Article │ Received 28 June 2023; Accepted 20 July 2023; Published 1 December 2023
https://doi.org/10.55092/pcs2023020006

Decision making for IoT task offload scheduling with edge computing: a survey

Dayong Wang[1,*], Kamalrulnizam Bin Abu Aakar[1], Babangida Isyaku[2]

1 Department of Computer Science, Faculty of Computing, Universiti Teknologi Malaysia, Johor Bahru, Johor, Malaysia
2 Department of Computer Science, Faculty of Information Communication Technology, Sule Lamido University, K/Hausa, Jigawa State, Nigeria

* Correspondence author; E-mail: bg4acd@126.com.

Abstract: The rapid development of Internet of Things (IoT) technologies has resulted in Terminal Devices (TDs) running more software to support ever-increasing functions and services. Due to cost and technical limitations, TDs only have limited computing power and battery capacity, which requires TDs to send computing-intensive tasks to the edge computing network for remote execution based on task offloading technology, thereby reducing TD's computing load and energy consumption. There are a lot of research on scheduling tasks to remote computing nodes in heterogeneous edge networks and cloud platform to achieve optimal matching of computing tasks and computing resources. The scheduling algorithm analyzes the calculation amount of the task, the operation time constraint, and the available resource status of the computing network, and then dynamically adjusts the allocation of offloading tasks. However, a complete analysis and review based on the perspective of task offloading decision-making is lacking. This study compares the existing task offloading decision-making methods in the IoT, and analyzes the advantages and disadvantages of various methods and their adaptability to different application scenarios. Thus, a panoramic view of IoT task offloading decision-making methods is given, the deficiencies and challenges of existing decision-making techniques are analyzed, and future research directions are discussed.

Keywords: Internet of Things; task offloading; decision-making; optimization; edge computing

1. Introduction

The ever-increasing functional requirements lead to IoT networks being loaded with more and more computing tasks. Some computing-intensive tasks will consume a lot of TD's computing power and battery Life [1]. However, TD's computing power and power supply are limited. This results in slow task execution and excessive battery drain, which severely impacts the user experience [2,3].

The emergence of task offloading technology provides a new solution to such problems, which allows TD to delegate computationally intensive tasks to the edge computing network instead of execution [4]. To make full use of edge computing network resources and achieve the best match between computing nodes and computing tasks, it is necessary to generate a task offloading decision based on a comprehensive analysis of the current available status of computing resources and computing task characteristics [5].

Existing task offloading decision-making methods are limited by many different application scenarios, and lack of consideration of network communication fluctuations [6]. This leads to a limited application range of the offloading decision method. In terms of technical classification, task offloading decision-making methods are mainly divided into: integer linear programming algorithm, heuristic algorithm, and intelligent algorithm based on machine learning. Figure 1 shows the taxonomy of task offloading decision methods.

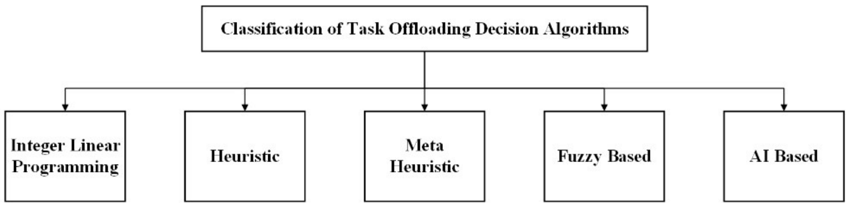

Figure 1. Classification of IoT task offloading decision-making methods.

This paper provides a comprehensive survey of optimization techniques for computing task offload in IoT and its recent developments by focusing on task offload decision-making. We discuss most of the important offload decision-making techniques proposed recently, classify, and compare various decision-making methods according to the technical principles, and providing a panoramic view of the field of task offload decision-making techniques. In addition, we investigate the difference between distributed offloading decisions and centralized offloading decisions from a problem modeling perspective. Moreover, we provide an in-depth analysis of the latest emerging decision-making methods for task offloading based on machine learning and deep learning techniques, and highlight some open research challenges and discuss future research directions.

2. IoT task offloading architecture

There are many ways of IoT task offloading, which can be divided into horizontal task offloading and vertical task offloading according to the path of task offloading. Horizontal task offloading refers to unloading tasks from a TD to other TDs. Vertical task offloading refers to offloading computing tasks from TD to the edge network or cloud platform. Due to differences in task requirements and dynamic changes in the state of computing resources, the process of offloading various tasks needs to achieve reasonable resource allocation and scheduling based on offloading decisions. Figure 2 shows the architecture of IoT task offloading and scheduling.

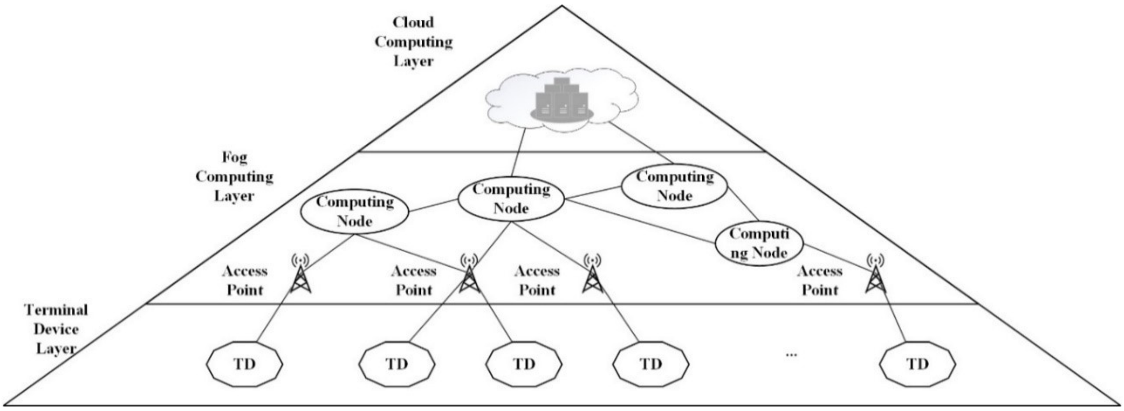

Figure 2. IoT task offload architecture.

The early task offloading architecture was relatively simple, and there were two types: IoT-Edge and IoT-Cloud. The latest complex computing task offloading architecture is IoT-Edge-Fog-Cloud. TDs can offload tasks to the edge network or cloud platform directly. In addition, the edge network can further offload tasks upward to other fog computing nodes. The fog computing network can also offload tasks to the cloud platform when the computational resource requirements of the offloaded tasks are very high. In addition, the latest research also pays attention to the idle computing resources of TDs. When a TD is idle, it can be considered to use its computing resources to aid other TDs. Therefore, IoT computing tasks can be offloaded not only to edge computing networks and cloud platforms, but also to other TDs in the horizontal direction.

The goal of task offloading decision-making is usually to optimize two main indicators, one is to shorten the execution time of the task, and the other is to reduce the energy consumption of TD. In addition, to improve the overall performance of IoT task offloading and computing networks, decision-making algorithms also need to consider more optimization objectives. These optimization goals include minimizing the energy consumption of terminal mobile devices, minimizing the operation and processing time of tasks, maximizing the reliability of task offloading, maximizing the accuracy of task assignment, minimizing The network transmission cost of task data, minimize the use cost of computing resources, maximize the working time of mobile devices relying on battery power, maximize the resource utilization of edge computing network, and minimize the task timeout percentage, *etc*. Figure 3 shows the main goals of task offloading.

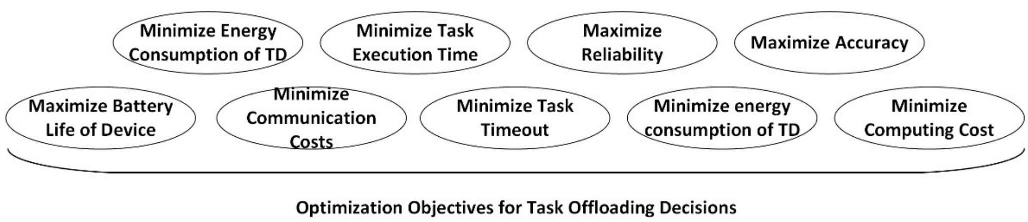

Figure 3. Main goals of task offloading decision-making.

The generation of offloading decisions is an important part in task offloading optimization. It collects the characteristics and completion time requirements of computing tasks, and monitors available edge computing network resources. Then, tasks are assigned to appropriate computing nodes based on multi-objective optimization constraints. It is complex and difficult for the task offloading decision-making algorithm to achieve the above multiple optimization goals, because the decision-making algorithm needs to consider multiple factors that affect the task offloading performance, including but not limited to load balancing, resource constraints, fault tolerance, security, costs, privacy, latency, and mobility, *etc*. Figure 4 shows the multiple factors affecting the generation of IoT task offloading decisions.

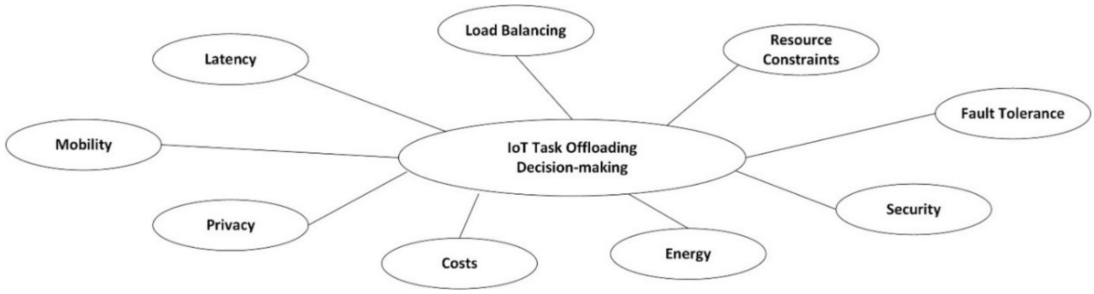

Figure 4. Main factors of task offloading decision-making.

3. Related survey and review

Jiang C *et al.* [7] provides a comprehensive research survey of task offloading decision techniques. The survey takes smart home as the main application scenario, and fully studies the requirements of multiple aspects of task offloading decision-making, including energy consumption minimization, service quality assurance, and experience quality enhancement. Lin H *et al.* [8] analyze and discusses different types of offloaded models based on various paradigms, such as MDPs, game theory, and reinforcement learning. And point out that most of them use state-action model to describe computation offloading. The survey points out that computing task offloading has large-scale and unpredictable characteristics, and RL-based methods can better deal with the high complexity of this task offloading decision-making problem. Abu-Taleb *et al.* [9] conducts a detailed analysis of various task offloading decision algorithms for mobile edge computing network application scenarios, proposes the most important issues and challenges that affect task offloading decisions, and summarizes the core contributions of decision offloading based on infrastructure and optimization methods.

Cao B *et al.* [10] focuses on the task offloading decision-making method based on deep learning, compares, and analyzes the characteristics, limitations, and application scenarios of various algorithms, and discusses some challenges of intelligent offloading in MEC. This research focuses on discussing many characteristics of DQN suitable for supporting task offloading decisions, and it is pointed out that the traditional learning method can work jointly with the DQN-based task offloading decision-making method. Shakarami A *et al.* [11] review of Machine Learning-Based Task Offloading Decision and Optimization Methods for Virtual Reality Application Scenarios. Further, various unloading decision-making methods are compared from two dimensions of performance index and performance evaluation. In addition, this study also discusses the dynamic task offloading decision mechanism to support autonomous driving. Shyalika C *et al.* [12] focuses on the analysis of dynamic task scheduling decision-making technology based on reinforcement learning for grid computing and industrial Internet application scenarios, and discusses the adaptability and scalability of such algorithms. This study analyzes and compares multiple decision-making methods for task offloading based on reinforcement learning and deep learning, and describes the characteristics of each decision-making method. In addition, the author also discusses how this dynamic task scheduling method can better support various application scenarios.

Jin H *et al.* [13] compare and analyzes the decision-making strategies for task offloading in a dynamic MEC environment. It is proposed that the task decision algorithm should consider factors such as resource allocation and content caching. In addition, the survey investigates the ability of various offloading decision algorithms to support mobility management and task transfer. Moreover, this study points out the impact of terminal device mobility on task offloading decisions. Maray M *et al.* [14] comparatively analyzes the optimization method of task offloading decision-making in distributed edge computing environment. This research focuses on minimizing task offloading delay and maximizing the energy consumption of terminal devices, and fully studies the impact of device mobility on task offloading decisions. In addition, this research also takes the commercial cost of task execution as Consideration indicators that affect task offloading decisions, not just research from the performance level. Akhlaqi MY *et al.* [15] using bibliometric analysis to review the evolution of task offloading decision-making techniques in mobile edge computing, focusing on mobile edge computing scenarios based on 5G communications. In addition, this study comprehensively compares the datasets used for performance verification of task offloading decision generation algorithms.

Saeik F *et al.* [16] reviews vertical multi-layer task offloading optimization methods, and discusses the impact of various dynamic parameters and user behaviors in the network on the optimization of task offloading decisions based on artificial intelligence techniques. This research focuses on the analysis of the heuristic task offloading decision generation algorithm, and compares the difference in applicable scenarios between the machine learning-based decision generation algorithm and the traditional decision generation algorithm. In addition, this research also pays attention to the information security and system fault tolerance issues involved in task offloading. Kar B *et al.* [17] summarizes joint task offloading optimization techniques under the fog-edge-cloud architecture. This research not only analyzes the distribution of computing tasks at multiple vertical computing network levels, but also focuses on the optimization of horizontal offloading of computing tasks to other nodes in the same layer. Due to the existence of computing task offloading at the same level, the study also specifically analyzes the difference between one-way task offloading and two-way task offloading. In addition, this study pays special attention to the partial offloading of tasks. Jin X *et al.* [18] analyzes and summarizes decision-making methods for computing task offloading in Mobile Cloud Computing (MCC) architectures. The special feature of this study is that tasks of different sizes are treated differently, and the optimization of task offloading decisions based on granularity differences is analyzed and discussed. In addition, static task offloading and dynamic task offloading decisions are analyzed separately in this study. Furthermore, the study also discusses other related technologies such as task offloading fault tolerance and privacy protection in the MCC architecture in depth, and proposes the advantages of active privacy protection based on task offloading over passive privacy protection.

Hamdi AMA *et al.* [19] discusses the decision-making and optimization method of computing task offloading in the vehicle fog computing network environment, focusing on the decision-making optimization method of computing task offloading between moving vehicles. In addition, this study analyzes the difficulties encountered by traditional task offloading decision generation methods in in-vehicle fog computing networks, and elaborates on the impact of vehicle movement on task offloading decisions. This study also fully considers the computational task Quality of Service (QoS) constraints in the vehicular fog computing network, and proposes a research direction for task offloading decisions that include QoS guarantees. Gupta P *et al.* [20] summarizes the multi-level task offloading optimization technology based on the IoT-Edge-Fog-Cloud architecture, and discusses the differences in task offloading optimization methods between different layers. A decision-making method for computing task offloading with timeliness as the main optimization objective. To maximize the completion efficiency of tasks, this research also analyzes the processing delay of tasks on heterogeneous computing nodes and the transmission delay of task data between multi-layer computing networks. In addition, this study also distinguishes different types of task offloading modes such as one-to-many and many-to-many, and discusses the optimization methods of offloading decisions under different offloading modes respectively.

Islam A *et al.* [21] discusses multiple algorithms for the two types of centralized task offloading decisions and user-side task offloading decisions separately, and provides an in-depth analysis of the differences between the two different types of task offloading decision architectures. The centralized task offloading decision is provided by the cloud computing platform to provide comprehensive optimization calculations and generate a unified task offloading strategy, while the user-side task offloading decision algorithm runs in a distributed manner on each mobile user device that needs to offload computing tasks. In addition, this study also discusses a decision-making method for user-cloud platform cooperation task offloading based on software-defined networking. Furthermore, several future research directions based on cooperative decision generation are proposed. Ahmed M *et al.* [22] provides a comprehensive survey of vehicle task offloading optimization techniques and classifies and studies task offloading optimization problems in communication modes such as vehicle-to-vehicle and vehicle-to-base station infrastructure. This research fully analyzes the characteristics of cellular communication, and incorporates communication power regulation and network slicing characteristics into the consideration factors of task offloading decision-making. However, this study does not consider the communication power control factors between vehicles, instead, only the data transmission delay is used to assist the offloading decision. In addition, open research challenges in this field are given.

Wang B *et al.* [23] classifies the optimization of task offloading decisions in mobile application scenarios from multiple dimensions, including joint offloading decisions, decentralized task offloading, data caching, security, *etc*. This research focuses on the impact of different task offloading decisions on the communication cost and computing cost of operators. In addition, the study also discusses the load balancing distribution of tasks on multiple edge computing nodes. Furthermore, the authors also extend the study of special decision generation for multi-hop cooperative offloading application scenarios. Heidari A *et al.* [24] divides computing task offloading decision-making optimization methods into static and dynamic categories, and discusses the adaptability of multiple algorithms in the two categories of technologies in different application scenarios. This study focuses on the impact of network communication quality on task offloading decisions, rather than just analyzing the computing power of fog computing nodes. In addition, allocation of computing resources is taken as a main issue in this study. The authors also investigate the scalability of task offloading target networks.

Kumari N *et al.* [25] discusses the mathematical formulation of task offloading decision and optimization problems, with full technical details of various solutions. This research focuses on the optimization details of the task offloading decision generation algorithm in the fog computing network, and fully studies the parameters and performance indicators of various decision generation algorithms. In particular, the authors emphasize reliability guarantees for task offloading. Shakarami A *et al.* [26] studies the offloading decision mechanism of mobile users randomly offloading tasks to edge computing network scenarios, and divides such optimization methods into three categories: Markov chains, Markov processes, and hidden Markov models. In addition, the study compares global decision-making methods and local decision-making methods for mobile devices.

Jamil B *et al.* [27] discuss task offloading decisions and dynamic scheduling techniques in the IoE environment and categorizes these methods into eight main categories. Afterwards, the advantages and disadvantages of various algorithms in the IoE environment are discussed. Kaur N *et al.* [28] examine the differences in multiple task offloading decisions and scheduling algorithms in terms of optimization metrics and simulation environment settings. Through the analysis, it is pointed out that time, cost, energy and load balance are the most concerned parameters in task scheduling. Alizadeh MR *et al.* [29] analyze which scheduling decision-making methods are more concerned, and discusses the network environment to which various algorithms are applicable. Furthermore, the authors discuss at length which scheduling metrics are closely related to offloading decisions.

The various author provide above detailed survey on task offload scheduling for IoT is illustrated in Table 1.

Table 1. Survey on task offload scheduling.

Works	Proposed	Algorithm Classification	Scenario	Strengths and future scope
[7]	Survey on several fundamental issues to be addressed for computational offloading decisions and optimization	Integer linear programming, Heuristic, Meta heuristic	Smart home, Industrial IoT	The basic theory of task offload and decision-making
[8]	Discusses different types of offloading models based on various paradigms	Integer linear programming, Heuristic, Meta heuristic, Fuzzy based, AI based	E-commerce, Smart cities	Based on software defined networking
[9]	An overview of the task offloading decision model is presented and task offloading between compute nodes is covered	Integer linear programming, Heuristic, Meta heuristic, Fuzzy based, AI based	Mobile apps	Offloading tasks between MECs
[10]	Deep learning-based task offloading and optimization methods are explored.	AI based	5G network, Artificial intelligence	Combining methods
[11]	A special review of machine learning-based task offloading decision-making and optimization methods.	AI based	Multimedia processing, Online games, Virtual reality	Considers the transfer of decided tasks to the MEC
[12]	Reinforcement learning-based decision-making methods for dynamic task scheduling are reviewed	AI based	Grid computing, Drones	Dynamic Task Scheduling
[13]	Review of task offloading optimization from traditional optimization algorithms to heuristic and intelligent decision-making algorithms	Heuristic, Meta heuristic, AI based	Internet of vehicles, Virtual reality, Augmented reality	Considering service migration optimization
[14]	The problems and challenges of task offloading optimization are discussed based on optimization methods, granularity and application scenarios.	Integer linear programming, Heuristic, Meta heuristic, AI based	Face recognition, Augmented reality, Mobile apps	Distributed computing offloading algorithm
[15]	Reviews the evolution of task offloading decision techniques, performance evaluation methods and datasets	Integer linear programming, Heuristic, Meta heuristic, Fuzzy based, AI based	Autonomous driving, 5G and Augmented reality	Benchmark analysis
[16]	This paper reviews the offloading decision of client computing tasks, and proposes an offloading optimization based on traffic demand forecasting	Integer linear programming, Heuristic, Meta heuristic, AI based	Virtual reality, Autonomous driving	Forecast traffic demand
[17]	The optimization of joint task offloading of machine learning methods in fog-cloud architecture is reviewed	AI based	Internet of vehicles, Industrial IoT, Smart city	Horizontal offloading
[18]	Review of computational offload optimization Methods in Mobile Cloud Computing	Integer linear programming, Heuristic, Meta heuristic	Mobile apps	Mobile cloud computing (MCC)

Table 1. *Cont.*

Works	Proposed	Algorithm Classification	Scenario	Strengths and future scope
[19]	Decision-making and optimization of task offloading in vehicle fog computing environment	Integer linear programming, Heuristic, Meta heuristic, Fuzzy based, AI based	Internet of vehicles	Task offloading in vehicular fog computing
[20]	Explore multi-level task offloading and scheduling optimization methods	Integer linear programming, Heuristic, Meta heuristic, Fuzzy based, AI based	Smart buildings, Smart cities, Smart transportation	IoT-Edge-Fog-Cloud
[21]	Multiple algorithms are discussed for both types of centralized task offloading decisions and user-side task offloading decisions	Integer linear programming, Heuristic, AI based	Virtual reality, Autonomous driving, Industrial IoT	User equipment (UE) side decisions
[22]	Review the decision-making and optimization techniques of task offloading in the application scenarios of Internet of Vehicles	Integer linear programming, Heuristic, Meta heuristic, Fuzzy based, AI based	Internet of Vehicles	Application scenarios of IoV
[23]	Classification of task offloading optimization methods in mobile application scenarios and exploration of future research directions.	Integer linear programming, Heuristic, Meta heuristic, AI based	Mobile network applications, Drones, Internet of vehicles	Taxonomy of task offloading optimization
[24]	IoT computing task offloading optimization methods are reviewed in detail from two categories of static and dynamic task offloading decisions, respectively	Integer linear programming, Heuristic, Meta heuristic, AI based	Mobile network applications, Smart buildings, Internet of Vehicles	Dynamic/Static offload decision classification
[25]	Provides a mathematical problem formulation for task offloading optimization	Integer linear programming, Heuristic, Meta heuristic, AI based	Internet of vehicles, Mobile cloud computing	Case analysis
[26]	Investigating decision-making methods for mobile users to randomly offload tasks to edge networks	Integer linear programming, Heuristic, Meta heuristic, Fuzzy based, AI based	Augmented reality, Virtual reality, Internet of vehicles	Random task offloading
[27]	A review of IoE-oriented task scheduling decision and resource allocation methods	Integer linear programming, Heuristic, Meta heuristic, Fuzzy based, AI based	Smart city, Smart transportation, Virtual reality	Internet of everything
[28]	This paper systematically reviews the challenges and commonly used algorithm evaluation methods for task offloading decisions in fog computing environments	Integer linear programming, Heuristic, Meta heuristic, Fuzzy based, AI based	Mobile network application, Internet of vehicles, Smart city	Multidimensional algorithm comparison and simulator
[29]	A systematic review on existing task scheduling approaches. The authors exhaustively discuss the correlation between scheduling metrics and offloading decisions	Heuristic, Meta heuristic	Smart building, Smart transportation, Internet of everything	Clear and effective scheduling indicators

4. Challenge and future research direction

The factors to be considered for task offload decision-making are complex due to the diversity and heterogeneity of IoT applications. Existing studies have analyzed and compared task offloading decision optimization methods in several dimensions. However, there are still many challenges and key issues in this area that need to be extended for future research.

- More research on stand-alone task offload optimization, but less on workflow task offload application scenarios
- Most of the studies only consider the amount of computation of the task, and lack of differentiated optimization studies for different task types
- Existing task offload decision optimization methods are not well supported for mobility
- Most of the existing studies assume a fixed size of computing network resources and lack support for dynamically scaled computing networks
- AI-based task offloading decision methods mostly target centralized decision architectures, while research for distributed decision architectures is lacking
- Most of the performance evaluation schemes used across studies are custom designed and there is a lack of uniform performance evaluation designs. This has led to difficulties in making quantitative comparisons between multiple studies
- There is a lack of publicly available data sets for relevant studies

According to the previous discussion, AI-based task offloading decision and dynamic offloading decision optimization for complex application scenarios will have more research prospects in the future.

5. Conclusion

The rapid development of software functions and the insufficient computing power of terminal devices have led to the emergence of task offloading technology. The complexity of task offloading and scheduling in mobile network application scenarios needs to be effectively resolved. In this paper focusing on survey on optimization of decision-making for IoT task offload scheduling with fog computing. This study sorts out and compares the advantages and disadvantages of the task offloading optimization algorithm from the aspect of the implementation technology of the decision-making algorithm. It is found that the AI-based task offloading optimization method is the trend of future development. This survey aims to form a comprehensive picture of the research progress of IoT task offloading decision optimization and enable researchers in follow-up studies to quickly understand the challenges and future research trends in this technology area.

Conflicts of interests

The authors declare no conflict of interest.

References

[1] Bellini P, Nesi P, Pantaleo G. IoT-enabled smart cities: A review of concepts, frameworks and key technologies. *Appl Sci*. 2022, 12(3):1607.

[2] Li Q, Zhao J, Gong Y, Zhang Q. Energy-efficient computation offloading and resource allocation in fog computing for internet of everything. *Chin Commun*. 2019, 16(3): 32-41.

[3] Bakar KB, Zuhra FT, Isyaku B, Sulaiman S. A Review on the Immediate Advancement of the Internet of Things in Wireless Telecommunications. *IEEE Access* 11, 2023, 21020–21048.

[4] Jaddoa A, Sakellari G, Panaousis E, Loukas G, Sarigiannidis PG. Dynamic decision support for resource offloading in heterogeneous Internet of Things environments. *Simul Model Pract Theory*. 2020, 101:102019.

[5] Xiao K, Gao Z, Shi W, Qiu X, Yang Y, *et al.* EdgeABC: An architecture for task offloading and resource allocation in the Internet of Things. *Future Gener Comput Syst*. 2020, 107:498-508.

[6] Isyaku B, Bakar KB, Ghaleb FA, Al-Nahari A. Dynamic routing and failure recovery approaches for efficient resource utilization in OpenFlow-SDN: a survey. *IEEE Access* 2022(10): 121791-121815.

[7] Jiang C, Cheng X, Gao H, Zhou X, Wan J. Toward computation offloading in edge computing: A survey. *IEEE Access* 7, 2019, 131543–131558.

[8] Lin H, Zeadally S, Chen Z, Labiod H, Wang L. A survey on computation offloading modeling for edge computing. *J Netw Comput Appl*. 2020, 169:102781.

[9] Abu-Taleb NA, Abdulrazzak FH, Zahary AT, Al-Mqdashi AM. Offloading decision making in mobile edge computing: A survey. In *2022 2nd International Conference on Emerging Smart Technologies and Applications (eSmarTA)*, 2022: 1-8.

[10] Cao B, Zhang L, Li Y, Feng D, Cao W. Intelligent offloading in multi-access edge computing: A state-of-the-art review and framework. *IEEE Commun Mag*. 2019, 57(3):56-62.

[11] Shakarami A, Ghobaei-Arani M, Shahidinejad A. A survey on the computation offloading approaches in mobile edge computing: A machine learning-based perspective. *Comput Netw*. 2020, 182:107496.

[12] Shyalika C, Silva T, Karunananda A. Reinforcement learning in dynamic task scheduling: A review. *SN Comput Sci*. 2020, 1:1-7.

[13] Jin H, Gregory MA, Li S. A review of intelligent computation offloading in multi-access edge computing. *IEEE Access* 10, 2022, 71481–71495.

[14] Maray M, Shuja J. Computation offloading in mobile cloud computing and mobile edge computing: survey, taxonomy, and open issues. *Mob Inf Syst*, 2022, e1121822.

[15] Akhlaqi MY, Hanapi ZB. Task offloading paradigm in mobile edge computing-current issues, adopted approaches, and future directions. *J Netw Comput Appl*. 2023, 212:103568.

[16] Saeik F, Avgeris M, Spatharakis D, Santi N, Dechouniotis D, *et al.* Task offloading in Edge and Cloud Computing: A survey on mathematical, artificial intelligence and control theory solutions. *Comput Netw*. 2021, 195:108177.

[17] Kar B, Yahya W, Lin YD, Ali A. A survey on offloading in federated cloud-edge-fog systems with traditional optimization and machine learning. *arXiv* preprint arXiv:2202.10628. 2022 Feb 22.

[18] Jin X, Hua W, Wang Z, Chen Y. A survey of research on computation offloading in mobile cloud computing. *Wirel Netw*. 2022, 28(4):1563-85.

[19] Hamdi AM, Hussain FK, Hussain OK. Task offloading in vehicular fog computing: State-of-the-art and open issues. *Future Gener Comput Syst*. 2022, 133:201-12.

[20] Gupta P, Sharma R, Gupta S. A review on task offloading mechanism for iot edge fog cloud data interplay. In *2022 IEEE Delhi Section Conference (DELCON)*, 2022, 1-10.

[21] Islam A, Debnath A, Ghose M, Chakraborty S. A survey on task offloading in multi-access edge computing. *J Syst Archit*. 2021, 118:102225.

[22] Ahmed M, Raza S, Mirza MA, Aziz A, Khan MA, *et al*. A survey on vehicular task offloading: Classification, issues, and challenges. *J King Saud Univ Comput Inf Sci*. 2022, 34(7):4135-62.

[23] Wang B, Wang C, Huang W, Song Y, Qin X. A survey and taxonomy on task offloading for edge-cloud computing. *IEEE Access*. 2020, 8:186080-101.

[24] Heidari A, Jabraeil Jamali MA, Jafari Navimipour N, Akbarpour S. Internet of things offloading: ongoing issues, opportunities, and future challenges. *Int J Commun Syst*. 2020, 33(14): e4474.

[25] Kumari N, Yadav A, Jana PK. Task offloading in fog computing: A survey of algorithms and optimization techniques. *Comput Netw*. 2022, 214:109137.

[26] Shakarami A, Ghobaei-Arani M, Masdari M, Hosseinzadeh M. A survey on the computation offloading approaches in mobile edge/cloud computing environment: a stochastic-based perspective. *J Grid Comput*. 2020, 18:639-71.

[27] Jamil B, Ijaz H, Shojafar M, Munir K, Buyya R. Resource allocation and task scheduling in fog computing and internet of everything environments: A taxonomy, review, and future directions. *ACM Comput Surv (CSUR)*. 2022, 54(11s):1-38.

[28] Kaur N, Kumar A, Kumar R. A systematic review on task scheduling in Fog computing: Taxonomy, tools, challenges, and future directions. *Concurr Comput Pract Exp*. 2021, 33(21): e6432.

[29] Alizadeh MR, Khajehvand V, Rahmani AM, Akbari E. Task scheduling approaches in fog computing: A systematic review. *Int J Commun Syst*. 2020, 33(16): e4583.