Load Balancing in Heterogeneous Network with SDN: A Survey

Jingbo Li, Li Ma(✉), Yingxun Fu, Dongchao Ma, and Ailing Xiao

School of Information Science and Technology, North China University of Technology, Beijing 100144, China
mali@ncut.edu.cn

Abstract. With the rapid development of the interconnection of things, a large number of different types of network protocols and network resources have emerged. There are traditional wired networks and wireless networks. Wireless networks include 4G/5G, NB-IoT, and industrial Internet of Things, world-ground integrated networks, satellite networks, ocean networks, and so on. Multiple networks enrich the scenarios and requirements, eliminate information islands. Building a consistent view of heterogeneous networks and load balancing of heterogeneous networks are realistic requirements for certain applications of future networks. The emergence of Software Defined Networking (SDN) has provided a brand new idea for this scenario and has become an important technology and hot research object in this direction. According to the research field of SDN in heterogeneous network load balancing strategy, this paper analyzes the research status and trends from two aspects: load balancing of data transmission and load balancing of resource allocation. Comprehensive research status and advantages show that the characteristics of centralized management, completely decoupled forwarding plane, and control plane provided by SDN can play an important role in the design of load balancing routing strategy. Using the SDN method can make the load balancing strategy more flexible, clear and controllable, which is of great significance for future development and has a far-reaching impact. Finally, it analyzes and predicts the development trend of SDN, and provides a reference for the construction of a new generation of network routing.

Keywords: Software defined networking · Routing strategy · Heterogeneous convergent network · Load balancing

1 Research Background

With the advent of the information age, technologies such as mobile communication networks, industrial Internet of Things, spatial information networks, and new types of Internet have developed rapidly, and various network forms have been varied. With the improvement of living standards and the increase in demand for new things, the integration of these different technologies is imperative, which forms a heterogeneous network environment. In this new type of network environment, traditional load balancing strategies can no longer meet the current dynamic requirements for information transmission,

L. Cui and X. Xie (Eds.): CWSN 2021, CCIS 1509, pp. 250–261, 2021.
https://doi.org/10.1007/978-981-16-8174-5_19

acquisition, and forwarding. With the explosive growth of data scale, netizens' demand for network bandwidth has increased rapidly, and the continuous expansion of the number of users has caused various traditional routing technologies to have to change with the changes of the times. As traditional routing technology uses a distributed network architecture, functions such as data forwarding and control need to be installed on each router and switch, so much so that network devices become increasingly bloated with too many protocols installed inside them, unable to meet the needs of network management, control, addition, deletion and maintenance due to the growth in the size and traffic of the Internet. At present, the traditional load balancing routing strategy of such a network cannot effectively cope with this change. At this time, the heterogeneous network load balancing strategy to become more flexible and changeable.

In 2008, Professor Nick McKeown of Stanford University and others based on the research results of the Ethane project [1], a paper entitled OpenFlow: Enabling Innovation in Campus Networks [2] was published in ACM SIGCOMM, in which SDN was introduced in detail for the first time. In 2009, the research team further proposed the concept of SDN, which has attracted great attention from the entire industry. In 2011, Google, Facebook and other companies jointly established the Open Networking Foundation (ONF), and formally proposed the concept of software-defined network SDN. In essence, SDN is an idea of separating control and forwarding, a programmable network architecture, and a new network design concept. This kind of thought and concept can be directly introduced into a heterogeneous network system dominated by IP, and the introduction has the following benefits:

- The network control function can realize decoupling, which solves the bloated situation of the edge gateway due to too many protocols, and also releases the ability of hardware resource equipment to packet forward;
- It can effectively abstract and encapsulate the physical resources in network, without considering the heterogeneous characteristics of physical hardware, and can realize the overall deployment and sharing of the underlying physical resources;
- The visibility of upper-layer services can be realized. Due to the heterogeneity of different services, different services can be disassembled through the northbound interface after using SDN, thereby achieving business scalability.

After more than ten years of development, software-defined network technology has developed rapidly. The combination of SDN technology and heterogeneous converged network technology can integrate the advantages of both aspects and play the greatest role in the future communication network. The progress of globalization and social development is of great significance.

In the past research reviews on SDN, most of them combine deep learning and other technologies with SDN to summarize and summarize from the application point of view. This article summarizes the research from two aspects: load balancing of data transmission and load balancing of resource allocation. Section 1 of this article introduces in detail the research background and significance, as well as the advantages of introducing SDN into the load balancing strategy. Section 2 summarizes the load balancing strategy based on data transmission. After different networks are connected, how to enable different networks to effectively transmit data to achieve the overall network

load balance is also the key content of many scholars' research. Section 3 summarizes the resource-based load balancing strategy. For heterogeneous networks, the types and efficiency of resources used by different networks are different. How to achieve a fair distribution of different resources is also a different study, one of the difficulties of constructing a network. Section 4 summarizes the existing problems of existing research centers, analyzes the research direction of SDN in the future heterogeneous networks, and looks forward to the direction and trend of future development. Figure 1 shows the technical architecture diagram of the SDN-based heterogeneous network load balancing strategy studied in this paper.

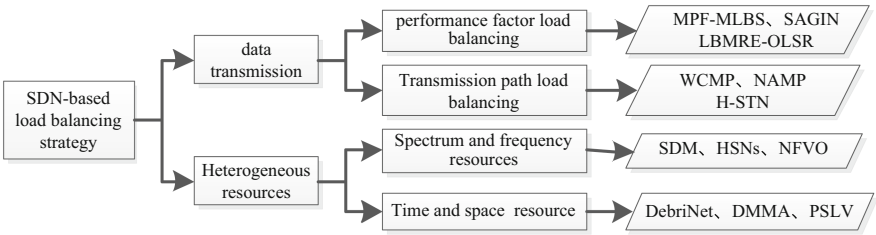

Fig. 1. SDN-based heterogeneous network load balancing technical architecture diagram.

2 Load Balancing in Data Transmission

As one of the common strategies to improve network performance, load balancing in data transmission has always been a hot issue and a difficult issue [3]. Load balancing can improve network performance because it provides a transparent, low-cost and effective method to expand the bandwidth of servers and network devices, enhance network data processing capabilities, and improve network availability and flexibility [4]. In the actual network use process, due to the characteristics of heterogeneous networks, the use of traditional load balancing routing strategies cannot effectively obtain real-time network link status, and thus cannot allocate and schedule network traffic transmission for load balancing in real time according to the actual situation. It is prone to problems such as excessive single-path transmission load, uneven resource allocation of the link, and poor data flow transmission efficiency, which is not enough to meet the development and needs of today's heterogeneous network environment. The maturity of SDN technical ideas provides new impetus for load balancing strategies. At present, common classifications in data transmission load balancing strategies include load balancing strategies based on performance factors and load balancing strategies based on paths. The characteristics of these different classification research programs are shown in Table 1.

Table 1. Comparison of data transmission load balancing strategies.

Literature	Load balancing		Put forward the model	Using technology	Advantage	Shortcoming
	Performance factors	Path				
5	√	–	√	SALB	Low energy consumption	High communication cost
6	√	–	MPF-MLBS	MPF	Low delay, high rate	A lot of data preprocessing
7	√	–	LBMRE-OLSR	SAGIN	Dynamic balance	Poor stability
8	√	–	√	QBA, QSR	Low delay, high speed	High communication consumption
10	–	√	–	WCMP	High bandwidth	Delay problem
11	–	√	NAMP	LPM	Low delay	Cutting complex
13	–	√	√	LTE/WLAN	Multicast communication	Poor scalability
14	–	√	√	MNO, H-STN	Spectrum sharing	Complex data preprocessing

2.1 Load Balancing Mechanism of Performance Factors

With the rapid increase of user groups and rapid growth of communication volume, the load and required energy of SDN equipment have increased significantly. Therefore, an SDN controller model that can load balance and reduce equipment energy consumption is needed. This demand document [5] proposed a new type of SDN controller energy-saving heterogeneous network load distribution framework, which is a combination of load balancing technology (SALB) and energy optimization framework. According to the communication requirements of different performance indicators, load balance is performed, and then efficient routing algorithms and selection procedures are combined to reduce energy consumption. In this way, combining the two technologies can interact with each other, so that the controller can reduce energy consumption while balancing network traffic to a large extent to achieve the purpose of load balancing. Literature [6] proposed an SDN multi-path load balancing strategy (MPF-MLBS) based on multiple performance factors (MPF). The strategy is divided into two stages: algorithm design and routing strategy implementation. In terms of algorithms, first, based on the characteristics of the SDN network architecture, combined with the advantages and disadvantages of the existing load balancing algorithm, considering the delay, bandwidth and link rate of the existing network links, a design based on multiple performance factors is designed Load balancing algorithm (MPF-CMP). In terms of strategy, first, build a multi-path network topology based on the SDN architecture, use the depth-first traversal algorithm to traverse the entire network topology to obtain various information about the link, and then combine the MPF-CMP algorithm and the OpenFlow group table technology to

complete The network traffic of each available path is distributed proportionally, so as to realize the load balancing of the SDN network multi-path.

The transmission efficiency of traffic in the space-ground integrated satellite network is very important to the use of the satellite network. Due to the limitation of transmission distance and technology, if reasonable data flow load balance is not carried out, the space-ground integrated network will not be put into actual use. To solve this problem, literature [7] studied routing algorithms in a software-defined space-air-ground heterogeneous network (SAGIN) to optimize load balancing in a heterogeneous communication network. First, a new software-defined network was proposed (SDN) model to solve the network topology is the characteristics of real-time changes because this model can improve the flexibility of the network. Based on the above model, the author proposes a new dynamic routing load-balancing algorithm, namely the load balancing algorithm based on multi-dimensional resources and energy (LBMRE-OLSR), the routing algorithm considers the multi-dimensional consumption of resources and energy, experiments The results show that the algorithm in SAGIN's dynamic routing effectively reduces the end-to-end delay and packet loss rate when the load changes, realizes the convenient and intuitive unified deployment of the complex three-dimensional heterogeneous network framework and improves The fluency of the overall network operation and the efficiency of routing. Literature [8] proposed a software-defined network framework based on software-defined networking (SDN) and network function virtualization (NFV) for heterogeneous satellite communications. The purpose of this framework is to realize flexible satellite network traffic engineering and a fine-grained QoS guarantee. Based on this framework, a prototype implementation method based on delay-tolerant network (DTN) and OpenFlow is given, and a QoS-oriented satellite routing (QSR) algorithm and a QoS-oriented bandwidth allocation (QBA) algorithm are proposed to ensure QoS requirements for multiple users. Experimental results show that the framework is effective in terms of file transmission delay and transmission rate.

2.2 Load Balancing of Transmission Path

At present, some multi-path load balancing routing is optimized and improved on the traditional single-path routing strategy, without changing the routing strategy in essence. There is also some multi-path load balancing routing strategies that use multiple paths to evenly distribute network traffic. This strategy does not allocate link resources according to requirements, which will easily cause partial link congestion and low overall traffic transmission efficiency [9]. Using the traditional ECMP algorithm will result in lower overall bandwidth utilization, especially when the path difference is large, the effect is very unsatisfactory. Aiming at the shortcomings of ECMP, literature [10] uses Weighted Cost Multi-path (WCMP) to solve the load balancing problem under the resource constraints of the data plane. The purpose of WCMP design is mainly to solve the problem of data center traffic load balancing and to solve the problem of unequal handling of topological problems by ECMP. However, WCMP usually sets the weight according to the bandwidth attribute of the path and does not consider the delay change of each link during the service transmission process. There is still a lot of room for improvement. On this basis, literature [11] proposes and implements a NAMP, a multi-path scheme that considers network heterogeneity, effectively optimizes the transmission time of stream

groups. Experimental results show that NAMP is 50% shorter than WCMP and 60% shorter than ECMP.

In the beyond 5G (B5G) era, the scale of wireless networks will grow very rapidly, which is believed to lead to scarcity of network capacity and degradation of service quality [12]. In a heterogeneous network, many cellular network users cannot enjoy high-quality multimedia services. To improve the service quality of these users, multicast uses an efficient spectrum method to transmit content. This method is considered to be a very effective method. Literature [13] proposed an SDN-based heterogeneous LTE/WLAN network architecture, which logically supports end-to-end (D2D) flexible multicast communication; because D2D communication can realize wireless peer-to-peer services, so in the vicinity directly establish a link between users for communication, which reduces the flow pressure of the backhaul. In addition, the introduction of SDN technology into heterogeneous networks can provide D2D users with reliable multicast content. Literature [14] established an SDN architecture that realizes spectrum sharing and traffic offloading in a heterogeneous satellite-terrestrial network (H-STN). This architecture supports efficient resource management and load balancing strategies and achieves large-capacity transmission and co-channel Interference control. In addition, this document also proposes an auction-based mechanism to facilitate the negotiation of traffic offloading between the mobile network operator (MNO) and the satellite. That is to say, the MNO announces its offloading rate threshold, and each beamed group of the satellite is based on its own Submit an unloading bid for the transmission rate of the MNO, and then calculates the best bidding rate for the beam group at different rates according to the different unloading rate thresholds announced by the MNO. This framework realizes the competition between the cellular network ground base station and the satellite-to-ground communication system multi-beam group and has achieved the purpose of traffic load balancing.

2.3 Brief Summary

In a heterogeneous network environment such as the Internet of Things, the number of various devices is huge, and the demand for transmission traffic is beyond imagination. How to distribute this traffic to a variety of devices in a balanced and reasonable manner requires extremely complex policy support. And the quality and effect of data transmission directly affect the experience of using heterogeneous networks. Although the use of performance factors considers many factors for load balancing, this method does not work well in the case of particularly large traffic. In the path-based load balancing strategy, the multi-path load balancing strategy has great advantages in robustness, fault tolerance and QoS compared with a single path. The use of a multi-path reduces the single link between different locations. Dependency risk, increase the transmission bandwidth and data transmission of the backup aging link without packet loss. However, multi-path routing will increase storage overhead. Data packets may require additional information, which increases the size of the data packets, and it also consumes additional processing power to propagate to other routers through multi-path.

3 Load Balancing of Heterogeneous Resources

Resource heterogeneity is a major feature in the context of the Internet of Things. According to the existing resources in the heterogeneous network, it is mainly divided into four aspects: frequency resources, space resources, time resources and power resources. With the development of the times, there are higher requirements for resource allocation load balancing strategies in heterogeneous converged networks. It is necessary to deploy resource load balancing with more flexibility, better scalability, and greater revenue costs for different types of services strategy. The main idea of SDN is to decouple the data plane from the control plane, and its controller can obtain a global view of the network, which facilitates the implementation of load balancing strategies. At present, resource load balancing strategies are classified according to different types of resources, including load balancing strategies based on frequency and spectrum resources, and load balancing strategies based on time and space resources. The characteristics of these different classification research programs are shown in Table 2.

Table 2. Comparison of load balancing strategies for heterogeneous resources

Literature	Resource allocation		Put forward the model	Using technology	Advantage	Shortcoming
	Frequency spectrum	Time space				
15	√	–	√	NFV, CCCP	Low power	Algorithm complex
17	√	–	√	A3C, EMC	High resource utilization	Low compatibility
18	√	–	HSNs	DRL	Intelligent manage	A lot of data preprocessing
19	–	√	DebriNet	PSLV	Low delay	Simple allocation strategy
20	–	√	√	PON	Delay monitoring	Poor scalability
21	–	√	DMMA	DHT	Strong scalability	High communication costs
22	–	√	√	K-means	Strong robustness	High deployment cost

3.1 Frequency and Spectrum Resource Balance

Load balancing strategies based on frequency and spectrum resources have certain similarities. For frequency resource allocation, on the one hand, according to Shannon's theorem, in a single user scenario, the efficiency of the system can be increased by increasing the bandwidth reasonably. On the other hand, according to Orthogonal Frequency Division Multiple Access (OFDMA) technology, in the scenario of multiple

users, increasing the transmission bandwidth of one user will reduce the bandwidth of other users, so bandwidth allocation is very important; For the load balancing of spectrum resources, it is mainly through the reasonable allocation of spectrum to improve the utilization rate of spectrum resources. Due to the rapid development of diversified communication services in recent years, the data transmission rate and the frequency spectrum are limited in the case of limited spectrum resources. The contradiction still remains unresolved, and this problem can only be solved through a reasonable allocation of spectrum resources.

The load balancing strategy for resources is different in different environments. In a heterogeneous cellular network environment, literature [15] proposed a joint load balancing allocation algorithm based on SDN power and bandwidth resources, which considers the main purpose of the fragmentation technology of network function virtualization is to achieve maximum energy efficiency for the different QoS requirements of fragmentation. Because it is difficult to realize the resource allocation algorithm using virtualization technology, we choose to transform the problem into a DC structure problem, so that the problem is transformed into two sub-problems, and the interior point method and the CCCP algorithm are used to iteratively find the optimal solution. The simulation results show that compared with the bandwidth optimization algorithm and the power optimization algorithm, the energy efficiency of this algorithm is increased by 201.5% and 1.8% respectively. Aiming at the problem of load balance distribution of space-based information networks (SIN), literature [16] first established space-based information network control architecture based on SDN. To solve the problem of unified management of SIN network transmission, caching and computing resources, intelligent resource load balancing distribution method based on A3C algorithm in deep reinforcement learning. In this architecture, the transmission resources depend on the degree of satellite coverage and the state of the communication link. The cached resources are provided by the cache, and the computing resources are provided by the EMC server. The load balancing distribution scheme can effectively improve the resource utilization rate of the space-based information network. Literature [17] proposes a new generation of heterogeneous satellite network resource management frameworks (HSNs), which realize the cooperation and resource load balancing between different satellite systems, and supports the mutual communication between different satellite systems. This framework integrates and manages heterogeneous resources based on SDN, applies deep reinforcement learning (DRL) to the system, combines DRL with resource allocation, and realizes integrated management of resource load balance across satellite systems.

3.2 Time and Space Resource Balance

Load balancing of time and space resources in a heterogeneous converged network is very precious and essential. In terms of time resource load balance distribution, due to the heterogeneous network protocol's disparity and randomness, the data in the device is also changing at any time. To improve the efficiency of data transmission, real-time scheduling must be carried out according to the delay of different services. In terms of space resource load balance distribution, it is mainly because of the use of multi-point

joint transmission that the placement of relay nodes is very important. Choosing a reasonable relay node can bring great space freedom to the system and improve transmission effectiveness.

In terms of time resource load balancing, literature [18] proposed a software-defined network platform concept: DebriNet, which uses the fourth stage of PSLV to establish a low-cost space-based communication network, which is a rocket fragment (called spent fuel level) low-cost software-defined network platform, which can be accessed by user equipment using ultra-low-cost terminals and extremely low latency. DebriNet uses an opportunistic packet handover mechanism that uses pre-calculated satellite positions on the orbit to optimize time resource allocation to ensure that packets are delivered to the destination as soon as possible, reduce network delays, and save time in the network Resources. Literature [19] proposes a real-time delay measurement based on SDN and it's the monitoring of 5G mobile converged passive optical network (PON). It is a real-time delay measurement scheme used to determine whether the network delay meets the requirements of the mobile network. The measurement scheme is based on the SDN idea. The implemented system can accurately measure the delay during network operation, and Monitor the real-time delay status, and judge whether the time resource load balance distribution is reasonable according to the delay status.

In terms of spatial resource arrangement, SDN requires a controller to manage the entire network, so how the controller is arranged in the space like relay nodes is particularly important for the load balancing of the entire network. This is also the focus of research in SDN. A reasonable controller distribution and optimal switching technology are essential for the load balancing of space resources. It can effectively reduce link delay and save a lot of time and space resources. Literature [20] proposes a seamless mobility management solution for users moving from one SDN controller coverage space to another SDN controller coverage space in a 5G heterogeneous network: DMMA, using key-value distributed hash tables (DHT) to capture user mobility in the distributed SDN controller. It solves the scalability and seamlessness of heterogeneous networks, that is, mobile devices can connect and leave between different associated SDN controllers. Literature [21] proposed an SDN-based air-space-ground integrated network framework, and designed an optimized K-means controller space configuration load balancing algorithm based on the characteristics of the dynamic topology of the UAV segment. Compared with the traditional K-means algorithm, this algorithm can effectively reduce the average delay and the maximum delay between the controller and the switch through a reasonable controller space configuration. This framework has the advantages of high throughput, wide coverage and strong robustness.

3.3 Brief Summary

In a heterogeneous network environment, resources are complex and scarce. Various resources are mixed together, and the load balance distribution of heterogeneous resources must be considered comprehensively. How to allocate these resources reasonably is extremely important to achieve load balancing in a heterogeneous network. Resource management in the existing resource management model is mainly for the management of a single resource within the network. Whether it is frequency, spectrum, virtual resources, forwarding resources, or time and space resources, it is an isolated

management mode, without considering the available resources of other networks. In the future load balancing of heterogeneous network resources, it is necessary to coordinate the processing of resources between multiple networks, and allocate the best network resources in real-time according to the user's business characteristics and needs, so as to ensure the quality of service of the heterogeneous network and maximize the Make use of heterogeneous network resources.

4 Research Trends and Prospects

With the flexible features of software-defined networks and the in-depth application of various network technologies, the integration of SDN and heterogeneous networks has become an inevitable trend in research and network design. In such an extremely complex environment as heterogeneous networks, SDN has the advantages of centralized control enable more precise decision-making, flexible management and intelligent judgment of load balancing strategies in heterogeneous networks, making it possible to deploy in actual environments in the future. At present, there are many research results on load balancing strategies for heterogeneous networks at home and abroad, but there are still some drawbacks and shortcomings. For example, load balancing strategies cannot fully integrate the characteristics of different networks for distribution and integration; some load balancing strategies have poor scalability. It can only be used in a specific heterogeneous network; some load balancing strategies need to consume a lot of various resources, and the cost is too high; although SDN increases the flexibility and adaptability of the network, how to design and improve dynamic adaptation Sex requires in-depth research. This article believes that the field of heterogeneous network load balancing strategies should be deeply integrated and explored in the following aspects in the future:

- The ability to handle large-scale complex heterogeneous networks. The idea of separating the control plane from the data plane in SDN can be abstracted and simpler for solving complex heterogeneous network environments. The trend of future heterogeneous networks must be large-scale and complex networks, and the scale of data must also be larger. It puts forward higher requirements for the load balancing strategy of heterogeneous networks.
- The ability to adapt to the dynamic changes of heterogeneous networks. At present, the actual operating network has dynamic characteristics, and the nodes and connection status on the network and the transmission environment are changing all the time. Introducing the network protocol that has the ability to monitor the network status in real-time in SDN is of great help in solving the problem of dynamic load balancing, and there is still room for further optimization in future development.
- The ability to integrate with new network technologies. The integration of heterogeneous networks and new technologies is a trend. Combining the advantages of each technology will help the efficient operation and processing of load balancing strategies and bring out huge potential. The combination of new technologies has higher challenges and requirements for the stability and security of the load balancing strategy.

- Broaden scenarios and application areas. The future network form will be more complex and changeable. For example, the emergence of new complex heterogeneous network scenarios, such as the industrial Internet, integrated spatial information networks, and world ground integrated ocean networks, requires an in-depth analysis of load balancing strategies in different application fields. Look for entry points to introduce new ideas and technologies such as SDN, better integrate the technology with the scene, and expand to a wider range of applications.

5 Conclusion

This article elaborates and analyzes the load balancing strategy of SDN in heterogeneous networks. The solution of introducing SDN into heterogeneous networks is an effective and feasible choice, but the future heterogeneous networks must have huge mobile bandwidth requirements and ultra-low mobile bandwidth requirements. With delay requirements, high reliability and more access devices, in the face of these high-quality requirements, a heterogeneous network load balancing strategy must not only increase the transmission range, but also ensure the reliability of the network. In the face of such requirements, the research and application of load balancing strategies based on SDN in a heterogeneous network environment are not very mature, and it is still in an exploratory stage in practical applications, and there are still many deficiencies that have not been discovered and resolved. In future research, a large amount of scientific research personnel will be required to invest. It is necessary to conduct an in-depth analysis of load balancing strategies in different application fields in a heterogeneous network environment combined with SDN research to find an entry point and apply SDN to a wider field of heterogeneous networks, Make a good theoretical foundation for practical application.

Acknowledgment. This work was supported by the National Key R&D Program of China (2018YFB1800302), Natural Science Foundation of China (62001007), Beijing Natural Science Foundation (KZ201810009011, 4202020, 19L2021).

References

1. Casado McFreedman, M.J., Pettit, J., et al.: Ethane: taking control of the enterprise. ACM SIGCOMM Comput. Commun. Rev. **37**(4), 1–12 (2007)
2. McKeown, N., Anderson, T., Balakrishnan, H., et al.: OpenFlow: enabling innovation in campus networks. ACM SIGCOMM Comput. Commun. Rev. **38**(2), 69–74 (2008)
3. Liu, Y., et al.: A novel load balancing and low response delay framework for edge-cloud network based on SDN. IEEE Internet Things J. **7**(7), 5922–5933 (2020)
4. AlKhatib, A.A.A., Sawalha, AlZu'bi, S.: Load balancing techniques in software-defined cloud computing: an overview. In: 2020 Seventh International Conference on Software Defined Systems, pp. 240–244. IEEE, Piscataway (2020)
5. Priyadarsini, M., Kumar, S., Bera, P., Rahman, M.A.: An energy-efficient load distribution framework for SDN controllers. Computing **102**(9), 2073–2098 (2019). https://doi.org/10.1007/s00607-019-00751-2

6. Li, D., Liu, H., Jin, Y.: MPF-MLBS: a multi-path load balancing strategy for sdn networks based on multiple performance factors. Math. Comput. Sci. **5**(3), 64–71 (2020)
7. Qu, H., Luo, Y., Zhao, J., Luan, Z.: An LBMRE-OLSR routing algorithm under the emergency scenarios in the space-air-ground integrated networks. In: 2020 Information Communication Technologies Conference, pp. 103–107. IEEE, Piscataway (2020)
8. Li, T., Zhou, H., Luo, H., Yu, S.: SERvICE: a software defined framework for integrated space-terrestrial satellite communication. IEEE Trans. Mob. Comput. **17**(3), 703–716 (2018)
9. Lu, L.: Multi-path allocation scheduling optimization algorithm for network data traffic based on SDN architecture. IMA J. Math. Control Inf. **37**(4), 1237–1247 (2020)
10. Wang, H., et al.: PrePass: load balancing with data plane resource constraints using commodity SDN switches. Comput. Netw. **178**, 107339 (2020)
11. Cheng, Y., Jia, X.: NAMP: network-aware multipathing in software-defined data center networks. IEEE/ACM Trans. Netw. **28**(2), 846–859 (2020)
12. Nawaz, S.J., Sharma, S.K., Wyne, S., Patwary, M.N., Asaduzzaman, M.: Quantum machine learning for 6G communication networks: state-of-the-art and vision for the future. IEEE Access **7**, 46317–46350 (2019)
13. Bukhari, J., Yoon, W.: Simulated view of SDN based multicasting over D2D enabled heterogeneous cellular networks. In: 16th International Bhurban Conference on Applied Sciences and Technology, pp. 926–929. IEEE, Piscataway (2019)
14. Du, J., Jiang, C., Zhang, H., Ren, Y., Guizani, M.: Auction design and analysis for SDN-based traffic offloading in hybrid satellite-terrestrial networks. IEEE J. Sel. Areas Commun. **36**(10), 2202–2217 (2018)
15. Ma, J., Pan, C., Yin, C., Li, X.: Slice-aware resource management in SDN enabled heterogeneous cellular networks. In: 2019 IEEE/CIC International Conference on Communications in China, pp. 869–874. IEEE, Piscataway (2019)
16. Meng, X., Wu, L., Jiao, J., Gong, X.: Research on resource allocation method of the SIN based on SDN. In: 2019 IEEE International Geoscience and Remote Sensing Symposium, pp. 10071–10074. IEEE, Piscataway (2019)
17. Deng, B., Jiang, C., Yao, H., Guo, S., Zhao, S.: The next generation heterogeneous satellite communication networks: integration of resource management and deep reinforcement learning. IEEE Wirel. Commun. **27**(2), 105–111 (2020)
18. Suraj, R., Babu, S., Dalai, D., Manoj, B.S.: DebriNet: an opportunistic software defined networking framework over PSLV debris. In: 2019 IEEE International Conference on Advanced Networks and Telecommunications Systems, pp. 1–6. IEEE, Piscataway (2019)
19. Oh, J., Ryoo, Y., Kim, K., Doo, K., Lee, H., Chung, H.: SDN based real-time latency measurement and its monitoring for 5G mobile convergence passive optical networks. In: 2019 Asia Communications and Photonics Conference, pp.1–3. IEEE, Piscataway (2019)
20. Alfoudi, A.S.D., Newaz, S.H.S., Ramlie, R., Lee, G.M., Baker, T.: Seamless mobility management in heterogeneous 5G networks: a coordination approach among distributed SDN controllers. In: 2019 IEEE 89th Vehicular Technology Conference, pp.1–6. IEEE, Piscataway (2019)
21. Qu, H., Xu, X., Zhao, J., Yue, P.: An SDN-based space-air-ground integrated network architecture and controller deployment strategy. In: 2020 IEEE 3rd International Conference on Computer and Communication Engineering Technology, pp.138–142. IEEE, Piscataway (2020)