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Edge Computing in SDN-Enabled IoT-Based Healthcare Frameworks:
Challenges and Future Research Directions

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ABSTRACT

Millions of smart devices and sensors continuously produce and transmit data to control real-world infrastructures using complex networks in the internet of things (IoT). These devices have limited computing, processing, storage, and communication resources to perform time-critical and rigorous computing tasks. Edge computing has emerged as a new model to resolve the above problems by performing computation near IoT devices. The IoT revolution is reshaping the modern healthcare system with promising technological, economic, and social prospects. IoT in healthcare not only helps patients but also doctors to monitor the patient's health condition from a remote place. Software-defined networking (SDN) is an effective and promising solution to overcome issues such as IoT device management, control, interoperability, and maintenance. In this paper, the authors perform an extensive survey to analyze the role of SDN and edge computing in healthcare. Finally, the paper is concluded with the ongoing research on SDN and edge computing to solve various issues in IoT based healthcare domain.

KEYWORDS

Edge Computing, *Healthcare*, *IoT*, *Machine Learning*, *Quality of Service (QoS)*, *SDN*

INTRODUCTION

Recent advancements made in the field of information technology, the IoT has received enormous attention and plays a vital role in our day-to-day life activities. Various interconnected sensors/devices produce a huge amount of data and exchange amongst themselves using new communication technologies. Due to the increase in connected devices and generation of a large volume of data, which impose new challenges to manage current networks effectively. The advent of cloud computing has made analysis, management, data processing, and controlling related tasks are performed in the best way at data centers that host platform and application layers. In a time-critical application such as

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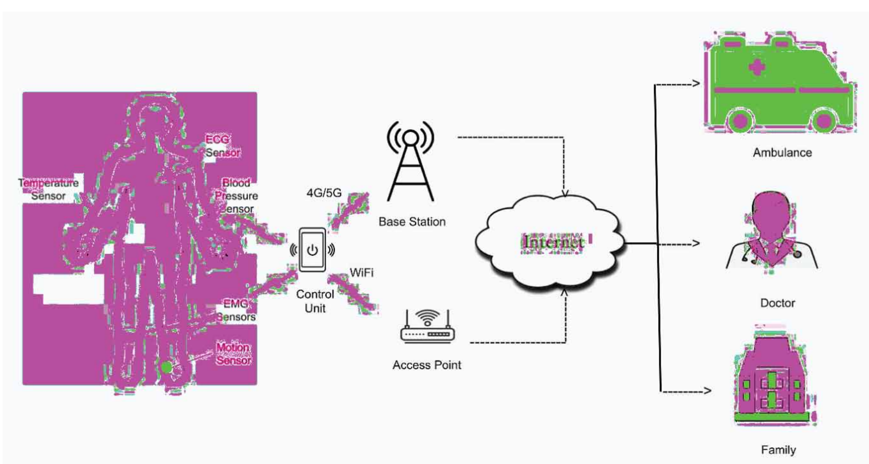
healthcare that requires real-time data delivery. Figure 1 shows the architecture of an IoT-based remote health monitoring system, where patient health data are gathered from sensors attached to the patient. The control unit gets and calculates the data from different sensors and sends it to a base station or access point. From the base station, data can be sent to the concerned authority for necessary actions.

One of the most important concerns in IoT is the presence of heterogeneous devices which generate a huge amount of data. Management of these heterogeneous devices and generated data is an open research challenge. Integration of the new networking paradigm SDN and edge computing with the IoT will completely transform the healthcare industry. SDN and edge computing provide features control network devices centrally with help of programming (Sallabi, Naeem, Awad, & Shuaib, 2018). SDN is a promising technology that can resolve the issues and meets the need of healthcare applications for high performance. It is cost-effective and capable of delivering low latency data services by optimizing the communication and computing power of IoT devices (Li et al., 2020) (Yongdong, n.d.).

Due to the rise in local storage capacity, edge computing is suitable to manage data adaptation and accumulation tasks. Although it is reliable data processing at the edge of devices adds a level of complexity that integrally increases risk in many applications. However, it is not easy to deploy additional computational resources close to the edge of the network and allowing them to be reachable ubiquitously. Apart from the complexity of technologies, there are many other challenges such as heterogeneity, scalability, mobility, limited energy, security, and privacy issues (Baktir, Ozgovde, & Ersoy, 2017) (Wang, Zha, Guo, & Chen, 2019). The complexities that arise due to the deployment of computational services at the edge of the network can be addressed by SDN with its inherent capability to manage resources centrally. SDN streamlines network management for the most complex networks by providing plug-and-play device setup and deployment and using the available resources very efficiently. However, it is still in the development stage and the application of SDN to Edge Computing is not yet fully resolved. Very few research papers address the combined perspectives of SDN and edge computing in IoT for healthcare applications.

Efficiently implementing edge computing in an SDN-based IoT environment in healthcare has certain requirements that it should fulfill. These requirements include latency, reliability, mobility support, real-time communication, interoperability, and security (Hassan, Gillani, Ahmed, Yaqoob, & Imran, 2018). Edge computing is expected to act as an important enabling technology in IoT applications (J. Bhatia, Dave, Bhayani, Tanwar, & Nayyar, 2020). Edge computing is used to reduce the volume of data sent to the cloud and minimize uptime. Recognizing the role of edge computing

Figure 1. IoT based remote health monitoring architecture (Taneja & Narayanamoorthy, 2019)



in IoT is a major research issue in the current scenario. Here in this survey, we have described the literature where IoT, SDN, and edge computing with collective work can deliver new services in healthcare and facilitate the management and operation of various IoT devices. Integration of SDN and edge computing with IoT greatly help in real-time health monitoring which can save lives in case of a medical emergency. It also provides interoperability, M2M communication, information sharing, and data transmission in healthcare that makes healthcare services more effective. With the help of IoT in real-time, we can collect, transmit and analyze the data generated by various sensors and medical IoT devices which help in quick decision making.

In healthcare applications, various types of edge devices generate a huge amounts of data and it's become very important to process and analyze it in real-time. In healthcare systems, need for data analysis near the edge devices arises as we need to take immediate decisions based on data processing. Machine learning techniques can be used to process and analyze the generated data to make a quick decisions in critical healthcare applications. Machine learning models should be suitable to deploy on small edge devices that have limited computational power and storage capacity. As edge devices have limited memory and computational power, it's become very important to modify the existing ML models so that they can be suitable and efficiently process the data(Murshed et al., 2021). Research on making intelligence edge devices for IoT using machine learning is still in its early stage, and it requires a lot of attention to improve its quality of service.

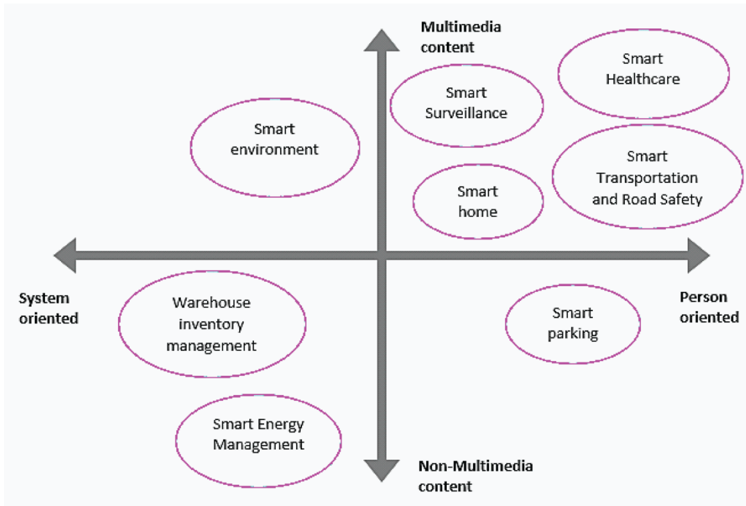
Internet of Things

There are many devices connected to the Internet, and these devices are constantly increasing. Rapid growth in IoT devices opens several applications in different domains. Figure 2 depicts the categorization of the IoT Applications based on multimedia and non-multimedia data (Floris & Atzori, 2016), and the type of end-user, that is, system or individual. The IoT is a new standard in the field of communications and has become the most important term in the research industry and academia in recent years. It has numerous variants and researchers named them during evolution such as M2M, IoE, IoA, IoMT, IIoT, and WoT. At the initial stage, IoT devices were not smart enough to fulfill the requirements and we need technologies to improve the capabilities of these devices. Therefore, it

Table 1. List of abbreviations

Acronym	Meaning
IoT	Internet of Things
SDN	Software Defined Networking
M2M	Machine to Machine
QoS	Quality of Service
CPS	Cyber Physical System
MEC	Mobile Edge Computing
RAN	Radio Access Network
NFV	Network Function Virtualization
IoE	Internet of Everything
IoMT	Internet of Medical Things
IoA	Internet of Anything
IIoT	Industrial Internet of Things
WoT	Web of Things
ML	Machine Learning

Figure 2. Categorization of IoT applications (Floris & Atzori, 2016)



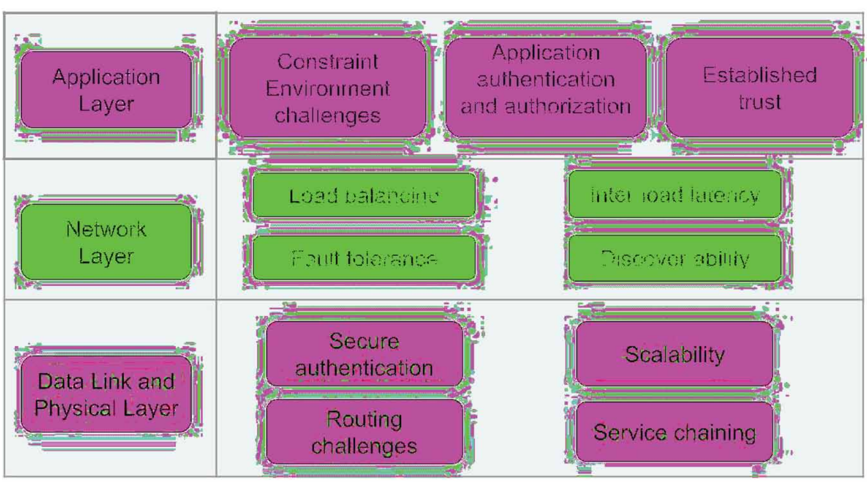
opens up many research challenges and opportunities for the research community (Li et al., 2020) (Rafique et al., 2020). Figure 3 shows the challenges faced by the various domains in IoT concerning layer architecture of simple IoT deployment.

IoT is using in various fields of human life which include, industry, healthcare, agriculture, communication, transportation, and many more areas. These different application domains put forward specific field requirements. Therefore, special attention must be paid to the consistent management of IoT communications. There is a high demand for using SDN to configure and manage distributed IoT networks.

Software Defined Networking

The rapid growth of communication technologies and the emerging use of IoT devices have generated an enormous amount of data. Traditional methods of implementing communication technologies

Figure 3. Classification of challenges faced by traditional IoT architecture (Mishra et al., 2019)



are usually based on hardware that limits the scalability of the network. SDN is proposed as the necessary technology to overcome this problem and provides high flexibility, scalability, low cost, and low power consumption. Due to the increasing demand for a large number of connected devices in the Internet of Things, a unified software-based model like SDN is required to maintain quality of service (QoS). SDN provides opportunities.

To solve issues, especially network configuration and resource management in IoT applications (Inag, Demirci, & Ozemir, 2019). The key idea behind the SDN is to separate the control plane and forwarding functions of the network i.e., the data plane (J. B. Bhatia, Dave, Bhavsar, Tanwar, & Kumar, 2021) (Bhatia, Govani, & Bhavsar, 2018). Figure 4 shows the SDN-IoT architecture consists of three different planes, the Infrastructure plane, Control plane, and Application plane. The infrastructure plane consists of multiple IoT devices that generate data, and the control plane plays the role of controlling the core network. The SDN controller and the IoT device communicate with each other through the southbound API. An application plane consists of multiple IoT applications using SDN strategies. The Key technologies like IoT, Cloud computing, Cyber-Physical systems (CPS) had led to the rapid growth of connections between various heterogeneous devices and the Internet. Due to its single point of failure, centralized control of the SDN architecture presents many challenges.

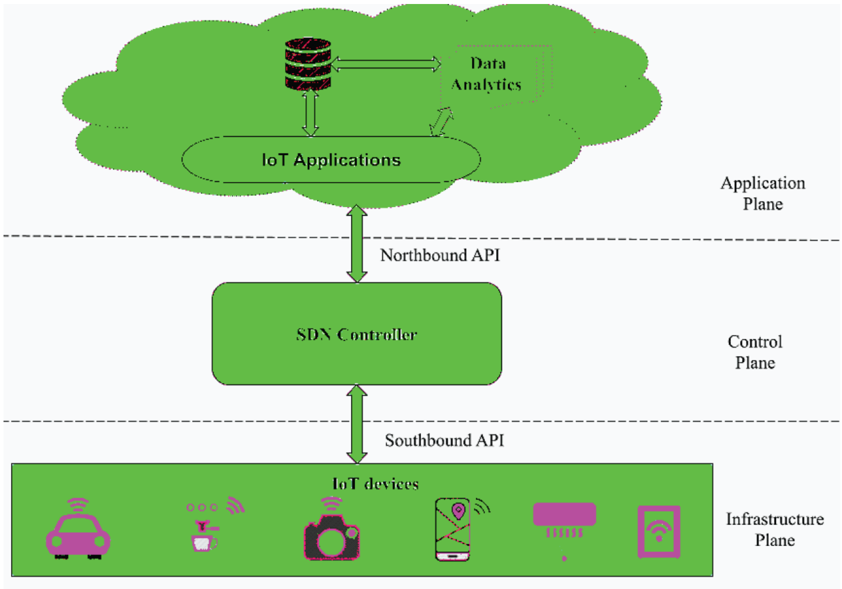
Edge Computing

In the past few years, cloud computing drew substantial attention especially in the context of IoT applications as it provides lower-cost solutions for changing and unexpected computational needs. Since IoT devices generate a large amount of data that leads to issues in communication time, bandwidth, storage, and data processing (Hamdan, Ayyash, & Almajali, 2020), so in such cases cloud computing paradigm is not performed well for new IoT applications. Edge computing is a cost-effective framework for extending cloud computing. It provides low-latency data services by bringing computing resources closer to the edge of the Internet of Things-based network. It helps in time-critical applications by minimizing the latency and response time. IoT applications can be categorized based on their delay sensitivity constraints (Hamdan et al., 2020). Based on delay sensitivity requirements, we can choose the appropriate implementation. IoT can be benefited from both Cloud and Edge computing due to its characteristics like enough computational power and larger storage capacity. However, edge computing performs well compared to cloud computing for IoT, though it has limited computational power and storage. IoT applications require real-time action rather than high computational power and storage. Figure 4 depicts the three-layer architecture of edge computing-based IoT. The bottom layer consists of various IoT devices, which generate the data. Data from the bottom layer send to the upper layer, where data processing and data analytics operations are performed at edge nodes to take real-time decisions. Based on decisions taken, data will be sent to cloud servers for detailed analysis and stored on the cloud for longer duration (Yu et al., 2018).

It has three implementation components; cloudlet, Mobile Edge Computing (MEC), and fog computing. These are different concerning their architecture, functionality, and node location:

- **Cloudlet:** It is a set of small-scale data centers denoting cloudlet nodes to provide services to IoT devices situated within the same geographic area.
- **Fog computing:** It is a distributed infrastructure of computing nodes that provides the services to the end-users, and computing takes place between end-users and the cloud. It consists of heterogeneous computing nodes such as switches and access points (Singh, Nayyar, Kumar, & Sharma, 2019) (Kumari et al., 2019).
- **Mobile Edge Computing (MEC):** It is a network that offers cloud computing services to mobile devices near the edge of a network, resulting reduction in latency. It processes enormous amounts of data before sending it to the cloud and reduces bandwidth utilization.

Figure 4. SDN-IoT Layered architecture



The remainder of the paper is organized as follows. Section II presented a related work of existing solutions combining SDN, edge computing, and IoT. Open discussion is presented in Section III. In section IV challenges and future research, directions are discussed. Finally, the paper concluded in Section 5.

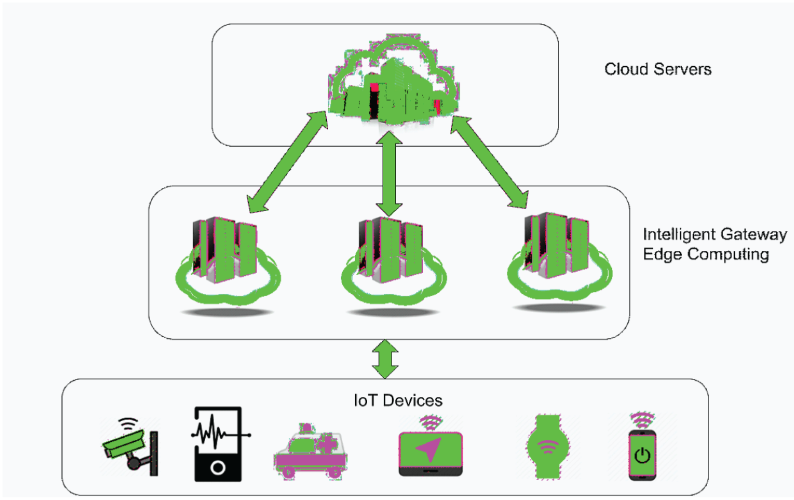
RELATED WORKS

The motivation of this survey comes from the recognition of the proliferation of smart IoT devices and their prime role in human life, specifically in healthcare. IoT in healthcare is a solution to numerous problems that have complemented the healthcare industry throughout history. Lower medication rates, shortage of treatment tools, and remote patient monitoring are a few. IoT devices generate a large amount of data that needs to be processed to obtain meaningful information.

Since IoT devices have limited computing power and processing speed, data needs to be sent to the remote data centers for further processing. Sending data to a remote server may cause latency, high energy consumption, security, and privacy issues. Edge computing offers optimum solutions for such power-limited devices and latency-sensitive applications. The rapid growth of the IoT infrastructure requires efficient grid management methods (Kumari & Tanwar, 2021). IoT devices are memory-limited, so they cannot be programmed to handle complex rules and dynamic traffic forwarding. SDN is a technology that provides centralized management to network resources. To the best of our knowledge, very few research efforts have been made in the joint perspective of IoT, SDN, and edge computing in the healthcare domain. Most of the proposed researches talk about specific aspects such as virtualization, standardization, and security. We need an integrated architecture to address the above issues. In this section, we reviewed the existing IoT solutions based on SDN and edge computing in the healthcare domain.

The article, (Yongdong, n.d.) briefly surveyed managing IoT services and the impact of integrating SDN and Edge computing. The author discusses the advantages of edge computing and SDN in IoT applications from the data and resource management perspectives. The amalgamation of edge

Figure 5. Edge computing based layered architecture of IoT (Yu et al., 2018)



computing and SDN through many of the challenges and complexities that the IoT services industry is facing.

In (Aggarwal & Srivastava, 2016) have made an effort to develop a method that uses SDN and Edge computing to provide security for the Internet of Things. They considered two options based on the way IoT devices connect to the Internet.

- The first scenario, When IoT devices connect to the internet through wireless access points and switches and use their specific ISP to connect further to the internet. This implementation consists of mainly three components Network Devices (OpenFlow Switches and Wireless routers), IoT Gateways, and SDN controller. This works for both Incoming and Outgoing network traffic and makes sure that the IoT devices are robust against any attack. The proposed work can prevent two types of attack i.e., ARP Spoof Attack and DoS attack.
- In the second scenario, the IoT devices are connected to the Internet through cellular networks (4G and 5G). In this approach, they modified the architecture of the existing radio access network (RAN) by introducing a new IoT gateway controller, which monitors all traffic passing from network devices. In case of any malicious packet or threat detection, the IoT gateway controller will update the corresponding flow table and send the information to the SDN controller to block specific IPs to route the network itself.

This proposed work is not tested for other types of major attacks and the system performance is also not measured during attack detection and mitigation.

In (Baktir et al., 2017) surveyed the benefits of SDN and edge computing integration and also discussed the challenges that arise due to bringing computational logic near to IoT devices. They have presented various practical architectures to demonstrate the idea of SDN and Edge computing integration with supportive use cases and scenarios. A service-centric access approach is also discussed to request by service name instead of IP address. Finally, the author advocates improving the interaction between SDN and edge computing for future IoT applications.

In (Taneja & Narayanamoorthy, 2019) assessed the successful approaches of IoT in healthcare. Further authors proposed a four-layer model called k-healthcare. These four layers work together to provide real-time service to patients based on information collected from the patient. In the future, a product or mobile application can be developed to get the information directly from sensors and processes. Security and privacy issues are not handled in the proposed model, so in the future, these issues can be explored.

In (Muhammad, Alhamid, Alsulaiman, & Gupta, 2018) proposed an edge computing supported voice disorder assessment and treatment framework using deep learning. The client's voice sample taken by smart sensors goes to edge computing for initial processing and then sends it to the cloud for further processing. After there it sends to a specialist to make the required decisions. The proposed framework offers interoperability, caching, and security. In the future, the proposed framework can be investigated with a compressed voice signal, which will reduce the bandwidth requirement.

In the article, (Kaur, n.d.) proposed a Multi-Access Edge Computing (MEC) architecture to solve current challenges facing IoT applications. It discusses the challenges such as limitation of computational resources, heterogeneity of the end devices, and load balancing between MEC servers in the proposed solution. Also how network programmability can be added to enhance the performance of the proposed MEC solution. In the proposed approach author has introduced a MEC coordinator that has real-time information about the resources and services which each MEC server offer. To provide network programming, SDN is used where the SDN controller is integrated with the MEC coordinator. SDN makes the network more flexible and dynamic, thus providing a global view of the core network. To reduce latency and offloading, MEC servers are positioned near the edge. Before transmitting the request to a specific MEC server, the MEC coordinator will make a decision based on the delay, power, and bandwidth requirements of the client's request. The author also discussed various issues such as mobility of user equipment and varying workload of MEC servers that need to be resolve in the successful implementation of the proposed approach.

In (Hartmann, Hashmi, & Imran, n.d.) surveyed the existing and emerging edge computing-based architectures in the healthcare domain. They also identified the needs and challenges of devices for various applications. Most of the surveys focus on architecture and types of application, here in this survey concerning Quality of Service(QoS) for data operations. Edge computing greatly helps in IoT for healthcare applications but still, there are some issues including privacy and data reduction techniques that need sincere attention. Future research directions motivate implementing edge computing in healthcare to provide a better quality of life for users.

In (Wang et al., 2019) discuss challenges faced in implementing edge computing to provide efficient network management. Discussed the challenges such as heterogeneity, interoperability, mobility, expressiveness, and smart network management at each layer, especially aiming at how they affect the network layer. The author has proposed a novel SDN-based network-layer framework to address the challenges explicitly for the Edge Computing paradigm. The authors extended the existing framework by adding several new modules and motivates to use advanced Artificial Intelligence and ML techniques for effectively managing the network resources.

In (Jha et al., 2019) proposed a new simulator IoTSim-Edge to measure performance and validation of IoT and edge computing integration. It lets users examine and exploit heterogeneous IoT and edge computing deployment. It is an extended version of CloudSim to integrate the various functions of edge and IoT devices. Authors have tested the effectiveness of a simulator for different use cases. Results show that the simulator is capable of modeling the mobility of IoT devices and resources provisioning for IoT applications.

In (Misra, Saha, & Ahmed, 2020) proposed a criticality aware traffic forwarding scheme for the mobile device to maximize the efficiency of an SDN-based healthcare system. Machine learning is used to find the criticality of flows and the position of the mobile device. The proposed protocol dynamically changes flow rules at the edge access points based on criticality levels in traffic. They assumed the network as SDN, and therefore there the system will be homogeneous, but the entire network may not deploy the SDN. In the future, a similar scheme can be proposed for heterogeneous network scenarios.

In (Rafique et al., 2020) thoroughly surveyed SDN and the edge computing systems to solve the challenges faced by IoT resource management. Introduced the latest research on software-defined IoT arrangements using Edge (SDIoT-Edge) and emphasized the key requirements for integrating these different architectures. It helps in solving issues faced in a cloud-based implementation. Furthermore, challenges such as limited storage capacity, energy constraint devices, computing resources, mobility, QoS management, etc., face difficulties for the recognition of SDIoT-Edge. Also, the centralized control mechanism in SDN can become a bottleneck. Its effective implementation depends on the success of the heterogeneous requirements of various architectures. Several case studies are discussed in detail to visualize basic concepts. It also features a comprehensive survey on security and privacy issues. Finally, the current research challenges and future research directions for providing efficient IoT services on SDIoT-Edge are discussed.

In (Li et al., 2020) an SDN-based edge computing security framework is proposed in the healthcare system that supports the IoT. To protect the system, the author proposes a lightweight authentication mechanism that uses an edge server to authenticate IoT devices. Only after successful authentication, these devices can exchange data with the edge server. This framework enables coordination between edge servers to use SDN controllers to solve high and real-time bandwidth requirements for load balancing and efficient network management. In the future, the proposed framework can be improved by protecting patient data. In addition, data patterns can be saved to data sets, and machine learning techniques can be applied to predict malicious activities on the network.

In (Yang, Liang, & Ji, 2021) analyzed the characteristics of the human, machine, and things in end side from the concerning data processing and then define the end intelligence to solve the problem of evaluation of heterogeneous devices. Also proposed is an end-edge cloud framework that enhances the efficiency of data processing and node placement. To verify the performance of the proposed framework, experiments are performed and the result is compared with existing traditional approaches. In the future, they have the plan to extend this work for the more complex healthcare system to cooperate with many hospitals.

Table 2 provides information about existing research in integration of Edge computing in SDN enabled IoT based healthcare applications.

OPEN DISCUSSION

The immense rise in IoT devices created new smart applications, but it also opens up new challenges in managing these devices. Currently, in the market, many technologies are integrated with IoT to improve performance. IoT in healthcare requires real-time data delivery, where we need to smartly process the data and send it to medical authorities for quick action. Academic and research institutes are trying to address the issues currently we are facing. SDN and Edge computing are very promising technologies that play an important role to increase the efficiency of IoT applications.

The SDN helps in controlling and managing networks employing programming. Edge computing provides low-latency data transmission by bringing computing resources closer to the edge of the network that supports the various Internet of Things applications. However, very few research efforts have been made in integrating SDN and Edge computing with IoT in the healthcare domain. In the healthcare system, IoT devices generate a large amount of data, so processing and storing this data in real-time require AI and machine learning techniques. Still, lots of efforts are needed to design AI and ML-based algorithms to process medical data. Table 2 shows the research carried out so far in this area. SDN-Edge integration provides several benefits to IoT in the healthcare system. But still, there are many research challenges such as heterogeneity, mobility of IoT devices, interoperability, security, and privacy need to be resolved. In the next section, we will discuss research challenges faced by researchers and also future research directions to solve those challenges in the healthcare domain.

The effectiveness of any IoT-based system depends on the quality of service it provides to the end-users. We can evaluate the quality of IoT systems using various quality attributes like latency,

Table 2. Current research in edge computing in SDN enabled IoT based healthcare

Author	Year	Key contributions	Limitations and Future research Directions
(Yongdong, n.d.)	2016	A brief survey of how to manage IoT services and can be improved by using Edge computing and SDN.	The integration of edge computing and SDN solve many of the issues and complexities that the IoT services are facing
(Aggarwal & Srivastava, 2016)	2016	A model is proposed to provide security to IoT using SDN & Edge Computing.	Proposed model need to implement and test against various major attacks and also, analyze system performance during attack detection and mitigation.
(Baktir et al., 2017)	2017	A comprehensive survey on related technologies of the Edge Computing and discussed the challenges facing in practical implementation of Edge computing in SDN-IoT	Improve an interaction between SDN and Edge Computing because SDN has the potential to enhance computational and network scenarios for future IoT applications.
(Taneja & Narayanamoorthy, 2019)	2018	Proposed a four layer model called k-healthcare to provide real-time service to patient based on information gathered	• Security and privacy issues are not handled • A mobile application can be develop to implement functionality of proposed model
(Muhammad et al., 2018)	2018	Proposed an edge computing based voice disorder assessment and treatment framework using deep learning. It offers interoperability, caching and security	• Proposed framework is not evaluated against the scalability and energy utilization. • Feasibility of framework can be investigated with compressed voice signal, which will reduce the bandwidth requirement
H. Kaur (Kaur, n.d.)	2018	Proposed a MEC architecture to address the challenges faced by current IoT applications. Introduced a MEC coordinator, integrated with SDN controller to provide network programming	Issues such as mobility of user equipment and varying workload of MEC servers need to be resolved
(Hartmann et al., n.d.)	2019	Surveyed the existing and emerging edge computing based architectures in healthcare domain and compared with respect to QoS parameters for data operations.	• Need to address the challenges related to managing large amount of data, data security and compatibility. • Also handle the tradeoff between complexity of AI techniques and accuracy.
(Wang et al., 2019)	2019	Discussed the challenges faced by Edge Computing to control advanced network technologies for cost-effective network management. Proposed a new network layer framework particularly for Edge Computing platform.	Advanced AI and machine learning methods can be used to manage the network resources efficiently.
(Jha et al., 2019)	2019	Proposed a new simulator IoTSim-Edge to measure performance and validation of IoT and edge computing integration.	Development of an IoT-Edge emulator in future to test mentioned functionality in a realistic situation.
(Misra et al., 2020)	2020	Proposed a ML based criticality aware traffic forwarding scheme for mobile device to maximize the efficiency of a SDN based healthcare system	Considered the entire network includes SDN, but in reality it may not be true. In future the similar scheme can be proposed for heterogeneous network scenarios.
(Rafique et al., 2020)	2020	Surveyed SDN and edge computing system (SDIoT-Edge) to solve the challenges faced in IoT resource management. Case studies are presented to visualize the basic concept pf proposed system.	Further research to be done for providing efficient IoT services in the SDIoT-Edge.
(Li et al., 2020)	2020	A security framework for edge computing based on SDN in healthcare systems supporting the IoT is proposed. It allows to solve the real-time and high-bandwidth requirements for load balancing and efficient network management through the SDN controller.	Framework can be enhanced by securing patients data. Furthermore, data pattern can be saved in a dataset and apply a ML techniques to predict malicious activities in the network.
(Yang et al., 2021)	2021	Proposed an end-edge-cloud framework which enhances the efficiency of data processing and node placement.	The proposed framework can be extended for complex scenario where multiple hospital work in cooperation.

energy utilization, security, privacy, and bandwidth utilization. Quality of service measurement of any IoT based system itself a very broad area of research. Here in this survey, quality evaluation techniques to measure the quality of the existing edge computing based healthcare solutions are not covered.

CHALLENGES AND FUTURE RESEARCH DIRECTIONS

Edge Computing and SDN integration look like exciting architecture in IoT applications. It is a new model which provides efficient resource deployment and management. Although Edge Computing and SDN have not grasped their potential yet, and may not fulfill the expectations and achieve the required QoS. Various research issues need to be solved, and more research efforts are required to solve these issues. Integration of SDN and edge computing with IoT is a challenging task to implement without solving issues such as Resource allocation, scalability, heterogeneity, availability, security, and privacy, etc. In this section, we provide open research challenges and future research directions for implementing edge computing in an SDN-IoT environment.

Resource Allocation at Edge Nodes

IoT devices are resource constraints and we need real-time data processing to control complex infrastructure. Compared to the cloud, edge nodes are limited in terms of resources, so smart decisions are needed to classify services, which can be processed at the edge and transferred to the central cloud. Numerous solutions have been proposed to solve the problem of managing allocation by researchers, though, these solutions are hardware-dependent and may not be appropriate for heterogeneous scenarios in healthcare systems (Rafique et al., 2020).

SDN and Network Function Virtualization (NFV), can be exploited to manage resource allocation. Distributed edge computing can be employed to address issues that arise due to low computations power at edge nodes in healthcare. Multiple edge nodes can cooperate to provide services, and SDN can resolve communication management issues.

Heterogeneous Network Devices

The heterogeneity in the SDN-enabled IoT environment exists in computing and communication technologies. The computing platform can have different operating systems and hardware architectures, and the communication technology can have different data rates, communication ranges, and bandwidths. To support heterogeneous structures, devices, and various service requirements are critical challenges in the SDNIoT edge computing environment for the smart healthcare system. Heterogeneous devices in the healthcare system generate lots of data, so managing the data pose data management challenges. These devices with different operating systems add to the complexity of file naming, resource allocation, and reliability management.

Scalability

As the number of devices increasing rapidly, it poses a challenge to scale these devices in existing infrastructure. One central controller in the SDN-IoT-based solution may not be adequate for managing these increasing devices. The cluster of controllers can be used to manage the large-scale network to minimize the workload of controller single controller (Baktir et al., 2017). However, a great deal of research work has been completed in this area but still, there is no comprehensive proposal that is effective and fully functional distributed control mechanism. Hence in future research, the focus should be given to making scalable smart healthcare systems to manage increasingly diverse healthcare applications.

Standardization

Standardization needs widespread deliberation due to the heterogeneity in the network infrastructure. Currently, various proposed frameworks are targeted to fulfill specific requirements. However, due to the diverse structures of the Internet of Things that need to be addressed, many similar requirements have emerged. In the healthcare field, many vendors manufacture various types of devices and products and that imposes diversity issues. Therefore, we need a standard IoT-based healthcare architecture for multi-purpose devices that supports mobility, interoperability, and synchronization.

Availability

Availability in SDN and edge computing-based IoT applications are referred to as anytime and anywhere availability of hardware and software-based resources and services. As the number of IoT devices is increasing, ensuring the availability of necessary resources and services becomes a challenging investigation for emerging IoT-based healthcare applications. Healthcare services are very critical, so we need further research efforts to ensure the availability of resources by minimizing the probability of failure and recovery time(Hassan et al., 2018).

Energy Management

Efficient network management in IoT is not a straightforward (Mishra et al., 2019). However, SDN provides a programming solution to manage networks dynamically. For integrating edge computing in an SDN-based IoT network, we need an efficient decision-making system to decide whether to send the service request to the cloud or process it at the edge node itself. It will save the transmission time and energy of IoT devices. IoT devices are energy-constrained, so further research efforts are required to optimize energy efficiency to provide better healthcare services.

Security and Privacy

The use of edge computing in SDN enabled IoT benefit to cybersecurity as in edge computing, data typically do not travel over a network. Edge nodes and heterogeneous IoT devices are part of a distributed architecture that makes it vulnerable to security. Communication between these heterogeneous devices causes data leakage issues in the absence of robust security solutions. The challenging task is to design robust security and privacy solution to manage heterogeneous devices for efficient resources in the healthcare system. A security solution using SDN and edge computing is proposed in (Aggarwal & Srivastava, 2016), but this has not been implemented and tested against major attacks. We can also analyze the performance of the system when detecting and mitigating future attacks. Blockchain can be used to ensure security and privacy for edge nodes and IoT infrastructure. Also, machine learning algorithms can be used to envisage malicious actions in the network.

CONCLUSION

IoT is a new standard to connect devices and enable smart applications, especially in healthcare. It is shifting the way we think to provide communication between an object in our surroundings which improve the quality of humans living standard. However, IoT still is an emerging technology in the healthcare field and facing many challenges such as data management of a huge amount of data generated by various devices, latency, scalability, and security. There are various other challenges that we need to address and start working on those challenges. SDN and edge computing are the two key technologies that help in improving the efficiency of IoT applications. In this paper, we have surveyed the existing solutions proposed by researchers to integrate edge computing in SDN-enabled IoT-based healthcare frameworks. We have categorized the various IoT applications based on latency requirement, so we can choose either cloud or edge computing based implementation. In the end, we have presented various challenges and future research directions for researchers.

CONFLICTS OF INTERESTS

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