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Towards Efficient 6G IoT Networks: A Perspective on Resource Optimization Strategies, Challenges, and Future Directions

ZHANG LIWEN^{1, 2}, FAIZAN QAMAR¹, (Member, IEEE), MAHRUKH LIAQAT³, (Member, IEEE), MHD NOUR HINDIA⁴, (Member, IEEE), KHAIRUL AKRAM ZAINOL ARIFFIN¹

¹ Center of Cyber Security, Faculty of Information Science and Technology, Universiti Kebangsaan Malaysia (UKM), 43600 UKM Bangi, Selangor, Malaysia.

² Faculty of Electrical Information Engineering, Pan Zhi Hua University, 617000 East District, Pan Zhi Hua, Sichuan, China.

³ Department of Electrical Engineering, College of Electrical and Mechanical Engineering, NUST, Rawalpindi, Pakistan.

⁴ Advanced Communication Research and Innovation (ACRI), Department of Electrical Engineering, Faculty of Engineering, University of Malaya, Kuala Lumpur 50603, Malaysia.

Corresponding author: Faizan Qamar (faizanqamar@ukm.edu.my)

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ABSTRACT The next generation (6G) wireless communication technology has super advantages in high transmission rates scenarios. Internet of Things (IoT) has been applied in recent years due to its wide connection. However, effective resource optimization methods must be analyzed to meet the high requirements of key performance indicators in 6G wireless IoT networks. This paper discusses a general investigation of the resource optimization strategies in the 6G IoT system. The study aims to find the main solutions to optimize 6G IoT network performance. First, an overall summary of current research is preferred resource optimization in latency, reliability, Energy Efficiency (EE), Spectrum Efficiency (SE), bandwidth utilization efficiency, rate, and power efficiency. Second, we propose the multi-indicator tradeoff strategies associated with the latest resource optimization approaches and investigate optimal strategies. Furthermore, we show the limitations of the current resource optimization methods and discuss the future works of resource optimization for IoT devices in 6G communication. Our survey aims to help researchers optimize 6G IoT network performance using advanced techniques.

INDEX TERMS 6G, 5G, IoT, Resource Optimization, Optimization Strategies

I. INTRODUCTION

With the large-scale commercial application of 5th Generation (5G) mobile communications, Internet of Things (IoT) application scenarios have become more diversified [1]. From 2nd Generation (2G) to 5G, network resource optimization is the key to success in mobile communication [2, 3]. However, wireless communications are approaching Shannon limits, and available resources are insufficient [4]. Compared to the 5G mobile communication network, the next generation (6G) communication system has a wider coverage, which can realize the integrated connectivity of satellite, sky, ground, and ocean [5]. Some new resource optimization strategies need to be introduced to ensure the Quality Of Service (QoS) in 6G

networks [6] [7].

IoT is the key technique in the 6G network. IoT combines various sensor devices and networks to realize the connection among humans, things, and equipment anytime and anywhere [8]. While the growth of IoT devices has brought massive data, there is an increasing risk of data privacy leakage. In the process of multi-user data interconnection, a series of data security problems have been exposed. There are three kinds of privacy protection scenarios: data collection, data sharing, and data use. In a data collection scenario, the sensing nodes of the IoTs are highly vulnerable to attacks by adversaries. The adversary can obtain or forge the legal identity through a series of means, and then obtain the trust of the sensing node, and

finally obtain the privacy data collected by the sensing node. In a data-sharing scenario, the problem of balancing data privacy and usability must be considered. In data use scenario, IoT devices are vulnerable to adversary attacks and uncontrolled sharing of dirty data, which destroys the availability of IoT application layer-related services. For the purpose of fulfilling better communication enforcement in 6G, further research will be needed in terms of user privacy protection and security. Especially in resource-constrained IoT networks, whether the appropriate privacy protection can be given to ensure that the data can be appropriately developed and utilized is one of the research hotspots of the current IoT.

Furthermore, resource optimization is a crucial question that should not be left in developing the 6G IoT system. [9]. The existing resource optimization technologies cannot match the QoS demands in 6G IoT networks [10]. Improving resource utilization and accommodating more users in limited available network resources is the main challenge for applying 6G IoT technologies [11].

This article aims to discuss more effective methods for resource optimization in 6G for IoT communication systems. Firstly, we analyzed the impact of multiple indicators on the communication performance of 6G IoT networks. Then, there are six key indicators to be found in the communication performance improvement in the 6G technology, which includes latency, Energy Efficiency (EE), Spectrum Efficiency (SE), bandwidth utilization, transmission reliability, and transmission rate. In addition, we proposed a joint optimization concept to improve resource optimization in 6G IoT systems. We compare current approaches of multiple indicators tradeoffs. Finally, the limitations of existing resource optimization strategies were investigated, and the future

research directions were presented.

A. MOTIVATIONS AND CONTRIBUTIONS

This paper makes remarkable contributions by identifying the universal methods of key performance indicators in resource optimization for IoT scenarios 6G wireless networks, discussing effective strategies for resource optimization, and recommending advanced related technologies. This review proposes many challenges in exploiting resource optimization approaches caused by performance indicators tradeoffs in prospective wireless communication. The following are the main key contributions made by this survey:

1. It comprehensively figures out the key performance indicators, which include latency, EE, SE, bandwidth utilization, transmission reliability, and transmission rate, in the general resource optimization ways and analyzes the optimal strategies to solve the actual drawbacks.
2. It highlights the joint optimization approaches among above key performance indicators in resource optimization of 6G IoT systems.
3. It highlights emerging research trends and anticipated challenges that need attention.

The remaining sections of the article are as follows: Section II proposes the resource optimization strategies of 6 different indicators in 5G and 6G IoT communication networks. Section III investigates the joint optimization method among the 6 indicators. Section IV presents the challenges of resource optimization, Section V presents future research directions, and Section VI shows the conclusions of this article. The organization of the study is shown in Figure 1.

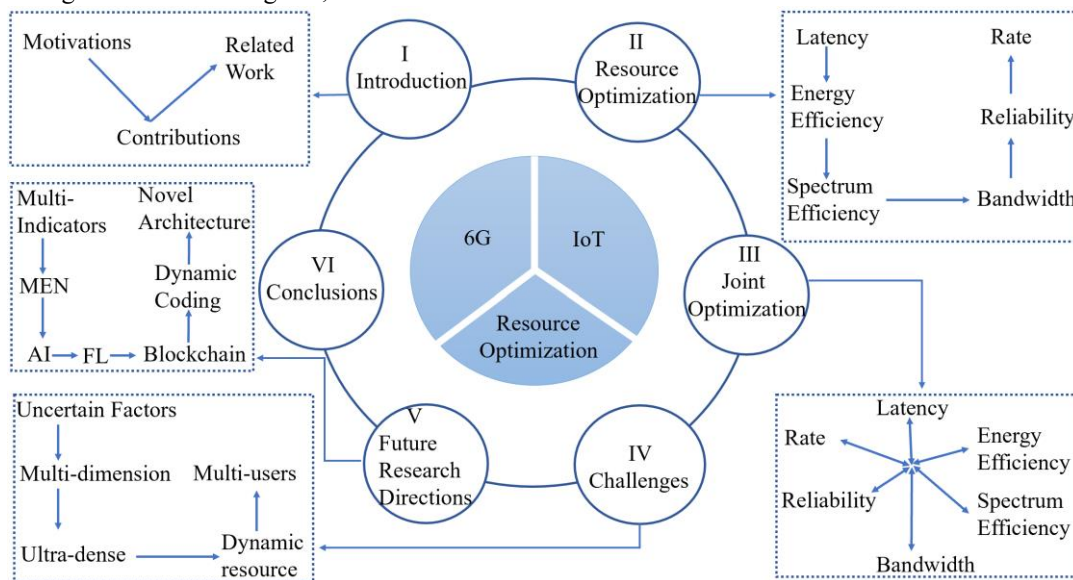


FIGURE 1. Organization of this study.

B. RELATED WORK

The following are the investigations of relevant research formed by several authors, including diverse resource optimization within the last three years.

In [12], the authors investigate EE strategies in 5G and beyond networks. Then, several related technologies and

frameworks in wireless systems of EE optimization are presented. Finally, they proposed new future research directions in terms of Device-to-Device (D2D) communications, Visible Light Communications (VLC), local caching, and mm-wave communications. Summaries of applications and services on different aspects of IoT and cloud computing are provided, and a novel gap in cloud computing

methods in IoT devices is presented [13]. They proposed that Delay-controlled, less resource exploitation, smooth connectivity, fewer costs, and less dense deployment of fog nodes were the critical elements for effective resource optimization in IoT network edge. In [14], they presented several requirements of IoT applications in 6G networks, such as ultra-reliability and low latency, which 5G networks could not provide due to the tremendous information explosion. This survey offers optimization strategies of the pivotal performance indicators, such as latency, EE, reliability, and transmission rate for prospect 6G systems.

Aiming to address the multi-application scaling and placement issues of the 6G Mobile Edge Computing (MEC), they provided a resource scaling service solution in IoT scenarios [15]. Then, the latest dynamic resource provisioning work is overviewed by classifying, and the study's service placement problem is stated. Finally, they propose the Intelligent IoT Resource Scaling and Service Placement Solution (IScaler) technology architecture for 6G communications. In [16], an investigation of the IoT Resource Management (RM) technique is researched, emphasizing the methods that improve spectrum management and sharing with blockchain and cyber twin. Availability, mobility, scalability, security, overall cost, and power utilization for the IoT network are also meaningful issues. These questions are analyzed comparatively with artificial intelligence (AI) algorithms to verify related performances. In [17], the authors outlined the pivotal questions in IoT for heterogeneous applications. They compared four different mutable service distribution models of resource optimization-based IoT services. Finally, the possibility of integrating with middleware-assisted service computation and process offloading in 6G is discussed to improve responses durative without backwardness.

The study in [18] discusses the necessity of resource optimization, rescheduling algorithms, task off-loading, edge technologies, and cloud architecture for 6G networks from the aspect of IoT communication are discussed. A comparable analysis of several resource optimization contributions, focusing on network capabilities, data rates, storage, and powerful computing, is presented. Approaches to resource optimization for the Internet of Medical Things (IoMT) were reviewed [19]. The two technologies, edge-empowered blockchain and Federated Learning (FL), were introduced, with an emphasis on the global learning mode in the FL system. In addition, they investigated the complex computing tasks of IoMT devices and their effective role in computing costs minimum [20]. The study in [21] discussed the relationship among 6G networks, AI technology, and edge computing. The literature survey proposed Space-Air-Ground Integrated Network (SAGIN), digital twin networks, vehicular networks, Unmanned Aerial Vehicle (UAV) networks, task offloading framework, and their integrated networks. Finally, latency, EE, model accuracy, and coverage were addressed.

The 6G network's resource optimization is summed up by automated network management deployment and advanced AI techniques, particularly the Explainable AI (XAI) approach [22, 23]. They discussed the potential of XAI-powered 6G architecture. Several resource optimization challenges and potential countermeasures for XAI-based 6G networks are

introduced. Edge learning, distributed Deep Learning (DL), centralized Machine Learning (ML), and FL are updated technologies that must be applied to fulfill the connection of IoT [24]. These methods are already used in 6G-enabled IoT networks, but several resource allocation problems exist. They provide an overview of these advanced technologies.

The above research proposed the importance of resource optimization in 5G and 6G IoT systems and extensively examined resource optimization strategies for 5G and beyond networks, particularly focusing on IoT systems and their integration with emerging technologies. The summaries and limitations of the investigated papers involved are preferred in Table I. Besides, several researches have also carried out resource optimization strategies of single indicators for 6G IoT networks, such as energy consumption, spectrum utilization, capabilities, data rates, and storage. Previous research provides outlooks on resource optimization architectures to improve communication quality. Meanwhile, some researchers focus on the integration of resource optimization and novel technologies for 6G IoT applications, such as AI technologies, cloud computing, blockchain, XAI, ML and FL.

However, key performance indicators (KPIs) of resource optimization are undefined for 6G communication systems. An urgently needed analysis of the key indicators in various application scenarios, which include latency, EE, SE, bandwidth, data transmission reliability, and rate, is needed. While previous research has unique insights into EE strategies, IoT resource management techniques, and optimization approaches, they also exhibit some limitations. For instance, there is a notable lack of consideration for real-world implementation challenges such as interoperability issues, scalability concerns, and integrating emerging technologies like blockchain and FL into practical IoT scenarios. Additionally, while the papers propose future research directions and potential solutions, there remains a gap in addressing the complexities of resource allocation and management in dynamic and heterogeneous IoT environments.

Moreover, the proposed solutions often lack comprehensive validation in real-world scenarios, highlighting the need for more empirical studies and experimental validation to assess their effectiveness and scalability. Furthermore, none of the surveys focus on IoT resource optimization by joint optimization in 6G IoT systems. A more effective strategy must be considered by applying joint optimization among the above key indicators. Moreover, there is still a big gap between new technologies and resource optimization. How to effectively apply novel techniques to improve resource optimization for 6G IoT networks in specific scenarios is worth further investigated. Overall, while the current research offers valuable insights into resource optimization in IoT networks, there is a need for further research to address the practical challenges and limitations encountered in real-world deployments.

TABLE I

SUMMARIES AND LIMITATIONS OF INVOLVED INVESTIGATION PAPERS FOR RESOURCE OPTIMIZATION.

Survey	Year	Summaries	Limitations
[12]	2021	Several related technologies and frameworks in wireless systems of EE optimization under D2D communications and so on are presented.	No other indicators are mention
[13]	2021	Provided a cloud computing survey for IoT edge scenarios. Discuss optimal node placement approach to resource exploitation. Highlight future research challenges based on integrating scalability and virtualization technologies.	Need more effective MEC appr
[14]	2021	A survey of the major performance parameters of 6G communication systems in several scenarios. Provides an operation principle for new technologies deployment methods in ulterior 6G communication systems. Prospective research directions and primary indicators are presented.	No new IoT application scenario is mentioned.
[15]	2021	Research of resource optimization organizations that scale resource service in 6G MEC scenarios is presented. Existing dynamic resource provisioning researches are classified.	No integration with AI technology.
[16]	2022	The AI-based resource optimization new techniques, applications, and existing methods are described. Spectrum optimization and sharing schemes have been compared according to overall cost, and power utilization related to 6G IoT.	No multi-indicators joint optimization.
[17]	2022	Different resource optimization architectures in IoT are discussed. Compare four types of mutable service distribution models to improve service response in IoT. Prospective investigations are proposed.	Need more MEC integration.
[18]	2022	Present current questions in the 6G IoT network. Compares existing optimization schemes in terms of network capabilities, data rates, storage, and powerful computing. Optimal scheduling policies are discussed.	No multi-indicators joint optimization.
[19]	2022	Described the corporate majorization of resource scheduling based on edge-empowered blockchain FL technique. IoMT mobility resource optimization solutions have been shown.	Need multi-indicators joint optimization.
[21]	2023	Introduces AI technology integration into 6G network. The advantages of a novel network framework in 6G communication are reviewed. The current 6G network performance is outlined and its improvement strategies are future directions.	No multi-indicators joint optimization.
[22]	2023	Provided a new XAI technology for resource optimization in 6G networks. Discussing the construction strategies of the RM system and analyzing the QoS of eHealth applications and services.	No joint optimization consideration.
[24]	2023	Overview of new technologies of edge learning, distributed DL, centralized ML, and FL in 6G-enabled IoT networks. Provided Network Intelligence (NI) with AI models to ensure resource optimization.	No joint optimization consideration.
This Work		1. Carried out resource optimization strategies of single indicators for 6G IoT networks. 2. Provided outlooks on resource optimization architectures. 3. Focused on integrating resource optimization and novel technologies for 6G IoT applications.	1. KPIs are undefined. 2. No joint optimization strategies for resource optimization. 3. No effective application of novel techniques for resource optimization.

II. RESOURCE OPTIMIZATION IN IOT NETWORK

IoT communication is a key technique in the 6G network. However, many questions, such as scarce wireless spectrum resources, the high energy consumption of sensor networks, low connection reliability, and high transmission latency, need to be addressed to evaluate and improve IoT communication performance in 6G work. Effective resource optimization must determine the key communication performance indicators in 6G IoT systems. The following are improvement methods for key communication performance indicators: coverage, latency, SE, and EE [25]. The resource optimization indicators and key methodologies are illustrated in Figure 2.

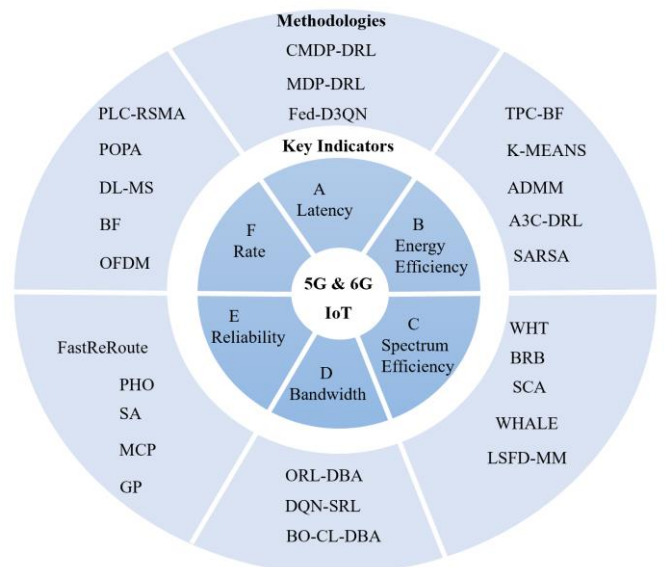


Figure 2. Resource Optimization and key methodologies.

A. LATENCY

Latency means the end-to-end delay in 5G and 6G IoT communication networks, where there are strong real-time data interaction ability demands to satisfy users' requirements. High latency will cause communication systems to break down and cause poor data interaction quality. Hence, latency performance has been highlighted as a main indicator for 6G wireless networks. In [26], channel variation and task arrival randomness problems are formulated to address latency minimum with a Constrained Markov Decision Process (CMDP)-based. Emulation consequences proved that the algorithm devised for Deep Reinforcement Learning (DRL) considered accuracy requirements and attained service latency execution improvements. Nevertheless, device mobility needs to be considered. In [27], the authors converted a task scheduling problem to an energy-CMDP the cause of reducing unloading latency and computing tasks for SAGIN of IoT system. Emulation consequences showed that the devised DRL algorithm can build up latency performance with UAV energy capacity constraint. Nonetheless, the multiple UAVs scenario in SAGIN is not mentioned. In [28], the authors utilized intelligent ultra-dense edge computing (I-UDEC) mechanics to analyze a Two-Timescale DRL (2Ts-DRL) way to decrease the computation unloading latency. The emulation consequences showed that the devised system reduces the latency of offloading tasks in 5G Ultra Dense Network (UDN) scenarios of heterogeneous. However, the FL technique must be applied for better latency implementation.

Regarding the dynamic network, the authors in [29] focus on improving the communication performance of massive vehicle networks; the author suggested a DRL-based approach to

minimize latency in IoT systems. The deep win of learn fast-policy hill-climbing (Deep WoLF-PHC) algorithm provided a more flexible resource allocation way for facing high mobility of IoT objective. Nonetheless, the dynamic latency threshold needs to be considered.

In [30], the authors scheduled a multiagent FL and Dueling Double-Deep Q-Network (Fed-D3QN) algorithm to improve power control and channel selection to satisfy the latency of Internet of Vehicles (IoV) for Vehicle-to-UAV (V2U) in dynamic air-ground integration network. The emulation consequences prove that the devised arithmetic is valid. Nonetheless, SE is not considered. In [31], the authors developed a Convolutional Neural Network (CNN) algorithm by applying a DRL method with MEC assists. The emulation consequences revealed that the devised Deep Dynamic Learning IoT-Edge Offloading (D2LIEO) strategy has lower latency for IoT systems. Nevertheless, the uncertain parameters of IoT devices are not mentioned.

The latency performance improvement strategies are analyzed in this section. To investigate latency minimization in 5G and 6G communication systems fully, several representative approaches are presented in this section. In particular, latency performance optimization based on DRL is defined as the main means of latency optimization of 5G and 6G IoT networks, which is proposed in [26], [27], [28], [31]. Other algorithms, like, Deep WoLF-PHC [29] and Fed-D3QN [30] are effective techniques against the latency of 5G and 6G IoT networks. The advantages and future directions of methods in latency performance optimization are described in Table II.

TABLE II

SUMMARY OF THE INVOLVED RESEARCH FOR LATENCY OPTIMIZATION.

Subject	Methodologies	Advantages	Future Directions	Ref.
Latency minimum	CMDP and DRL	Reduce latency with accuracy requirements	Device mobility is not considered.	[26]
Reduce latency with energy constraint	MDP and DRL	Reduce latency of offloading and computing task	Multiple UAVs are not referenced.	[27]
Improve offloading latency	2Ts-DRL	It is effective in UDN scenarios	FL technique is not considered.	[28]
Minimize latency for dynamic IoT network	DRL	Reduce latency for mobility of vehicles.	Dynamic latency threshold is not considered.	[29]
Satisfy the latency requirement	Fed-D3QN	Work in dynamic scenarios.	SE is not considered.	[30]
Reduce latency of IoT devices.	CNN on MEC devices.	Reduce latency while increasing EE.	Uncertain parameters of IoT devices are not mentioned.	[31]

B. ENERGY EFFICIENCY

With the rapid growth of wireless data and IoT devices in 5G and 6G networks, there is a rising energy consumption and an urgent need for EE optimization of 5G and 6G IoT communication systems.

In [32], the authors developed a Total Power Constraint Beamforming Scheme (TPC-BF) and a Per-Antenna Power Constraint Beamforming (PPC-BF) scheme to maximize EE with low complexity for UAV of Satellite-Aerial-Terrestrial Network (SATN). The emulation consequences presented that the devised method is practical. The imperfect Channel State

Information (CSI) scenario is not mentioned. In [33], the authors investigated Non-Orthogonal Multiple Access (NOMA) and Multi-Input Multi-Output (MIMO) techniques for Terahertz (THz) band communication underlaid ultra-high capacity networks. The results justify the enhanced K-means ML algorithm and distributed Alternating Direction Method of Multipliers (ADMM) algorithm to improve EE. Nevertheless, dynamic bandwidth is not figured out.

In [34], the authors designed integer linear programming models based on Long Range (LoRa) solutions to connect smart city devices for resource-constrained IoT networks intelligently. The emulation consequences prove that the

designed system minimizes the energy depletion of terminal nodes with reliability requirements. Nonetheless, the dynamic reconfiguration of nodes is not solved.

In [35], the authors focus on dynamic changes by introducing a distributed federated learning (DBFL) framework to avoid energy consumption via IoT mobile devices. The results of the simulation show that the proposed scheme achieved better performance with high accuracy and energy efficiency. Nevertheless, the proposed method is constrained by the limitations of computational complexity and model size.

In [36], the designed Asynchronous Advantage Actor Critic (A3C) algorithm optimized the DRL framework to satisfy the EE requirement of the 5G heterogeneous IIoT. The emulation consequences demonstrate that the designed DRL exceeds conventional DRL algorithms. However, real-time constrain is not considered. In [37], the authors utilized the Reinforcement Learning (RL) algorithm to develop a State Action Reward

State Action (SARSA) strategy to meet the network capacity constraint by reducing BS energy consumption for UDNs. The emulation consequences prove that BS's devised energy-saving evaluable model and sleep mode policies attain effective EE improvements. Nevertheless, mobile BS needs to be considered.

The EE performance improvement strategies are analyzed in this section. Several typical approaches are presented in this section to comprehensively investigate EE maximization in 5G and 6G communication systems. EE optimization based on ML and RL is generally defined as the main means of EE optimization of 5G and 6G IoT networks, which is proposed in [33], [36], [37]. Besides, BF [32], integer linear programming [34], and DBFL [35] are effective techniques for EE optimization of 5G and 6G IoT network [38]. The advantages and future directions of methods in EE performance optimization are described in Table III.

TABLE III
SUMMARY OF THE INVOLVED RESEARCH FOR EE OPTIMIZATION.

Subject	Methodologies	Advantages	Future Directions	Ref.
Maximize EE	TPC-BF and PPC-BF	It has low implementation complexity.	Imperfect CSI is not considered.	[32]
Maximize EE	Enhanced K-means ML and ADMM	Improve EE in the THz-NOMA-MIMO system.	Dynamic bandwidth is not considered.	[33]
Minimize energy consumption	Integer linear programming models	It is effective in resource-constrained scenarios.	Dynamic reconfiguration is not solved.	[34]
Dynamic change in the network to reduce energy consumption	DBFL framework	high accuracy and energy efficiency.	Limitation of computational complex and model size.	[35]
Meet EE requirement	A3C algorithm in DRL	Outperform traditional DRL	Real-time constrains are not considered.	[36]
Reduce energy consumption	SARSA based on RL	Considering QoS requirements	Mobile BS is not considered.	[37]

C. SPECTRUM EFFICIENCY

The purpose of SE is to maximize the spectrum utility while reducing the interference. SE has a big influence on IoT system performance[39]. Recently, numerous SE optimization solutions have been studied.

In [40], the authors provided a joint optimization strategy that considers spectrum sensing and spectrum utilization concurrently to improve MAC-layer sensing efficiency by developing a Weighted Huffman Tree (WHT) method in cognitive networks. It was demonstrated that the spectrum occupancy for IoT communication could be optimized by using the devised WHT algorithm. Nevertheless, the dynamic channel scenario is not considered.

In [41], the authors developed an exclusive-use spectrum access (DESA) strategy to optimize spectrum efficiency for dynamic mobile networks. Simulation results indicate that the proposed method offers more flexible solutions for sharing spectrum in IoT networks. Nonetheless, dynamic BS frameworks need to be considered.

In [42], the authors utilized a joint optimization method to maximize SE in Cooperative Power Beacon-Enabled Wireless Powered Communication Networks (CPB-WPCNs). The emulation consequences reveal that the devised Lagrange-Dual algorithm, Branch-Reduce-And-Bound (BRB) algorithm, and

distributed Successive Convex Approximation (SCA) algorithm are effective with low complexity. However, imperfect CSI fails to be considered.

In [43], the authors analyzed and optimized the sensing time to improve Spectrum Utilization Efficiency (SUE) with low interference constraint for Cognitive Radio (CR) systems. The emulation consequences reveal that the devised method attains improvements in the light of maximum SUE. Nonetheless, the dynamic spectrum scenario is not considered. In [44], the authors suggested a multi-objective whale algorithm and fuzzy integral algorithm to maximize spectrum throughput and interference detection probability to enhance SE in cognitive wireless networks. The emulation consequences justified that the devised approaches achieve SE optimization. Nevertheless, AI techniques are not applied to achieve more reliable results in practical scenarios. In [45], the authors explored two-layer Large-Scale Fading Decoding (LSFD) and closed-form Minorization-Maximization (MM) strategies to improve SE in Cell-Free (CF) massive MIMO system. The emulation consequences proved that the devised algorithms are effective under different transmit power and hardware impairment values scenarios. However, the multiple CPUs scenario needs more attention.

The SE performance improvement strategies are analyzed in this section. Several typical approaches are presented in this

section to comprehensively investigate SE maximization in 5G and 6G communication systems. SE optimization based on spectrum sensing is notably defined as the main means of SE optimization of 5G and 6G IoT networks, which is proposed in [40], [43]. In addition, DESA [41], SCA [42], Multi-objective

Whale Algorithm [44], LSFD, and MM [45], are effective techniques for SE optimization of 5G and 6G IoT networks. The advantages and future directions of methods in SE performance optimization are described in Table IV.

TABLE IV.
SUMMARY OF THE INVOLVED RESEARCH FOR SE OPTIMIZATION.

Subject	Methodologies	Advantages	Future Directions	Ref.
Optimize SE	WHT	Tradeoff spectrum sensing and spectrum utilization	Dynamic channel scenario is not considered.	[40]
Optimize SE for dynamic mobile networks	DESA	more flexible for sharing spectrum in actual IoT networks.	Dynamic BS frameworks need to be considered.	[41]
Maximize SE	Lagrange-dual, BRB, and SCA algorithm	Effective with low complexity	Imperfect CSI needs to be considered.	[42]
Maximize SUE	Optimize sensing time	Lower interference	Dynamic spectrum is not considered.	[43]
Improve SE	Multi-objective whale algorithm.	Low complexity. Fast convergence.	AI techniques need to be applied.	[44]
Improve SE	LSFD and MM	Effective in different transmit power and hardware.	Multiple CPUs scenarios needs more attention.	[45]

D. BANDWIDTH

Bandwidth in 5G and 6G communication systems decides data saving and management reliability. High bandwidth utility is good for optimizing data transmission efficiency and enhancing network performance. Hence, the Bandwidth Allocation (BA) strategy is a direction worthy of study.

In [46], the authors developed a Bee Colony Optimization (BO) algorithm with a Cross-Layer (CL) bandwidth framework to improve bandwidth efficiency for broadband satellite communication systems. The emulation consequences indicate that the devised method accomplishes better utility implementing beyond the currently optimal approach in the Adaptive Coding Modulation (ACM) scenario. In [47], the authors introduced a Deep Q-Network (DQN) strategy based on the DRL algorithm for optimizing BA for IoT devices in SDN. The emulation consequences demonstrated that the more optimal transmission bandwidth management could be achieved. Nonetheless, large traffic flows in 6G communication are not found. In [48], the authors identified a DBA concept for SDN-based analysis of the utilization of bandwidth methods while achieving energy saving. The emulation consequences reveal that the bandwidth potency of the SDN system can be improved by simultaneously enhancing resource utilization. However, the latency of switch nodes was not pondered. In [49], the authors formulated a conversion issue between a Passive Optical Network (PON) and a Local Area Network (LAN) to optimize BA. The emulation

consequences proved that the designed timeslots reused scheme outperform. Nevertheless, the complexity of the algorithm is not mentioned.

In [50], the authors utilized the Online Reinforcement Learning (ORL) algorithm to analyze the Dynamic Bandwidth Allocation (DBA) method toward improving the bandwidth decisions of dynamic networks. The results justify the devised ORL-DBA approach optimizes bandwidth decisions. However, simulation experiments were not sufficient for a stationary environment.

In [51], to cope varying channels in actual IoT networks, the authors proposed a joint optical wireless transport network architecture that integrates an Optical-Backhaul and Wireless Access (OBWA) network framework and a joint channel and route allocation (JCRA) strategy. Nonetheless, the method that has been proposed is constrained by a limited number of simulation packets.

The bandwidth performance improvement strategies are analyzed in this section. Several typical approaches are presented in this section to comprehensively investigate bandwidth maximization in 5G and 6G communication systems. In particular, bandwidth optimization based on DBA is defined as the main means of bandwidth optimization of 5G and 6G IoT networks, which is proposed in [46], [48], [50]. On the other side, DQN-DRL [47], timeslots reused [49], and JCRA [51] are effective techniques for bandwidth optimization of 5G and 6G IoT networks. The advantages and future directions of methods in bandwidth performance optimization are described in Table V.

TABLE V
SUMMARY OF THE INVOLVED RESEARCH FOR BANDWIDTH OPTIMIZATION.

Subject	Methodologies	Advantages	Future Directions	Ref.
Dynamic bandwidth optimization.	BO-CL-DBA.	Optimize bandwidth efficiency in dynamic scenarios.	New techniques need to be applied.	[46]
Optimize bandwidth management	DQN-DRL	Outperform in the light of output jitter and latency.	Large traffic flows are not considered.	[47]
Optimize bandwidth utilization.	DBA with SDN.	Improve bandwidth efficiency with resource	Latency is not considered.	[48]

		utilization optimization.		
Improve BA	Timeslots reused.	Outperform in the light of latency, throughput, and load balancing.	The complexity of the algorithm is not mentioned.	[49]
Optimize bandwidth decisions.	ORL-DBA.	Improve bandwidth decisions in changing scenarios.	Not for stable traffic scenarios.	[50]
cope varying channels in actual IoT networks	OBWA with JCRA	Optimize bandwidth efficiency in changing channels scenarios.	Need more simulation packets to verify.	[51]

E. RELIABILITY

The reliability of 5G and 6G IoT systems involves data processing time and task response time, which is a key performance indicator of network exception warning and solving. There is currently a big challenge to achieving the reliability requirement of 6G IoT systems, especially under multiple IoT device scenarios [52].

In [53], the authors investigated a reliability issue for IoT devices underlaid heterogeneous networks. Reliability optimization mode was utilized to determine the optimal security-reliability tradeoff indicators, considering two scenarios, instantaneous and statistical. The results justify the devised model to improve network performance for IoT devices. Nevertheless, interference is not considered in the devised scenario.

In [54], the authors exploited an anti-intracacy near-optimal method to optimize the packet loss probability and Base Station (BS) activation while considering cache size limitation for BSs energy consumption cost of Industrial Internet of Things (IIoT) networks. The emulation consequences prove that the devised Geometric Program (GP) concept and Modified Cluster Process (mCP) distributions are effective for reliability performance in heterogeneous networks. However, dynamic caching size is not mentioned.

In [55], the authors utilized the Light communication (LiFi) concept to meet high-reliability requirements in dynamic IoT networks. Simulation results indicate that the proposed Distributed MIMO (D-MIMO) topology could enhance reliability performance. Nonetheless, there are limited number of implementation examples to verify the proposed method.

In [56], the authors identified an IoT-aware Business Processes (BP) decentralization method to improve reliability.

The emulation consequences revealed that the devised Simulated Annealing (SA) algorithm attains partly improvements in the IoT device's communication scenario. Nevertheless, the risk probability of IoT systems needs to be considered.

In [57], the authors proposed a proactive recognition of plugging scenarios and cranking Proactive Handover (PHO) scheme that integrates ML and Computer Vision (CV) for high-frequency vehicle IoT. The emulation consequences showed that the designed object detection and localization (ODL) algorithm achieved blockage prediction to optimize reliability. Nonetheless, the devised method is not attained in low light and weather conditions.

In [58], the authors discussed the Fast Link Failure Recovery Routing (FastReRoute) scheme that can be managed at Software Defined Networking (SDN) to solve link failure problems. The emulation consequences indicated that the devised strategy can minimize the recovery time to achieve IoT network reliability. However, dynamic link parameters are not considered.

The reliability performance improvement strategies are analyzed in this section. Several typical approaches are presented in this section to comprehensively investigate reliability maximization in 5G and 6G communication systems. In particular, reliability optimization based on ML is defined as the main means of reliability optimization of 5G and 6G IoT networks, which is proposed in [54], [56], [57]. Other concepts, like reliability function [53], LiFi [55] and FastReRoute [58], are effective techniques for reliability optimization of 5G and 6G IoT networks. The advantages and future directions of methods in reliability performance optimization are described in Table VI.

TABLE VI
SUMMARY OF THE INVOLVED RESEARCH FOR RELIABILITY OPTIMIZATION.

Subject	Methodologies	Advantages	Future Directions	Ref.
Improve the reliability in heterogeneous IoT.	A security reliability tradeoff function.	Improve network performance.	Interference is not considered.	[53]
Optimize the reliability of IIoT	GP and MCP approach.	Joint optimization is effective.	Dynamic caching size is not mentioned.	[54]
Meet high-reliability requirement in dynamic IoT networks.	Distributed MIMO (D-MIMO) with LiFi.	Enhance reliability performance in mobile IoT device networks.	There are a limited number of implementation examples	[55]
Improve reliability.	SA algorithm.	Effective in IoT-aware BP system.	The risk probability of the IoT system needs to be considered.	[56]
Improve reliability in high-frequency scenarios.	PHO and ODL with ML and CV.	Achieve blockage detection and prediction.	The real natural environment is not tested.	[57]
Reduce packet loss.	FastReRoute	Obtain the IoT network reliability.	Dynamic link parameters are not considered.	[58]

F. RATE

High requests for high rates with long-distance transmission are put forward in 5G and 6G IoT communication systems. Achieving a higher data rate is one of the urgent targets for 6G IoT networks.

In [59], the authors discussed an Orthogonal Frequency Division Multiplexing (OFDM) based Simultaneous Wireless Information and Power Transfer (SWIPT) cooperative Decode and Forward (DF) relaying approach that can improve subcarriers and Power Allocation (PA) to optimize the sum transmission rate in 6G IoT networks. The emulation consequences showed that the devised algorithm offers an effective solution for IoT applications with high data rates. Nonetheless, more intelligent models need to be solved.

In [60], the authors utilized the Reconfigurable Intelligent Surfaces (RIS) technique to increase the rate of UAV systems. The consequences justify the devised RIS's passive BF improves rate performance in 6G IoT networks. However, uncertainty IoT devices environment, such as wind speed, is not considered.

In [61], the authors designed a DL-based adaptive Mode Switching (MS) concept to optimize the rate of a dual-mode SWIPT system. The emulation consequences indicate that the devised strategy can complete better rate performance under energy constraints. Nevertheless, interference and throughput performance need to be considered.

In [62], the authors developed a Proactive Online Power

Allocation (POPA) concept to analyze the Ergodic Sum Rate (ESR) maximum issue. The emulation consequences proved that the designed low-complexity bisection method achieves power optimization to maximize the sum rate in the IoT-NOMA network. However, multi-slot latency optimization needs to be considered.

In [63], the authors explored a SCA concept to gain better rate optimization. The emulation consequences demonstrate that the devised Power Line Communication Rate-Splitting Multiple Access (PLC-RSMA) algorithm outperforms the transmission rate in power IoT networks. Nonetheless, the multiple transmitter scenario is not mentioned.

In [64], the authors developed a mobile resource-sharing framework to improve the data rate for dynamic IoT devices of 6G mobile edge servers. The simulation results showed data rate of 6G IoT networks can be improved by applying EdgeGO framework. Nevertheless, algorithm complexity needs to be considered.

The rate performance improvement strategies are analyzed in this section. Several typical approaches are presented in this section to comprehensively investigate rate maximization in 5G and 6G communication systems. Rate optimization based on PA enhancement is defined as the main mean of rate optimization of 5G and 6G IoT networks, which is proposed in [59], [62], [63]. On the other hand, RIS [60], MS [61], and EdgeGO [64] are effective techniques for rate optimization of 5G and 6G IoT networks. The advantages and future directions of methods in rate performance optimization are described in Table VII.

TABLE VII
SUMMARY OF THE INVOLVED RESEARCH FOR RATE OPTIMIZATION.

Subject	Methodologies	Advantages	Future Directions	Ref.
Maximize transmission rate.	OFDM-based SWIPT.	Effective by improving subcarriers and PA	More intelligent models need to be solved.	[59]
Improve rate performance.	RIS's passive BF	Achieve a higher rate.	Uncertainty environment is not considered.	[60]
Achieve rate improvement.	DL-MS algorithm based on SWIPT.	Achieve a higher rate under energy constraints.	Interference and throughput are not considered.	[61]
Maximize the sum rate.	POPA algorithm	Effective under power constraint.	Multi-slot latency optimization needs to be considered.	[62]
Maximize transmission rate.	PLC-RSMA	More robust and better transmission rate than PLC-NOMA.	Multiple transmitter scenario is not mentioned.	[63]
Improve data rate for dynamic IoT devices	EdgeGO framework.	Effective for 6G mobile edge servers.	Algorithm complexity needs to be considered.	[64]

III. JOINT OPTIMIZATION STRATEGIES

With the development of 5G and 6G communication, a variety of IoT devices have popped up so there are many communication challenges for network resource-limited devices with 5G and 6G communication requirements. Various key performance parameters optimization approaches have been researched to improve IoT system performance. For now, there has been a lot of investigation on the resource optimization method for single indicators, such as latency optimization in Section A, EE optimization in Section B, SE optimization in Section C, bandwidth optimization in Section

D, reliability optimization in Section E, and rate optimization in Section F. However, the network demands of users often appear in multiple ways, so the impact of onefold performance indicator optimization on the overall network performance improvement is very restricted. This section analyzes joint optimization methods due to higher quality 5G and 6G IoT networks.

A. LATENCY

Overemphasizing latency may result in the deterioration of other performance metrics in 5G and 6G networks. For

example, reducing latency may lead to high energy consumption, low spectrum efficiency, low bandwidth utility, and low data transmission reliability; that is, latency minimum and optimal EE, SE, bandwidth, reliability, and rate are not available simultaneously. Hence, it is essential to investigate joint optimization strategies for multiple key performance parameters to achieve optimal performance of the whole communication network. Several indicators that are related to latency are shown in Fig.3. The joint optimization methods are illustrated in this section.

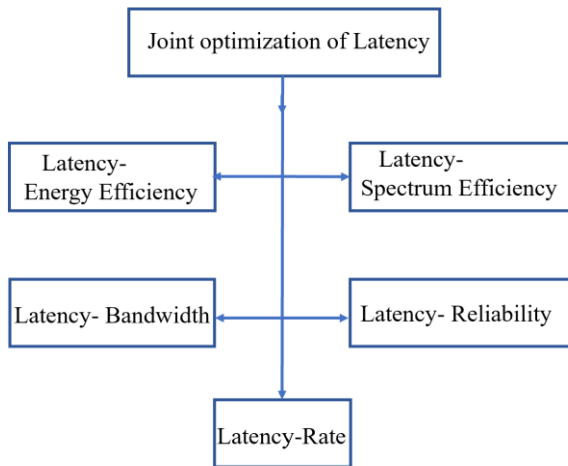


FIGURE 3. Tradeoff among key indicators.

1) LATENCY-ENERGY EFFICIENCY

In [65], the authors examined the EE optimization issue of IoT networks in a maritime scenario which is excessive traffic and limited resources. The emulation consequences show that the devised Joint Optimal Offloading Algorithm (JOOA) gains superior latency performance with energy consumption restrictions. However, the authors considered the lack of AI in the Maritime IoT network resource optimization.

In [66], the authors proposed a multi-user multi-task computation offloading model to lower the total latency of IoT networks and ensure EE for MEN. The emulation consequences showed the devised JPEG and MPEG4 compression strategies have superior performance in large-scale scenarios. Nonetheless, the mobile IoT devices' dynamic movement scenario was not considered.

In [67], the authors scheduled a Deep Deterministic Policy Gradient (DDPG) framework to reduce the energy consumption and computation time delay of IoT networks by

Dynamic Computation Offloading (DCO). The emulation consequences showed that the DDPG scheme is effective because of the actional first-rank unloading policies. Nonetheless, the energy harvesting of the devised model was not thought about.

In [68], the authors discussed a Multi-Access Edge Computing (MEC)-based Satellite-Terrestrial Integrated Networks (STINs) to balance energy dissipation and computing latency for services that have high requirements of computation and delay intermediately varying sorts of mobile devices in the 6G communication networks. The emulation consequences validate the efficacy of the devised scheme. Nevertheless, the collaboration of multiple Low Earth Orbit Satellites (LEOs) was not considered.

In [69], the authors developed a Multi-Player Multi-Armed Bandit (MP-MAB) algorithm to improve latency and energy consumption for MEC-In-A-Box (M-box) devices of 5G vehicular networks. The emulation consequences verified the energy-latency tradeoff is achieved. However, dynamic vehicular traffic distribution is not considered.

To achieve a low latency and high EE communication network, numerous effective optimization strategies for optimizing latency and EE simultaneously for 5G and 6G IoT communication systems have been given in this section [65], [66], [67], [68], [69]. The five papers explore strategies to optimize EE and reduce latency in various IoT network scenarios. [65] focuses on maritime IoT networks and proposes a JOOA to enhance latency performance while considering energy consumption constraints. [66] introduces a multi-user multi-task computation offloading model for MEN, showcasing superior performance in large-scale scenarios but lacking consideration for dynamic device movement. [67] utilizes a DDPG framework for DCO in IoT networks, effectively reducing energy consumption and computation time delay but overlooking energy harvesting. [68] discusses MEC-based STINs to balance energy dissipation and computing latency in 6G networks, emphasizing scheme efficacy while neglecting LEO satellite collaboration. Finally, [69] presents an MP-MAB algorithm for M-box devices in 5G vehicular networks, achieving an energy-latency tradeoff but overlooking dynamic vehicular traffic distribution. While each paper contributes valuable insights, holistic approaches considering dynamic network conditions and diverse IoT applications are needed. The advantages and limitations of methods in latency and EE joint optimization are summarized in Table VIII.

TABLE VIII.

SUMMARY OF THE RELATED WORK FOR LATENCY AND ENERGY EFFICIENCY TRADEOFF.

Issue	Methodologies	Advantages	Limitations	Ref.
Latency-energy efficiency	JOOA strategy	Good for multiple computing tasks.	No AI technology application.	[65]
	JPEG and MPEG4 compression algorithms.	EE-Latency tradeoff in the large-scale scenario.	Not for dynamically mobile IoT users.	[66]
	DCO with DDPG framework.	Low computation latency and energy consumption	No energy harvesting considered	[67]
	Multi-layer MEC technology	Minimize energy dissipation with low computing latency	Not for multi-LEO scenario	[68]
	MP-MAB algorithm	It is effective in a distributed and autonomous way.	Dynamic vehicular traffic distribution is not considered	[69]

2) LATENCY-SPECTRUM EFFICIENCY

In [70], the RL method operates on the centralized self-organizing spectrum optimization in the low latency of vehicle IoT. It was revealed that the devised approach provides better property improvements in spectrum utilization and latency. However, the dynamic rates of IoT devices were not thought about.

In [71], the authors preferred an RL concept that integrates Q-learning and DNN into a unified strategy to analyze scarce spectrum issues to minimize latency for 5G mobile networks. The emulation consequences demonstrated that the scarce-spectrum constraints for real-time communication could be achieved by applying the devised approach. Nevertheless, the overload spectrum resources scenario needs to be considered.

In [72], the authors designed a Sub-band Random Sensing (SRS) grant-free uplink strategy to improve spectrum sensing performance under latency requirements for URLLC networks. The emulation consequences showed that the devised algorithm outperformance in terms of collision probability. However, more realistic scenarios need to be considered.

To achieve a low latency and high SE communication network, numerous effective optimization strategies for optimizing latency and SE simultaneously for 5G and 6G IoT communication systems has been given in this section [70], [71], [72]. The three papers explore different methodologies to optimize spectrum utilization and minimize latency in various networking contexts. [70] utilizes a RL-based approach for centralized spectrum optimization in vehicle IoT, yielding improvements in both spectrum utilization and latency, albeit without accounting for dynamic IoT device rates. In contrast, [71] integrates RL, Q-learning, and DNN to address spectrum scarcity in 5G networks, successfully minimizing latency but neglecting considerations for overloaded spectrum resources. Meanwhile, [72] introduces a SRS strategy for URLLC networks, enhancing spectrum sensing performance but lacking realism in scenario representation. Despite their individual contributions, addressing overlooked factors like dynamic IoT device rates and realistic network scenarios would further bolster the practical applicability of these approaches. The advantages and limitations of methods in latency and SE joint optimization are summarized in Table IX.

TABLE IX.

SUMMARY OF THE RELATED WORK FOR LATENCY AND SPECTRUM EFFICIENCY TRADEOFF.

Issue	Methodologies	Advantages	Limitations	Ref.
Latency-spectrum efficiency	RL with centralized self-organizing spectrum optimization	Better performance improvements in spectrum utilization, and latency	Not for dynamic rates scenario	[70]
	RL with Q-learning and DNN.	Reduce latency with insufficient spectrum resources.	No network resources overloaded scenario.	[71]
	SRS grant free uplink.	Lower collision probability.	Not for realistic scenarios.	[72]

3) LATENCY-BANDWIDTH

In [73], the authors developed an Opera approach to achieve time-varying expander graphs to satisfy low-latency and high-bandwidth requirements. The simulation result showed that the devised method gains more rapid reconfiguration without network status and circuit scheduling limitations. Nonetheless, method complexity is not mentioned.

In [74], the authors proposed a Particle Swarm Optimization (PSO) based request allocation approach that integrates bandwidth utilization and latency restraint into a joint optimization strategy for large-scale scenarios. The emulation consequences prove that the designed algorithm improves bandwidth utilization with an average latency requirement. However, stochastic requests are not considered.

In [75], the authors discussed an optimal bandwidth-sharing strategy to improve latency performance for MEN devices. The emulation consequences demonstrate that the designed Fast Converging Iterative Bandwidth Allocation (FCI-BA) algorithm could be effective in resource-constrained edge networks. Nonetheless, devices selected to achieve lower latency need to be considered.

In [76], the authors formulated a latency minimum issue of 10-Gigabit-Capable PON architecture in 5G to develop Immediate Allocation with Colorless Grant DBA (IACG-DBA) and Cooperation DBA (CO-DBA) algorithm. The emulation consequences indicate that the devised status and systems effectively decrease latency. Nevertheless, the complexity of the method has not been mentioned in detail.

In [77], the authors designed an Evolutionary Game (EG) architecture to optimize bandwidth efficiency for cutting down the latency in FL networks. The emulation consequences justify that the devised EGBA concept make latency minimum of FL service, however, interference needs to be considered.

To achieve a low latency and high bandwidth utilization communication network, numerous effective optimization strategies for optimizing latency and bandwidth simultaneously for 5G and 6G IoT communication systems have been given in this section [73], [74], [75], [76], [77]. The five papers present diverse methodologies to improve latency and bandwidth efficiency in different networking scenarios. While [73] focuses on achieving rapid reconfiguration through time-varying expander graphs and [74] employs Particle Swarm Optimization for bandwidth utilization optimization, [75] discusses optimal bandwidth-sharing strategies for resource-constrained networks. Additionally, [76] introduces algorithms for latency minimization in PON architecture, and [77] presents an Evolutionary Game architecture for bandwidth efficiency in FL networks. Although each paper demonstrates promising results in their respective domains, common limitations include overlooking stochastic requests, device selection for latency optimization, interference considerations, and method complexity. Addressing these limitations would enhance the practical applicability and effectiveness of the proposed methodologies. The advantages and limitations of methods in latency and bandwidth joint optimization are summarized in Table X.

TABLE X.
SUMMARY OF THE RELATED WORK FOR LATENCY AND BANDWIDTH TRADEOFF.

Issue	Methodologies	Advantages	Limitations	Ref.
Latency- bandwidth	Opera approach	Achieve high bandwidth and low latency for static and dynamic topologies.	Method complexity is not mentioned.	[73]
	PSO	Effective	Stochastic requests are not considered.	[74]
	FCI-BA	Effective in resource-constrained edge network	The devices selected need to be considered.	[75]
	IACG-DBA and CO-DBA algorithms.	Effective in both fronthaul traffic and non-fronthaul traffic scenario.	Method complexity is not mentioned.	[76]
	EG-based DBA algorithm.	Consider the dynamic users of FL service under an insufficient information scenario.	Interference needs to be considered.	[77]

4) LATENCY-RELIABILITY

In [78], the authors discussed massive MIMO, multi-connectivity, source-channel coding, and protocol design techniques in 5G wireless systems of URLLC. The emulation consequences satisfy the latency and reliability requirements for end-to-end communication. Nevertheless, increasing energy consumption requires attention and consideration when the reliability is improved.

In [79], the authors discussed an energy-aware task optimization strategy of Intelligent Transportation Systems (ITS) in the edge computing scenario of Ultra Reliable Low Latency Communications (URLLC) over cloud networks. The research consequences of the emulation revealed the importance of choosing optimal computation nodes to boost the network's property in the latency and reliability scenario limitation. Nevertheless, the dynamic status of factors was not thought about.

In [80], the authors suggested a mathematical model for the URLLC of IIoT communication. The emulation consequences demonstrated the devised approach can satisfy the URLLC service requirements. However, the dynamic number of transmission attempts in the devised method was not thought about.

In [81], the authors proposed a CMDP algorithm to analyze variable-length Finite-Blocklength Coding (FBC) to improve latency and reliability for URLLC. The emulation consequences showed that the designed Frequency-Domain Variable-Length Finite-Blocklength Coding (FD-VLFBC) and Time-Domain VLFBC (TD-VLFBC) achieve better latency-reliability tradeoff. Nevertheless, dynamic bandwidth and channel interference are not considered.

In [82], the authors used FBC in the high Signal-To-Noise Ratio (SNR) method to improve the latency and error

feasibility performance for time-sensitive devices in the resource limitations scenarios of multiple antenna communication. The emulation consequences showed that the devised linear gain conservation equation strategy achieves a latency-reliability tradeoff. However, power efficiency was not thought about.

In [83], the authors proposed three key performance indicators of latency-reliability tradeoff and developed a function placement strategy to enhance the latency and reliability performance in edge clouds scenarios. The emulation consequences demonstrate that the devised tunable greedy concept improves the latency-reliability tradeoff performance for mobile edge networks. Nonetheless, the dynamic server availability scenario is not mentioned.

To achieve a low latency and high-reliability communication network, numerous effective optimization strategies for optimizing latency and reliability simultaneously for 5G and 6G IoT communication systems have been given in this section [78], [79], [80], [81], [82], [83]. The six papers collectively explore various methodologies to enhance latency and reliability performance in URLLC scenarios. While each paper presents distinct approaches, such as massive MIMO and multi-connectivity, energy-aware task optimization, mathematical modeling, coding algorithms, and function placement strategies, they all aim to improve the efficiency of URLLC systems. However, common limitations include overseeing dynamic factors like bandwidth allocation, channel interference, and server availability, which are crucial for optimizing real-world URLLC deployments. Addressing these dynamic aspects would enhance the practical applicability and effectiveness of the proposed methods in URLLC scenarios. The advantages and limitations of methods in latency and reliability joint optimization are summarized in Table XI.

TABLE XI.
SUMMARY OF THE RELATED WORK FOR LATENCY AND RELIABILITY TRADEOFF.

Issue	Methodologies	Advantages	Limitations	Ref.
Latency- reliability	Massive MIMO and multi-connectivity techniques.	Meet requirements of reliability and latency in URLLC	Energy consumption increasing.	[78]
	Energy-aware task optimization strategy	Achieve optimal computation nodes by choosing	No dynamic status of factors attention.	[79]
	Connection-less radio access model	Effective tradeoff between latency and reliability.	No dynamic transmission is considered.	[80]
	CMDP	Effective for single and multiple users' scenarios.	No dynamic characteristics are considered.	[81]

FBC	Adapt to high SNR with time-sensitive scenario	No power efficiency is considered.	[82]
Function placement strategy	Achieve latency-reliability tradeoff	No dynamic server scenario is mentioned.	[83]

5) LATENCY-RATE

In [84], the M-parallel look-ahead pointers generation algorithm was implemented to optimize rate matching and reduce the overall latency of the 5G New Radio (NR) system. The emulation consequences reveal that the devised strategy gains better results with a high transmission rate. However, dynamic bandwidth is not mentioned.

In [85], the authors investigate the latency minimum of NOMA users with a link-layer rate maximum. The consequences revealed that latency and rate demand for URLLC systems could be accomplished by applying Monte-Carlo simulations. Nonetheless, dynamic channels need to be considered.

In [86], optimal linear precoders are used in block lengths minimum strategy to reduce latency with a high transmission rate. Emulation consequences demonstrate that the Rate-Splitting Multiple Access (RSMA) method attains significant performance improvements in the URLLC system. Nevertheless, imperfect CSI needs to be considered.

To achieve a low latency and high rate communication network, numerous effective optimization strategies for optimizing latency and rate simultaneously for 5G and 6G IoT communication systems have been given in this section [84], [85], [86]. The three papers collectively aim to address latency issues in wireless communication systems, each employing distinct techniques. The study in [84] uses the M-parallel look-ahead pointers generation algorithm to optimize rate matching and reduce 5G NR system latency. Meanwhile, [85] investigates achieving latency minimum for NOMA users, and [86] utilizes optimal linear precoders to minimize latency, particularly for URLLC systems. While all papers demonstrate improvements in latency-related metrics, they share common limitations such as overlooking dynamic bandwidth, dynamic channels, and imperfect CSI. Improving these aspects would boost the practical usefulness and efficiency of the proposed methods in real-world communication scenarios. The advantages and limitations of methods in latency and rate joint optimization are summarized in Table XII.

TABLE XII.
SUMMARY OF THE RELATED WORK FOR LATENCY AND RATE TRADEOFF.

Issue	Methodologies	Advantages	Limitations	Ref.
Latency-rate	M-parallel look-ahead pointers generation algorithm	Improve the rate matching and reduce the overall latency	No dynamic bandwidth mentioned	[84]
	Monte-Carlo simulations	Achieve the latency and rate requirements	No dynamic channels considered	[85]
	Optimal linear precoders	Reduce latency with a high transmission rate	Not for an imperfect CSI scenario	[86]

B. ENERGY EFFICIENCY

Exclusively prioritizing EE may lead to a decline in other performance indicators across 5G and 6G networks. For example, enhancing EE may lead to low spectrum efficiency, low bandwidth utility, low reliability of data transmission, and

low transmission rate, that is, EE maximum and optimal SE, bandwidth, and reliability is not available simultaneously. Hence, it is indispensable to investigate joint optimization strategies for multiple key performance parameters to achieve optimal performance of the whole communication network. Several indicators that are related to EE are shown in Fig.4. The joint optimization methods are illustrated in this section.

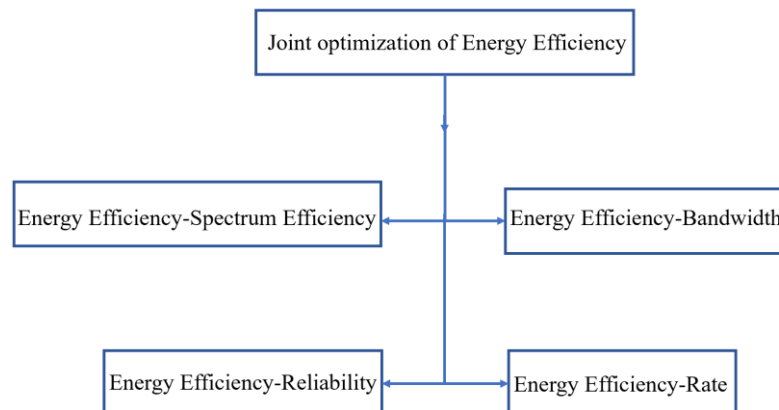


FIGURE 4. Tradeoff among key indicators.

1) ENERGY EFFICIENCY-SPECTRUM EFFICIENCY

In [87], the authors investigated the SE and EE problem by using Co-Operative Spectrum Sensing (CSS) for CR networks of future wireless networks. The emulation consequences demonstrate that the formulation strategy could solve the conflicts between SE and EE. Nonetheless, the SE-EE tradeoff for multiple links needs to be considered.

The authors formulated the utility function to tackle the issue of EE-SE tradeoff by considering channel allocation and power control in heterogeneous networks [88]. They evaluated the effectiveness and convergence of the devised algorithms based on a properly chosen EE-SE tradeoff factor. Whereas, latency was not thought about.

In [89], the authors formulated a Mixed Integer Nonlinear Programming (MINLP) issue to balance EE and SE for CR networks in IoT scenarios in which the spectrum resource is scarce. The consequences revealed that a modified EE-SE tradeoff measure exceeded the Data Rate Requirements (FDR) approach in the light of model validity and polynomial intricacy. Nonetheless, the transmission latency of CR-based IoT networks is not considered.

In [90], the authors proposed a 3rd dimension (3D) Vehicle-To-Vehicle (V2V) channel model to optimize the EE-SE balancing based on cognitive satellite-vehicular systems to connect smart vehicle systems intelligently. The simulation

factor of proposed schemes could easily accommodate three varying Vehicular Traffic Density (VTD) scenarios, where there are different priority levels of EE and SE. Nonetheless, minimizing latency needs to be considered.

In [91], the authors investigated a sparse RIS-aided CF MIMO framework to balance SE and EE by using the Dinkelbach method. The devised mechanism achieved a tradeoff. Nevertheless, the latency and reliability of the networks were not considered.

To achieve a high EE and high SE communication network, numerous effective optimization strategies for optimizing EE and SE simultaneously for 5G and 6G IoT communication systems have been given in this section [87], [88], [89], [90], [91]. The five papers explore strategies to balance SE and EE in wireless networks, each proposing distinct approaches tailored to specific network scenarios. Papers [87], [88], [89], [90], and [91] address this challenge through CSS, utility function formulation, MINLP, 3D channel modeling, and sparse RIS-aided CF MIMO frameworks, respectively. While the papers demonstrate effectiveness in achieving the SE-EE tradeoff, common limitations include overlooking factors such as latency, reliability, and transmission delays. Enhancing these elements would increase the practical relevance and efficacy of the proposed methods. The advantages and limitations of methods in EE and SE joint optimization are described in Table XIII.

TABLE XIII
SUMMARY OF THE RELATED WORK FOR EE AND SPECTRUM EFFICIENCY TRADEOFF.

Issue	Methodologies	Advantages	Limitations	Ref.
Energy efficiency-spectrum efficiency	Optimize sensing duration in CSS	Solve the conflicts between SE and EE.	Not multiple links are considered	[87]
	Optimize spectrum utility	Good function convergence	No latency is considered.	[88]
	MINLP	Maximize energy and spectrum supplement	No transmission latency is considered.	[89]
	3D V2V channel model	Adapt to different VTD scenarios	Latency is not considered.	[90]
	Precoding and RIS phase shift optimization	For different EE-SE compromise requirements	No latency and reliability are considered.	[91]

2) ENERGY EFFICIENCY-BANDWIDTH

In [92], the joint optimization problem of energy efficiency in Wireless Local Area Network (WLAN) and ZigBee-based Wireless Sensor Network (WSN) with bandwidth optimization has been investigated. The energy-efficient prioritized bandwidth resource allocation approach was demonstrated to improve energy consumption, downlink data speed, and bandwidth resource allocation. However, interference in real circuits is not considered. In [93], the authors developed bandwidth and power cost-optimized Medium Access Control (MAC) protocols to grow the energy efficiency of IoT networks. The emulation consequences showed that the devised Restricted Client Position Aware Single Point of Communication Oriented Intelligent Clustering (RCPA-SPC-O-IC) protocol improved bandwidth utilization and reduced energy consumption. Nevertheless, the dynamic IoT devices scenario is not considered. In [94], the author proposed a False Alarm-based bandwidth allocation design that coupled spectrum sensing, and bandwidth allocation with energy consumption mergers. Emulation consequences reveal that the

devised strategy can gain a balancing of bandwidth utility and EE. Nevertheless, dynamic bandwidth optimization needs to be considered.

To achieve a high EE and high bandwidth utilization communication network, numerous effective optimization strategies for optimizing EE and bandwidth simultaneously for 5G and 6G IoT communication systems has been given in this section [92], [93], [94]. The three papers explore strategies to enhance energy efficiency in wireless networks, each focusing on distinct aspects such as joint optimization of energy efficiency and bandwidth allocation in WLAN and ZigBee-based WSNs [92], development of energy-efficient MAC protocols for IoT networks [93], and proposing a False Alarm-based bandwidth allocation design coupled with spectrum sensing for energy-efficient bandwidth allocation [94]. While the papers demonstrate improvements in energy consumption and bandwidth utilization, they commonly overlook dynamic factors such as interference, dynamic IoT devices, and dynamic bandwidth optimization. Addressing these considerations would amplify the practical utility and impact of the proposed

methods in real-world communication settings. The advantages and limitations of methods in EE and bandwidth joint

optimization are described in Table XIV.

TABLE XIV
SUMMARY OF THE RELATED WORK FOR EE AND BANDWIDTH TRADEOFF.

Issue	Methodologies	Advantages	Limitations	Ref.
Energy efficiency-bandwidth	Energy efficient prioritized bandwidth resource allocation	Minimize energy consumption with bandwidth resource optimization	No interference considered	[92]
	RCPA-SPC-O-IC	Obtain the least energy consumption and highest bandwidth utilization	Not for dynamic devices	[93]
	False Alarm-based bandwidth allocation scheme	Achieve balancing of EE and bandwidth utility	Not for dynamic bandwidth	[94]

3) ENERGY EFFICIENCY -RELIABILITY

In [95], the author identified reliability optimizing for dense IoT scenarios in Low-Power Wide Area Networks (LP-WANs). The results demonstrated that the low interference and high-reliability requirements with low energy consumption could be achieved by applying the Choir approach which solves signals colliding. Nevertheless, dynamic interference and stochastic signals collide and need more attention and consideration.

In [96], they utilized the continuity of signal frequency concept to analyze interference-removing methods performed together efficiently. Emulation consequences demonstrate that the FTrack, a parallel decoding method, improves reliability performance in LP-WANs. Nevertheless, bandwidth needs to be considered to optimize the capability of FTrack transmission. In [97], a mixed integer linear programming (MILP) pattern is used to improve the reliability of IoT networks with EE constraints. The emulation consequences revealed that the devised standby routes selection scheme (SBRS), desired reliability level scheme (DRLS), reliability-based sub-channel scheme (RBS), and reliability-based data compression scheme (RBDS) have better performance in the case of EE and reliability. However, the storage capability needs to be

attention.

To achieve a high EE and high-reliability communication network, numerous effective optimization strategies for optimizing EE and reliability simultaneously for 5G and 6G IoT communication systems has been given in this section [95], [96], [97]. The three papers investigate methods to enhance reliability in IoT networks, addressing different aspects of the challenge. Paper [95] focuses on interference mitigation and reliability optimization in dense IoT scenarios using the Choir approach, while [96] analyzes interference-removing methods, particularly the FTrack parallel decoding method. On the other hand, [97] employs mixed integer linear programming to improve reliability with energy efficiency constraints, incorporating schemes such as standby routes selection and reliability-based data compression. While all papers demonstrate improvements in reliability and energy efficiency, common limitations include overlooking dynamic factors such as interference and stochastic signal collisions that need considerations regarding bandwidth optimization and storage capability. Rectifying these factors would elevate the practical feasibility and performance of the proposed methods in real-world IoT environments. The advantages and limitations of methods in EE and reliability joint optimization are described in Table XV.

TABLE XV
SUMMARY OF THE RELATED WORK FOR EE AND RELIABILITY TRADEOFF.

Issue	Methodologies	Advantages	Limitations	Ref.
Energy efficiency - reliability	Choir	Achieve reliability with low energy consumption	Not for dynamic interference	[95]
	Ftrack	Remove interference	No bandwidth considered	[96]
	MILP	Ensure energy efficiency and reliability	No capability considered	[97]

4) ENERGY EFFICIENCY -RATE

In [98], the authors evaluated the energy efficiency, data rate, and transmit power integrated 5G IoT networks. The results justify that the devised retransmission scheme improves energy efficiency for adaptive data rate in IoT systems. Nevertheless, interference was not thought about.

In [99], they utilized three optimization approaches to improve rate, energy efficiency, and reduce energy consumption in Narrowband (NB) IoT. The emulation consequences prove that the received power enhancement strategy offers more effective solutions in light of data rates and EE. Nevertheless, dynamic bandwidth was not thought about.

In [100], to improve the communication performance in terms of transmission rate and energy efficiency, the authors

suggested a UAV-assisted data collection multi-objective optimization problem (UAVDCMOP) and used an improved multi-objective grey wolf-based optimization (IMOGWO) algorithm to optimize rate and EE. Emulation consequences indicate that the devised strategy can optimize EE and rate performance. Nevertheless, multi-UAV systems need to be considered.

To achieve a high EE and high rate communication network, numerous effective optimization strategies for optimizing EE and rate simultaneously for 5G and 6G IoT communication systems has been given in this section [98], [99], [100]. The three papers investigate methods to enhance energy efficiency and data rate in IoT networks, each focusing on distinct approaches and techniques. Paper [98] evaluates the

integration of 5G IoT networks, proposing a retransmission scheme to improve energy efficiency. [99] utilizes optimization approaches for NB IoT, mainly focusing on received power enhancement strategies. Meanwhile, [100] suggests a UAV-assisted optimization problem to optimize energy efficiency and data rate. While all papers demonstrate improvements in energy efficiency and data rate, they commonly overlook

dynamic factors such as interference, dynamic bandwidth, and delay for considerations for multi-UAV systems. Attending to these factors would strengthen the practical implementation and success of the proposed methods in real-world communication applications. Table XVI describes the advantages and limitations of EE and rate joint optimization methods.

TABLE XVI
SUMMARY OF THE RELATED WORK FOR EE AND RATE TRADEOFF.

Issue	Methodologies	Advantages	Limitations	Ref.
Energy efficiency -rate	Retransmission scheme	Improves energy efficiency for adaptive data rate	No interference considered	[98]
	Received power enhancement strategy	Effective in light of data rates and EE	No dynamic bandwidth considered	[99]
	UAVDCMOP and IMOGWO	Improve rate and EE performance	Not for multi-UAV systems	[100]

C. SPECTRUM EFFICIENCY

Singularly focusing on SE could cause a compromise in other performance parameters within 5G and 6G networks. For example, enhancing SE may lead to low bandwidth utility, low reliability of data transmission, and low transmission rate, that is, SE maximum and optimal bandwidth, reliability, and rate are not available at the same time. Hence, it is necessary to investigate joint optimization strategies for multiple key performance parameters to achieve optimal performance of the whole communication network. Several indicators that are related to SE are shown in Fig.5. The joint optimization methods for SE and other indicators are illustrated in this section.

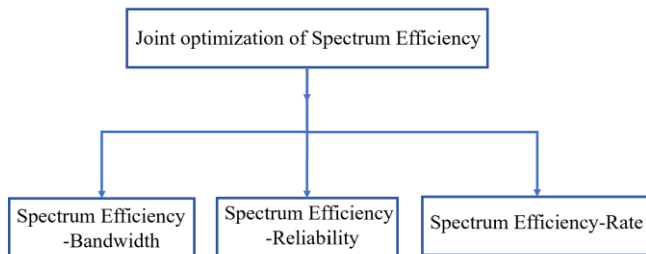


FIGURE 5. Tradeoff among key indicators.

1) Spectrum Efficiency-Bandwidth

In [101], a spectrum and bandwidth efficiency problem is formulated for spectrum and system band-sharing architecture to optimize spectrum management based on Licensed Spectrum Access (LSA). The emulation consequences revealed that the devised approach has improved SE and bandwidth efficiency with user equipment (UEs) fairness. Nevertheless, a

lower-cost model was not thought about. In [102], the authors showed an adaptive bandwidth control method to enhance spectrum utilization of multi-band IoT networks. The emulation consequences reveal that SE could be improved in spectrum-sharing systems. Nonetheless, latency and reliability are not considered. In [103], they discussed the spectrum resource evaluation scheme to improve spectrum utility and bandwidth optimization. The consequences of the emulation reveal that the devised modified lowest fragmentation fit dynamic bandwidth allocation (LFF-DBA) algorithm achieves outstanding overall performance with a low blocking rate. However, latency needs more attention.

To achieve a high SE and high bandwidth utilization communication network, numerous effective optimization strategies for optimizing SE and bandwidth simultaneously for 5G and 6G IoT communication systems have been given in this section [101], [102], [103]. The three papers explore methods to optimize spectrum efficiency and bandwidth utilization in wireless networks, each focusing on distinct approaches. Paper [101] formulates a spectrum and bandwidth efficiency problem for spectrum and system band-sharing architecture, demonstrating improved spectrum efficiency and bandwidth utilization with fairness for UEs. In contrast, [102] proposes an adaptive bandwidth control method for multi-band IoT networks, showcasing enhanced spectrum utilization. Meanwhile, [103] discusses a spectrum resource evaluation scheme, particularly emphasizing the modified LFF-DBA algorithm, which achieves outstanding overall performance with low blocking rates. However, common limitations across the papers include overlooking dynamic factors such as latency and reliability for cost-effectiveness considerations. The advantages and limitations of methods in SE and bandwidth joint optimization are proposed in Table XVII.

TABLE XVII
SUMMARY OF THE RELATED WORK FOR SE AND BANDWIDTH TRADEOFF.

Issue	Methodologies	Advantages	Limitations	Ref.
Spectrum efficiency-bandwidth	LSA	Higher SE and bandwidth efficiency with UE fairness	High-cost model	[101]
	Adaptive control method	Enhance SE in spectrum sharing	No latency and reliability considered	[102]
	LFF-DBA	Lower blocking rate.	No latency considered	[103]

2) Spectrum Efficiency-Reliability

In [104], a heuristic algorithm is modeled as a link reliability problem that is constrained by SE requirements in vehicular IoT communication. The emulation consequences revealed that in comparison with the Greedy algorithm, Random algorithm, and AutoReuse algorithm, the devised system has improved SE and link reliability performance. However, latency is not considered.

For a network utilizing out-of-band spectrum technique, [105] explored the link reliability concerning sharing spectrum. Emulation consequences reveal that the spectrum access system gains valid improvements in the light of SE and link reliability by using customer premise equipment (CPE) attachment and registration method. Nonetheless, EE is not mentioned. In [106], they introduced a spectrum reservation method for optimizing spectrum availability and block probability (BP). It was demonstrated that the dynamic spectrum reservation (DSR) algorithm improves SE and network reliability performance. Nevertheless, EE needs more attention. To achieve a high SE and high-reliability communication network, numerous effective optimization strategies for optimizing SE and reliability simultaneously for

5G and 6G IoT communication systems has been given in this section [104], [105], [106]. The three papers investigate methods to enhance various aspects of wireless communication networks, each focusing on distinct approaches. Paper [104] introduces a heuristic algorithm to improve SE and link reliability in vehicular IoT communication, demonstrating superior performance compared to other algorithms. In contrast, [105] explores link reliability in networks utilizing out-of-band spectrum techniques, highlighting SE and link reliability improvements through spectrum access system enhancements. Meanwhile, [106] proposes a spectrum reservation method to optimize spectrum availability and block probability, showcasing SE and network reliability enhancements. However, common limitations across the papers include overlooking dynamic factors such as latency and energy efficiency, which need further EE considerations. Improving these aspects would boost the practical usefulness and efficiency of the proposed methods in real-world communication scenarios. The advantages and limitations of methods in SE and reliability joint optimization are described in Table XVIII.

TABLE XVIII
SUMMARY OF THE RELATED WORK FOR SE AND RELIABILITY TRADEOFF.

Issue	Methodologies	Advantages	Limitations	Ref.
Spectrum efficiency-reliability	A heuristic algorithm	Better se and link reliability performance	No latency considered	[104]
	CPE attachment and registration	Improve SE and reliability performance	No EE considered	[105]
	DSR	Improve SE and reliability	No EE considered	[106]

3) SPECTRUM EFFICIENCY-RATE

In [107], they formulated a joint optimization issue of spectrum efficiency, decoding speed, and computational complexity to improve the bit rate in a spread spectrum communication system. The emulation consequences prove that the designed orthogonal convolutional codes method offers a lower bit error rate (BER). Nonetheless, dynamic coding lengths need more attention.

In [108], the NOMA, cooperative NOMA, and SWIPT methods optimized the data transmission rate to satisfy the high-speed requirement of 5G and 6G networks with the spectrum limitations of IoT devices. The consequences revealed that the rate and SE necessities for 5G IoT systems can be accomplished by applying SWIPT NOMA approaches. Nevertheless, EE needs to be considered. In [109], the author investigated SE and Average Sum Rate (ASR) optimizing for IoT devices (IoTDs). The emulation consequences prove that the designed IoT Gateway (IoT-GW) strategy offers superior solutions for the application of SE-rate balance in IoT network. Nevertheless, multi-IoTDs and IoT-GW needs more attention. To achieve a high SE and high rate communication network, numerous effective optimization strategies for optimizing SE and rate simultaneously for 5G and 6G IoT communication systems has been given in this section [107], [108], [109].

The three papers investigate distinct approaches to enhance

communication systems, targeting various aspects such as spectrum efficiency, data transmission rate, and ASR optimization for IoT devices. Paper [107] focuses on improving bit rate in spread spectrum communication systems by formulating a joint optimization problem and utilizing orthogonal convolutional codes, while [108] explores NOMA and SWIPT methods to optimize data transmission rate for 5G IoT systems, emphasizing the efficacy of SWIPT NOMA approaches.

On the other hand, [109] investigates spectrum efficiency and ASR optimization for IoT devices, proposing an IoT-GW strategy. However, common limitations across the papers include overlooking dynamic factors such as dynamic coding lengths and energy efficiency considerations, which need further consideration regarding multi-IoTDs and IoT-GW. Addressing these factors would be vital for ensuring practical applicability and effectiveness. The advantages and limitations of methods in SE and rate joint optimization are described in Table XIX.

TABLE XIX
SUMMARY OF THE RELATED WORK FOR SE AND RATE TRADEOFF.

Issue	Methodologies	Advantages	Limitations	Ref.
Spectrum efficiency-rate	Orthogonal convolutional codes	Lower BER	No dynamic coding lengths considered	[107]
	SWIPT NOMA	Achieve high-speed transmission with SE	No EE considered	[108]
	IoT-GW strategy	Achieve SE-rate balance	Not for multi-IoTDs and IoT-GW	[109]

D. BANDWIDTH

Placing excessive emphasis on Bandwidth might overshadow the performance of other metrics in both 5G and 6G networks. For example, enhancing bandwidth utility may lead to low reliability of data transmission and low transmission rate, that is, bandwidth efficiency and optimal reliability, and rate is not available at the same time. Hence, it is necessary to investigate joint optimization strategies for multiple key performance parameters to achieve optimal performance for the whole communication network. Several indicators that are related to bandwidth are shown in Fig.6. The joint optimization methods for bandwidth and other indicators are illustrated in this section.

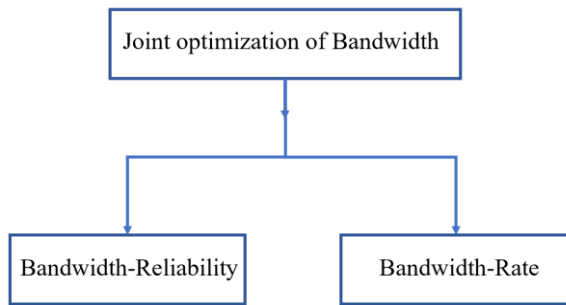


FIGURE 6. Tradeoff among key indicators.

1) BANDWIDTH-RELIABILITY

In [110], low-density parity-check (LDPC) models accomplish low repair bandwidth and high reliability. Emulation consequences reveal that the minimum repair bandwidth concept improves reliability compared to the current Reed-Solomon codes method. Nonetheless, reducing latency needs more attention.

In [111], the authors evaluated the reliability and bandwidth of integrated end-to-end (E2E) networks by leveraging martingale theory and stochastic network calculus. The emulation consequences revealed that the bandwidth

abstraction concept and slice instantiation strategies were devised to achieve the reliability requirement for each node with bandwidth constraint. Nevertheless, dynamic nodes are not mentioned.

In [112], the authors suggested the Reliable Communication Network Switching (RCNS) concept to improve the reliability of IoT edge networks with available bandwidth constraints. The emulation consequences justify the devised rule-based reliable communication network switching (R-RCNS) algorithm that improves reliability in poor IoT networks. However, latency needs to be considered.

To achieve a high bandwidth utilization and high-reliability communication network, numerous effective optimization strategies for optimizing bandwidth and reliability simultaneously for 5G and 6G IoT communication systems has been given in this section [110], [111], [112]. [111] provides new way for bandwidth optimization algorithms. The four papers collectively address the challenge of optimizing communication networks by balancing bandwidth and reliability, recognizing that a sole focus on bandwidth may compromise other performance indicators. Paper [110] employs LDPC models to enhance reliability while minimizing repair bandwidth, while [111] leverages martingale theory and stochastic network calculus to integrate reliability and bandwidth in E2E networks. In contrast, [112] introduces the RCNS concept to enhance reliability in IoT edge networks with bandwidth constraints. However, common limitations across the papers include overlooking factors such as latency and dynamic nodes, which are essential for real-world applicability. Thus, while each paper contributes to optimizing communication networks, a holistic approach considering various performance parameters is necessary to achieve optimal network performance. Table XX describes the advantages and limitations of bandwidth and reliability joint optimization methods.

TABLE XX
SUMMARY OF THE RELATED WORK FOR BANDWIDTH AND OTHER KEY INDICATORS TRADEOFF.

Issue	Methodologies	Advantages	Limitations	Ref.
Bandwidth-reliability	LDPC codes	Higher reliability	No latency considered	[110]
	Bandwidth abstraction algorithm	Better reliability for each node with bandwidth constraint	Not for dynamic nodes	[111]
	R-RCNS	Effective for IoT edge devices with poor network	No latency considered	[112]

2) BANDWIDTH-RATE

In [113], the limitation of bandwidth and sampling rate problems have been addressed in deep-spread spectrum satellite communication. Emulation consequences indicate that

the devised interpolation rate matching module strategy can meet the sampling rate requirements with bandwidth constraint. However, the dynamic bandwidth scenario is not considered.

In [114], the authors developed a Fair Bandwidth Allocation (FaBA) algorithm to improve the flexibility of rate

performance for PON of 6G communication. The results justify that the devised approach outperforms the Round Robin-DBA (RR-DBA) algorithm in terms of transmission rate and bandwidth utility under traffic load and latency constraints. Nevertheless, applying AI techniques to reduce the complexity of the algorithm needs to be considered.

In [115], the authors utilized rate improvement of UAV concepts to analyze bandwidth slice optimization methods for 5G networks and developed a Rate and Distance based Bandwidth Slice Allocation (RDBA) concept. The emulation consequences reveal that bandwidth resource allocation of UAVs systems could be improved by simultaneously optimizing UAV rates with throughput maximum. Nonetheless, the multi-dimension dynamic UAV scenario needs to be considered.

In [116], the authors utilized Faster-Than-Nyquist (FTN) technology to analyze rate optimization methods performed together efficiently. The results demonstrated that the bandwidth requirements for short-reach interconnect could be achieved while meeting a high symbol rate by applying a pre-processing-free decoding structure. However, more practical application scenarios need to be considered.

To achieve a high bandwidth utilization and high-rate

communication network, numerous effective optimization strategies for optimizing bandwidth and rate simultaneously for 5G and 6G IoT communication systems has been given in this section [113], [114], [115], [116]. The four papers collectively tackle challenges in optimizing bandwidth and rate performance across diverse communication scenarios. Paper [113] addresses bandwidth and sampling rate limitations in deep-spread spectrum satellite communication, while [114] introduces the FaBA algorithm for enhancing rate performance flexibility in 6G PON communication. [115] focuses on bandwidth slice optimization methods for 5G networks using rate improvement of UAV concepts, and [116] utilizes FTN technology to analyze rate optimization methods for short-reach interconnects. While each paper presents effective strategies to enhance bandwidth and rate performance, they commonly overlook dynamic scenarios such as dynamic bandwidth and multi-dimensional UAV scenarios, which are crucial for practical applicability in real-world communication environments. Addressing these factors would be essential for achieving optimal network performance in diverse communication scenarios. The advantages and limitations of methods in bandwidth and rate joint optimization are described in Table XXI.

TABLE XXI

SUMMARY OF THE RELATED WORK FOR BANDWIDTH AND OTHER KEY INDICATORS TRADEOFF.

Issue	Methodologies	Advantages	Limitations	Ref.
Bandwidth - rate	Interpolation rate matching module	Meet the requirements of sampling with a bandwidth constraint	Dynamic bandwidth scenario is not considered.	[113]
	Faba	Better than RR-DBA	High complexity.	[114]
	Bandwidth slices RDBA	Tradeoff bandwidth, rate, and throughput	No multi-dimension dynamic UAVs considered.	[115]
	FTN	Break bandwidth limitation	More scenarios need to be considered.	[116]

E. RELIABILITY-RATE

Blindly prioritizing the rate may inadvertently neglect the optimization of other performance indicators in 5G and 6G networks. For example, enhancing reliability may lead to a low transmission rate. Hence, it is required to investigate joint optimization strategies for multiple key performance parameters to achieve optimal performance of the whole communication network. The joint optimization methods for reliability and rate are illustrated in this section.

In [117], the joint optimization problem of Fixed Transmit Rate (FTR) in wireless communication networks with reliability constraints has been investigated. Emulation consequences indicate that the devised rate control concept could accomplish greater reliability constraints in multiple antennas. However, imperfect CSI needs to be considered.

In [118], the allocation of received signal power in fading channels is used to intensify the reliability and sum rate of the power-domain NOMA (PD-NOMA) network. The emulation consequences justify the devised dynamic power threshold decreasing strategy to obtain the highest sum rate and reliability in IoT systems. Nonetheless, IoT devices need to be considered for greater mobility.

In [119], the author identified transmission rate optimizing for ultra-reliability constraint in URLLC. The emulation

consequences prove that the designed Extreme Value Theory (EVT) offers superior solutions for the application of reliability-rate tradeoffs in the significant fading networks. Nevertheless, real-time algorithm needs more attention.

To achieve a high reliability and high rate communication network, numerous effective optimization strategies for optimizing reliability and rate simultaneously for 5G and 6G IoT communication systems have been given in this section [117], [118], [119]. The three papers collectively address challenges related to optimizing reliability in wireless communication networks, employing various techniques and approaches. Paper [117] focuses on joint optimization of FTR with reliability constraints, utilizing a rate control concept. In contrast, [118] investigates power allocation in fading channels to enhance reliability and sum rate in PD-NOMA networks, while [119] identifies transmission rate optimization for ultra-reliability constraints in URLLC using EVT. While each paper demonstrates improvements in reliability, common limitations include considering imperfect CSI [117], addressing IoT device mobility [118], and enhancing real-time algorithm performance [119]. Addressing these factors would enhance the practical applicability and effectiveness of the proposed methods. Table XXII outlines the benefits and constraints of methods in reliability and rate joint optimization.

TABLE XXII
SUMMARY OF THE RELATED WORK FOR RELIABILITY AND RATE TRADEOFF.

Issue	Methodologies	Advantages	Limitations	Ref.
Reliability- Rate	Rate control strategy	Adapt to multiple antennas.	Not for Imperfect CSI	[117]
	Allocation of received signal power	Effective in fading channel	Needs more mobility considered	[118]
	EVT	Effective for the fading network.	No real-time algorithm	[119]

IV. CHALLENGES OF RESOURCE OPTIMIZATION IN 6G IoT COMMUNICATION SCENARIOS

As 6G technology advances, IoT techniques become ubiquitous. Low latency, high reliability, EE and SE, high rate, and high bandwidth efficiency are needed to support these IoT devices. Resource optimization requires considering variational 6G IoT communication scenarios. The paper has addressed the purpose of improving several pivotal parameters that are preparing for ulterior IoT device information interaction via the 5G and 6G communication networks. This section reveals these main application scenarios from the standpoint of facing the challenges of 5G and 6G IoT.

A. UNCERTAIN FACTORS SCENARIO

1) CHALLENGES

Numerous studies have been conducted to solve the problem of designing an optimal algorithm with perfect spectrum sensing and certain channel status, with the final aim of obtaining better network performance indicators, such as SE, EE, throughput, and interference [120]. However, the above strategies have great limitations for real communication channels and are ineffective due to uncertain spectrum parameters. In particular, applying a single algorithm might not achieve satisfactory resource optimization performance, where perfect channel state information cannot be picked up at the receiver [121]. Therefore, the research challenges of optimizing in uncertain factors scenarios are how to design network protocols to support the state awareness and interaction of optimization algorithms and evaluate and verify them in the real network environment to provide support for the actual deployment and application of the algorithms.

2) PROPOSED SOLUTIONS

Based on the uncertain spectrum sensing and strict transmission latency requirements, practical methods have been proposed to minimize transmission latency while improving spectrum sensing accuracy in 6G IoT networks. Moreover, to further close to a real communication channel environment, collaboration optimization models for uncertain channel parameters are proposed to enhance resource optimization effectiveness. However, the devised concept is grounded on the assumption that the network state information is all observable [122], and the lack of support for the network protocol makes it difficult to deploy in real network scenarios.

B. MULTI-DIMENSION SCENARIO

1) CHALLENGES

Recently, traditional terrestrial wireless communication has experienced explosive growth in the light of application scale and complexity, which makes it tough to fulfill the advanced

needs of future networks [123]. In addition, due to the limitation of communication system status and coverage, telluric wireless networks cannot front users with high-speed and high-reliability wireless access services anytime and anywhere, especially in crude scenarios such as mountain and sea territories [124]. Hence, it is urgent to develop updated communication system frameworks to adapt to the applications of different services [125].

Compared with the traditional communication network architecture, which mainly relies on ground BSs, the 6G network will have a disruptive breakthrough. The 6G network will not only be limited to the ground BS but focus on a higher dimension and create an integrated network architecture of space and ground. However, in the actual scenario, the space-ground network could also face the demand for green communication with high energy and spectrum efficiency requirements.

Mobile IoT devices would require a more dynamic spectrum and PA framework, though satellite communication technology is a hopeful project that will solve the lack of terrestrial infrastructure coverage in IoT communications [126].

2) PROPOSED SOLUTIONS

Satellites and near-space vehicles are used to establish space and space communication systems to make up for the inherent defects of cellular cells relying on ground resources and construct the space-ground integration network architecture of satellite and ground integration, which has become a core technical means for 6G to realize global ubiquitous communication [127].

In addition, satellite-terrestrial integrated networks can overcome the shortcomings of independent operation of satellite and terrestrial communication systems through effective coordination and operation mechanisms and provide effective coverage for sparsely populated areas and high capacity and economic services for densely populated areas [128].

The satellite communication system is used to achieve global communication coverage, which can fill the diverse business requirements of IoT devices in multiple scenarios, support the extreme performance experience, and improve the wireless network architecture of 6G global coverage and elastic adaptation.

The Space-Air-Ground-Sea Integrated Network (SAGSIN) connects sky-based, vacuum-based, ground-based, and ocean-based networks by modern information technology, can improve 6G IoT communication quality and efficiency [129]. Therefore, it is a meaningful topic to analyze the resource optimization problem of complex environments with multi-dimensional resources [130].

C. ULTRA-DENSE SCENARIO

1) CHALLENGES

There is challenging to apply terahertz communications with higher frequency bands as a new solution for the current capacity constraints in 6G technology, especially for the lack of spectrum because of the dense ground communication networks in 6G IoT [131]. With the continuous deepening of NI, the 6G wireless communication system will face more questions about the intelligent integration of the network and the intelligent connection of everything. How to design the deployment scheme of IoT devices heterogeneous integrated network based on the topology variable characteristics of the multi-computer network and consider the flexible switching method between heterogeneous cells will be particularly important.

2) PROPOSED SOLUTIONS

There was an effective cache-enabled MEN architecture to contest the extensive number of terminal units and huge data traffic. Furthermore, satellites have been used as large-scale computing centers in satellite-ground networks to provide wide area coverage with high-capacity backhaul for dense users on the ground. However, for the above challenges, 6G communication-based ultra-dense network integration still needs more attention in future wireless networks' development process [132].

D. DYNAMIC RESOURCE SCENARIO

1) CHALLENGES

Due to different communication distances that will lead to different strengths of the wireless data received by the signal receiver, achieving more reasonable network resource allocation becomes a challenge to improve the wireless connection latency and the FL model training latency in IoT systems.

Moreover, in the actual 6G communication scenario [133], the high-speed movement of IoT users will bring the high time-varying characteristics of wireless channels, and adopting a more practical dynamic channel transmission model is a challenging research question to increase the potency of resource optimization.

2) PROPOSED SOLUTIONS

In the low-power IoT system based on FL, the resource allocation method is mainly grounded on the topology of a static wireless network, in which the IoT terminal device is fixed in the network and cannot move [134]. Therefore, the delay of wireless communication is largely affected by the deployment location of the terminal equipment and the cloud technique [135].

Besides, the terminal devices in the network have high mobility in some IoT applications, such as intelligent robots, which introduce dynamic characteristics into the system [136]. According to this, the novel research for adaptively reducing latency have focused on analyzing the maneuverability pattern of the terminal device, and predicting its wireless data transmission performance [137].

E. MULTI-USERS SCENARIO

1) CHALLENGES

In recent years, the birth of various new industries and services has made it impossible to be in touch with the requirements of current IoT equipment by only considering the communication mode of a single user.

Since there are multiple BBUs in a real communication environment, coming up with novel solutions to design optimal cache strategy between Remote Radio Head (RRH) and BBUs under the bandwidth requirement of Forward Communication Link (FCL) is important and challenging for IoT networks.

Therefore, investigating the slice cache in the RRH-BBUs connection system is a novel challenge for future research. Further integration of multi-user communication has become a general trend, such as multiple UAVs, CPUs, LEOs, links, transmitters, and BSs.

2) PROPOSED SOLUTIONS

Resource optimization in a Single Baseband Unit (BBU) scenario has been the topic of plenty of current publications [138]. However, there are communication blind areas, delays, and limited bandwidth defects in single-user communication systems.

A multi-user cooperative communication system has the interests of low communication latency and high reliability. There is some new research on multi-user cooperative communication systems to achieve seamless global coverage and provide high-capacity transmission for users [139].

V. FUTURE RESEARCH DIRECTIONS OF RESOURCE OPTIMIZATION IN 6G IoT COMMUNICATION

The resource allocation requires low complexity, and high accuracy algorithms. Multiple key indicators can assert the joint optimization performance of the whole system. The paper for improvements in the key indicators' joint optimization affords an overall perception of the prospect study vision for 5G and 6G IoT. There are huge chances for optimization using advanced techniques. This section proposes future research directions that combine advanced techniques into resource optimization in 5G and 6G IoT networks.

A. MULTI-INDICATORS JOINT OPTIMIZATION

The transmission technology of the IoT will be a significant investigation task for 5G and 6G networks in the future, and it will come up with more stringent service needs for the IoT systems. There are higher data transmission rate requirements in 6G IoT systems, so they need wider spectrum bandwidth, but the existing spectrum resources below 5G are minimal [140]. In addition, the existing IoT-related technologies cannot meet the stringent technical requirements of 6G for IoT service quality; for example, the delay requirement reaches 10–9s.

The key indicator performance optimization of IoT communication is increasingly being adopted in practical devices. More research on optimization strategies is effective for improving the communication capacity of IoT networks [141]. There is still an enormous probability of integrating latency, EE, SE, rate, reliability, and bandwidth into key performance indicators collaboration optimization algorithms. Therefore, it is possible to confirm the feasibility of the techniques for solving the questions in confronting the devised aim.

Strategies of collaboration optimization can exploit the potential characters of multiple key indicators demanded by IoT devices and 6G communication [142]. The use of tradeoffs for the two indicators among latency, EE, and SE is a widely accepted problem statement. For example, synergism in variable IoT unit scenarios could also be recommended in the DDPG-based architecture to optimize the performance of learned deals. However, the better optimization lies in the overall consideration of multiple indicators during the application of the real scenarios. Reliability is one of the most important indicators in evaluating the criteria of 6G communication issues. The bandwidth utility needs to be improved to face resource limitations for huge IoT devices. Therefore, the focus on jointly optimizing reliability, latency, SE, EE, and rate performance is significant.

B. DECENTRALIZED ARCHITECTURE-BASED MEN

In dense scenarios of ground hotspots such as office buildings and large shopping malls as a result of plenty of users [143], the traditional centralized resource allocation method has high computational complexity, and the distributed algorithm iterative elements require a large number of interactions to achieve convergence [144]. As far as prospective research is concerned, decentralized computation offloading strategies could be studied. This may command a layered DRL architecture-based.

In addition, 6G IoT is huge and complex, and it is difficult to obtain all the signaling of the whole IoT through one site, and it is even more difficult to ensure that each signal is not polluted by noise or affected by time delay [145]. Therefore, only a part of the information on the oriented signaling is affected by noise pollution, attenuation of the threadless channel, and latency. This requires the study of distributed algorithm design methods and the mathematical derivation and probability statistical solution of robustness to obtain the IoT access technology with the best statistical performance for the corresponding one or more parameters.

C. AI-BASED ML/DL

In the future, ML or DL models will be used to monitor the changes in resource usage and the number of data releases, and on this basis, a more efficient resource optimization strategy will be designed to improve resource availability. At the same time, the indicators jointly determine the practical and effectiveness of the optimization algorithm. Some research only analyzes the data utility of network resources under single indicators [146], and in the future, the relationship between resource utility and network performance will be analyzed by using advanced ML or DL algorithms.

D. FL FRAMEWORK

The existing resource optimization mechanisms are designed for static IoT scenarios, without considering the impact of node mobility and learning performance [147]. In the future study, we will be centered on the model training problem of frequent switching between end nodes and central nodes in mobile scenarios by using the FL framework and design a node optimization scheme oriented to the importance of data to fill the needs of high reliable and low latency in scarce resource 6G IoT communication.

E. BLOCKCHAIN

Existing technologies can effectively improve resource utilization through spectrum sharing to meet the huge spectrum demand of massive IoT devices accessing 5G/6G networks [148]. However, the centralized spectrum access system restricts the further application of 6G IoT due to administrative costs, efficiency issues, and transaction costs. Recently, blockchain has received a lot of attention. Blockchain primes a safe distributed database of all computing by capacitating all contributors to file data blocks, where each block of record contains an encrypted hash, a timestamp, and a record of the transaction [149]. Therefore, blockchain-based spectrum sharing can state a safe, flexible, low-cost, and efficient distributed spectrum sharing scheme for 6G mobile communication. There is a positive weight to research the resource optimization issue of IoT based on blockchain.

F. DYNAMIC MODULATION AND CODING MODE

Existing studies consider beamforming, cache offloading, and other techniques in improving IoT network performance [150]. Due to its unique properties, dynamic modulation and coding mod will replace current technology in future communications. Many advanced bandwidth allocation algorithms will be combined with novel modulation and coding techniques in 6G networks.

G. NOVEL NETWORK ARCHITECTURE

The 6G IoT networks are looking forward to being combined with the proposed Smart Integration Identifier network architecture [151]. The intelligently connected devices are ulteriorly infrastructural constructions. The concept of knowledge areas can be used for smart identification services in the smart integration identifier network architecture. Consequently, the 6G system Gleichschaltung in the smart integration identifier network framework is a competent way to receive tremendous IoT devices.

VI. CONCLUSIONS

Resource optimization is a rising and dynamic issue and is a critical element in meeting 6G IoT network demand. This study provides an extensive overview of resource optimization, analyzing recent and previous studies on techniques, indicators, and application scenarios. We also emphasize the importance of resource optimization for the next generation of 6G networks. Furthermore, we compare different published approaches for 6G IoT network performance measures, including bandwidth, dependability, latency, energy efficiency, and data rate. This comparison illustrates the advantages and disadvantages of various strategies. Furthermore, our research significantly advances the field by offering a comprehensive analysis of cooperative resource optimization techniques especially designed for the setting of 6G IoT networks. We examine the difficulties encountered in this field and provide interesting directions for further study to improve 6G IoT network performance. Overall, we hope that our work will shed light on how resources are optimized in 6G IoT networks and lay the groundwork for future developments in this quickly advancing industry.

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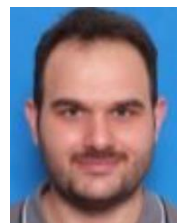
ZHANG LIWEN is currently pursuing a Ph.D. degree at the Faculty of Information Science and Technology, Universiti Kebangsaan Malaysia (UKM), Selangor, Malaysia. She completed the M.S. degree in Electronics and Communication Engineering from University of Electronic Science and Technology of China, China, in 2014, and B.E. degree in Electronics Information from Northeastern University, China, in 2011. Her research interests include Internet of Things, performance analysis, 5G and 6G communications, wireless resource optimization, artificial intelligence assisted resource allocation.



FAIZAN QAMAR is currently serving as Senior Lecturer in the Faculty of Information Science and Technology, Universiti Kebangsaan Malaysia (UKM), Selangor, Malaysia. He has a Ph.D. degree in Wireless Networks from the Faculty of Engineering, University of Malaya, Kuala Lumpur, Malaysia in October 2019. He had completed M.E. degree in Telecommunication from NED University, Karachi, Pakistan in 2013, and B.E. degree in Electronics from Hamdard University, Karachi, Pakistan, in 2010. He has more than nine years of research and teaching experience. He has authored and co-authored numerous ISI & Scopus journals and IEEE conference papers. He also serves as a reviewer in more than 15 high-reputation journals with different publishers such as IEEE, Elsevier, Springer, Wiley, Hindawi, etc. His research interests include interference management, millimeter-wave communication, ad-hoc network, Internet of Things, D2D communication and Quality of Service enhancement for future wireless networks.



MAHRUKH LIAQAT received her BS(Hons.) degree in Electrical Engineering from COMSATS University, Islamabad, Pakistan in 2012, and her Ph.D. in communication systems from University Malaya, Kuala Lumpur, Malaysia. She is currently serving as an Asst. Professor at National University of Science and Technology, Islamabad, Pakistan. Her research interest includes Wireless Cooperative Networks, RF Energy Harvesting, Multiple Access Technologies, and Interference Management.



MHD NOUR HINDIA (Member, IEEE) received the Ph.D. degree from the Faculty of Engineering in Telecommunication, University of Malaya, Kuala Lumpur, Malaysia, in 2015. He is currently a Postdoctoral Fellow with the Faculty of Engineering in Telecommunication, University of Malaya. He is also involved with research in the field of wireless communications, especially in channel sounding,

network planning, converge estimation, handover, scheduling, and quality of service enhancement for 5G networks. He has authored or coauthored a number of science citation index journals and conference papers. He has participated as a reviewer and a committee member of a number of ISI journals and conferences.



KHAIRUL AKRAM ZAINOL ARIFFIN earned his Bachelor's and Master's degrees with First Class Honours in System Engineering with Computer Engineering from the University of Warwick, the United Kingdom, in 2008 and 2009. He later joined Universiti Teknologi PETRONAS (UTP) in 2010 to pursue his journey toward academic research and teaching courses to earn his Ph.D. During his time at

UTP, many journal articles and conference papers were produced and published internationally. Then, he was appointed as a researcher in the Digital Forensic Department, CyberSecurity Malaysia, and he was entrusted with research on embedded systems and live forensics. Currently, he is a chairperson for the Center for Cyber Security, Faculty of Information Science and Technology, Universiti Kebangsaan Malaysia, to pursue his passion in research towards cybersecurity, malware analytics, digital forensics, algorithms, and embedded systems. He is GCFA certified and a member of Cyber Security Academia Malaysia (CSAM), IEEE and IET.