergence, which were caused by the increase of computational complexity with massive connectives. Additionally, it is hard to achieve the continuous processing of the action space. Therefore, deep deterministic policy gradient (DDPG) algorithm is considered as an effective solution to the above problems by combining the deterministic policy gradient algorithm with a deep neural network [7]. A solution of resource allocation for NOMA-MEC-assisted ultra-dense networks was studied in ref. [7], aiming to minimise the system computational cost under the strict constraints of user's deadlines. In particular, the advanced algorithm is proposed to combine the DDPG algorithm with the mean-field game (MFG) in order to obtain the MFG equilibrium. Moreover, in ref. [13], an efficient algorithm to combine the DDPG algorithm and the graph convolutional network for the sake of solving the joint partial offloading and resource allocation problem in highly dynamic MEC scenarios with energy harvesting. Then, the proposed scheme attains the superior performance for the average weighted cost of task completion time. Unlike Q-learning and DQN, the DDPG is used to obtain the optimal flight trajectory of the UAV, in terms of the advantages of high-dimensional and continuous action space optimisation, which could obtain a better latency performance at the end [13]. Nevertheless, AI methods will be preferentially selected in some specific scenarios, and the cooperation of AI-method as well as the game theory would significant improve the system's performance.

Based on the previous discussions, the AI enabled offloading and resource management algorithm in cloud-assisted CR-MEC networks is shown in Figure 2. In the DDPG-enabled algorithm for resolving the resource management issues, environmental state is defined as S_t, consisting of both the state of the channel and the servers. After the state and action are initialled, an corresponding action could be obtained. After the agent executes this action, the next state S_{t+1} could be obtained. So are the reward r_t and the Q-value $Q(a)$. In addition, the actor network is trained by maximising the state-value function. The duty of critic network is updating the actor network.

4 | JOINT COMMUNICATION AND COMPUTATION RESOURCE SCHEDULING IN CLOUD-ASSISTED CR-MEC NETWORKS

In a holistic manner of cloud-assisted CR-MEC networks, by considering the overhead of the realistic aspects such as the energy efficiency and total system's latency was lack for the comprehensive resource allocation scheme. In addition, the preferences and satisfactions of the mobile users be treated as an important limitation of these comprehensive resource scheduling approaches. To elaborate further, a realistic three-side matching algorithm based on Gale-Shapley stable matching theory [8] are proposed to address the above shortcomings in cloud-assisted CR-MEC networks.

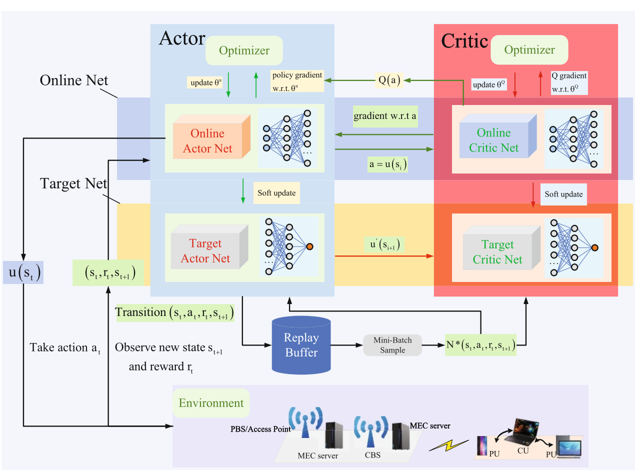

FIGURE 2 The DDPG enabled offloading and resource management algorithm in cloud-assisted CR-MEC networks.

4.1 | Offloading decision algorithm based on hybrid offloading mode

Three-sided matching is a three-dimensional variant of stable marriage problem, which consists of three sets, such as men, women and pets [8]. In addition, the preference lists are the essential factor of disjoint sets of players in three-sided matching theory, which influence the relative matching decisions. In particular, the main factors are three disjoint sets of players, their corresponding preference lists and their obtained utility functions. We introduce an offloading decision algorithm based on three-sided matching theory [8] for solving the joint communication and computing resources allocation problem in the considered cloud-assisted CR-MEC networks. In particular, in considered networks, the PUs, CUs, and BS are treated as the three disjoint players. Based on the principle of three-sided matching theory, the PUs and CUs form the temporary user pairs based on their individual preference lists at the first stage. Thus, CUs occupy the PUs' spectrum to upload their computation tasks under the PUs' agreement. Meanwhile, at the second stage, the BS would particular into the game and allocate the computation time slots to the temporary user pairs of the PUs and CUs for their offload process. Further, the remaining PUs would get chances to process their tasks controlled by the BS while the number of CUs are less than the PUs. Meanwhile, the choice of choosing either local server or the MEC server or cloud server is determined by the assigned time allocations. The structure of the proposed algorithm is described in Figure 3. The left part of Figure 3 shows the steps of the proposed three-sided matching algorithm in the conceived networks, including initialisations, two

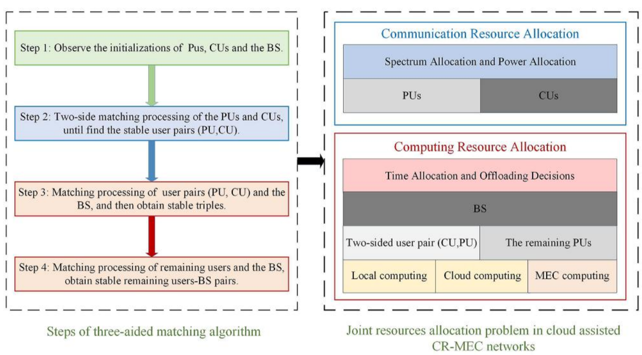

FIGURE 3 Offloading decision algorithm based on the three side matching theory for joint communication and computing resources allocation in cloud assisted CR-MEC networks.

side matching processing between the PUs and CUs, matching processing between the stable user pairs and the BS, and the last step is about the matching between the remaining PUs and the BS. Meanwhile, the right part of Figure 3 presents the comprehensive resources allocation problem in the cloud-assisted CR-MEC networks, in which the computing allocation problem includes the local, MEC and cloud computing offloading. In particular, the proposed algorithm is employed by appropriately allocating the communication and computing resources, aim to minimise the system's energy consumption.

Additionally, the PUs and CUs of conceived networks could benefit from offloading the computationally intensive tasks to the local servers, the MEC server or the cloud for increasing the CR access diversity. In the cloud assisted CR-MEC networks, the BS is integrated with a MEC server for computing amounts of users' tasks. Meanwhile, each user's local server can compute the tasks of corresponding user as well, but the ability of computation is much weaker than the MEC server. In the conceived networks, the hybrid offloading mode is applied, including the binary offloading and partial offloading modes. Under the binary offloading mode, the users' tasks are decided to compute either at the local servers or at the MEC/cloud server. Furthermore, in the partial offloading mode, the parts of computation tasks are computed at their local servers, and the rest parts are computed at the MEC/cloud server. Moreover, two kinds of triples are obtained. For the triple taking the binary offloading, user pairs offload all the tasks to the MEC server during the corresponding time slot. For the triples taking the partial offloading, user pairs offload partial tasks according to the proportion during the corresponding time slot. Furthermore, the PUs in PU-BS pairs offload tasks to the MEC server taking the mode of binary or partial offloading as well. Finally, the remaining users' tasks are computed by the local access point or cloud server. So that, users' tasks can be computed by the local servers or cloud and MEC servers based on the offloading decisions, which realises the reasonable joint resources allocation with low energy consumption. The relative performance of this offloading decision algorithm by employing the binary and hybrid offload modes is shown in Figure 4.

5 | OPPORTUNITIES AND CHALLENGES FOR FUTURE RESEARCH DIRECTIONS

Although the advantages in cloud-assisted CR-MEC networks based on the AI technique as well as the three-sided matching theory have been emphasised for user associations, task computing, and task offloading decision. There still remains some potential challenges and future research directions to be addressed in the future, which are described as follows:

NGMA-based Reconfigurable Intelligent Surface (RIS): RIS is a novel technology for future wireless communication. Based on the instruction of the RIS controller, reflecting elements are capable of adjusting both the phase and the amplitude of the reflected signals. In the RIS-assisted

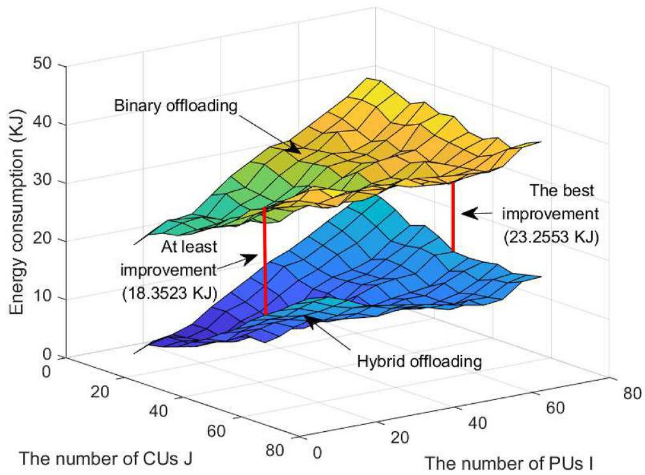

FIGURE 4 The performance of energy consumption for proposed three sided matching theory while employing the binary offloading mode and hybrid offloading mode.

CR-MEC networks, an RIS could deploy near the offloading users and its passive beamforming need to be designed for reshaping the computation load distributions [14]. Simultaneously, each reflecting element provides supplementary communication links between the MEC servers and the mobile devices, while the direct communication links between the user and cloud are blocked. By considering the benefits of IRS technology, the computation offloading delays can be greatly reduced. Additionally, the significant performance of spectrum efficiency and energy consumption could be enhanced by considering the cloud-MEC collaborative of the CR networks. More explicitly, RIS technology has inspired a range of new design, which is capable of dramatically improving the spectral efficiency of CR networks. More explicitly, RIS technology has inspired a range of new design, which is capable of dramatically improving the spectral efficiency of CR networks. Recently, the novel concept of simultaneously transmitting and reflecting RIS has been developed, which the incident wireless signal could be divided into transmitted and reflected signals passing into both sides of the space surrounding the surface. Furthermore, the task processing, user mobility and system security could be further developed in the cloud-assisted CR-MEC networks.

Integrated sensing and communications (ISAC): ISAC has been treated as a key technology towards the 6G wireless networks. Driven by the recent success of AI technology, the integration of AI-enable method and ISAC is important to unlock the full potential of CR networks. In particular, the intensive computation AI tasks from the cloud to distributed wireless nodes are processed at the edge of the CR network. However, the ISAC [15] is expected to generate a large number of information at distributed transceivers of the CR-edge networks, which needs to be properly processed by the AI algorithms in an appropriate manner, aim to support applications with ultra-low-latency demands. Furthermore, the federated learning has been treated as a promising solution, so that the mobile devices could execute their trained AI methods, and exchange their decisions iteratively for achieving the desired goal in the distributed manner.

Intergation of communication, computing, and caching: Storage ability is very important for facilitating the universal computation service. Thus, an integration of caching based on the cloud-assisted CR-MEC framework needs to be further developed, in order to improve the system's effectiveness, meanwhile reducing the computational complexity and system's overhead. In particular, the framework design of caching and computing ability may be discussed. Additionally, the trade-off among the communication, computing as well as the caching revenues will be realised for the future research.

6 | CONCLUSIONS

In this article, a novel architecture of cloud-assisted CR-MEC networks has been investigated. Additionally, some efficient algorithms enabled comprehensive communication-computation resource allocation has been studied in detail, which are the game theory, AI techniques as well as the three-side matching theory. However, there are still some important open issues remain to be solved before cloud-assisted CR-MEC can be utilised. A range of useful research directions were identified and discussed in this paper.

AUTHOR CONTRIBUTIONS

Wei Liang: Project administration; resources; software; writing – original draft; writing – review & editing. **Jiankang Zhang**: Conceptualisation; supervision. **Dawei Wang**: Investigation. **Lixin Li**: Investigation; resources. **Soon Xin Ng**: Investigation; resources.

ACKNOWLEDGEMENTS

The work was supported by the National Nature Science Foundation of China under Gants 62101450, in part by the Foundation of State Key Laboratory of Integrated Services Networks of Xidian University under Grant ISN22-03 and in part by the Shenzhen Science and Technology program under Grant JCYJ20210324121006017.

DATA AVAILABILITY STATEMENT

Data available on request due to privacy/ethical restrictions.

ORCID

Wei Liang https://orcid.org/0000-0002-9211-734X
Jiankang Zhang https://orcid.org/0000-0001-5316-1711
Soon Xin Ng https://orcid.org/0000-0002-0930-7194

REFERENCES

1. Zhang, Z., et al.: 6G wireless networks: vision, requirements, architecture, and key technologies. IEEE Veh. Technol. Mag. 14(3), 28–41 (2019). https://doi.org/10.1109/mvt.2019.2921208
2. Huang, M., et al.: A Cloud¨CMEC collaborative task offloading scheme with service orchestration. IEEE Internet Things J. 7(7), 5792–5805 (2020). https://doi.org/10.1109/jiot.2019.2952767
3. Zhao, J., et al.: Computation offloading and resource allocation for cloud assisted mobile edge computing in vehicular networks. IEEE Trans. Veh. Technol. 68(8), 7944–7956 (2019). https://doi.org/10.1109/tvt.2019.2917890
4. Wang, D., et al.: Intelligent cognitive radio in 5G: AI-based hierarchical cognitive cellular networks. IEEE Wireless Commun. 26(3), 54–61 (2019). https://doi.org/10.1109/mwc.2019.1800353
5. Liang, W., Ng, S.X., Hanzo, L.: Cooperative overlay spectrum access in cognitive radio networks. IEEE Commun. Surv. Tutorials 19(3), 1924–1944 (2017). https://doi.org/10.1109/comst.2017.2690866
6. Tan, L., et al.: Energy-efficient joint task offloading and resource allocation in OFDMA-based collaborative edge computing. IEEE Trans. Wireless Commun., 1 (2021)
7. Li, L., et al.: Resource allocation for NOMA-MEC systems in ultra-dense networks: a learning aided mean-field game approach. IEEE Trans. Wireless Commun. 20(3), 1487–1500 (2021). https://doi.org/10.1109/twc.2020.3033843
8. Cui, J., et al.: QoE-based resource allocation for multi-cell NOMA networks. IEEE Trans. Wireless Commun. 17(9), 6160–6176 (2018). https://doi.org/10.1109/twc.2018.2855130
9. Wu, S.-H., et al.: A cloud model and concept prototype for cognitive radio networks. IEEE Wireless Commun. 19(4), 49–58 (2012). https://doi.org/10.1109/mwc.2012.6272423
10. Chen, J., et al.: A multi-leader multi-follower stackelberg game for coalition-based UAV MEC networks. IEEE Wireless Commun. Lett. 10(11), 2350–2354 (2021). https://doi.org/10.1109/lwc.2021.3100113
11. Fang, T., et al.: Joint task offloading, D2D pairing and resource allocation in device-enhanced MEC: a potential game approach. IEEE Internet Things J., 1 (2021)
12. Shen, J., et al.: Interactive artificial intelligence meets game theory in next-generation communication networks. IEEE Wireless Commun. 28(2), 128–135 (2021). https://doi.org/10.1109/mwc.001.1800554
13. Chen, J., Wu, Z.: Dynamic computation offloading with energy harvesting devices: a graph-based deep reinforcement learning approach. IEEE Commun. Lett. 25(9), 2968–2972 (2021). https://doi.org/10.1109/lcomm.2021.3094842
14. Bai, T., et al.: Latency minimization for intelligent reflecting surface aided mobile edge computing. IEEE J. Sel. Area. Commun. 38(11), 2666–2682 (2020). https://doi.org/10.1109/jsac.2020.3007035
15. Cui, Y., et al.: Integrating sensing and communications for ubiquitous IoT: applications, trends, and challenges. IEEE Network 35(5), 158–167 (2021). https://doi.org/10.1109/mnet.010.2100152

How to cite this article: Liang, W., et al.: NGMA-based intergrated communication and computing for 6G-enabled cognitive radio networks. IET Netw. 13(3), 262–269 (2024). https://doi.org/10.1049/ntw2.12102