International Journal of Computer Networks and Applications (IJCNA)
DOI: 10.22247/ijcna/2019/190369 Volume 6, Issue 6, November – December (2019)

SURVEY ARTICLE

A Survey on Edge-Based Internet-of-Things

Hushmat Amin Kar
Department of Electronics and Communication Engineering, National Institute of Technology, Srinagar, India
hushmat.kar@gmail.com

G.M. Rather
Department of Electronics and Communication Engineering, National Institute of Technology, Srinagar, India.
ghulammohdrather@yahoo.com

Published online: 30 December 2019

Abstract – Internet of Things (IoT) is improving the overall quality of our lives by helping us to connect, measure and control the different parameters of the system in an automated manner. The IoT devices are generating massive volumes of data that needs to be processed and on the basis of the results, decisions are made. The IoT devices have limited resource capabilities, so these devices utilize the services of the cloud servers. The issue in utilizing the services of the cloud is that it fails to provide support for real-time and time-critical applications. In order to reduce the response time of the system, another service layer is added to the architecture i.e. Edge computing. The IoT devices will now send their requests to the edge servers. Utilizing the services of the edge servers will reduce both the network traffic to the cloud and response time of the system. This paper presents a detailed survey of Edge-based IoT taking various parameters like architecture, bandwidth, security, energy, payload, etc. into consideration.

Index Terms – IoT, Edge, Cloud, 5G.

1. INTRODUCTION

IoT is a revolution in the existing internet where a large number of intelligent devices are connected through the internet. These devices (nodes) sense, gather and communicate the data with each other through improvised communication protocols [1-4]. A large amount of data collected by these devices need processing for extracting intelligence to provide services to end-user. In traditional computing, the data collected by the nodes is uploaded to the cloud server for further processing and results are transferred back to nodes for a needful response. This approach has a drawback of using costly bandwidth and other resources. Also with the increase in data size the transmission time increases which is unacceptable for time-sensitive applications like Smart transportation [5] smart city [6-8], Smart Grid [9,10], Smart healthcare [11].

Battery life is an important concern in an IoT device, so it is better to send the data to a nearby edge device with higher power backup and computational capabilities. The processing of data nearby the source will reduce the transmission time, power cost, etc. The edge device gives the nodes services like processing and storage close to the device at the edge of the network instead of than sending it to the cloud server. Thus, the amount of the data flow is reduced which in turn utilizes lesser bandwidth of the network. It minimizes the response time of computational nodes and also reduces the pressure of traffic and computation from the centralized cloud servers. By utilizing the services of edge nodes the IoT devices having limited battery can shift the processing and communicational overheads to the edge node having more resources as compared to the IoT nodes. Thereby, increasing the overall IoT node life.

2. SURVEY OF IOT AND EDGE

This section discusses the fundamental concept of the IoT, EDGE computing and the benefits of combining these two concepts.

2.1 IoT

IoT is an interconnected ecosystem of uniquely addressable devices having the capabilities of sensing, computation, and actuation and the ability to communicate and interoperate through the internet. The IoT can be defined as a dynamic infrastructure providing self-identifiable adaptive capabilities in nodes, in order to make them intelligent. These nodes recognize the triggers in the surrounding environment and accordingly react in an appropriate manner. This new environment will create new application services and each application service will achieve a common goal.

IoT is an evolving technology that is expanding its horizons in different areas at a very fast rate. The number of IoT devices is expected to increase to 50 billion connected devices, with over 200 billion intermediate connections by 2020 [12]. The main aim of IoT technology as described by Gartner [12] are:

• Integration of the physical and virtual worlds.

• Embedding the intelligence everywhere.

• Effect of the digital transition on technology

The improvement in the areas of sensors, Big Data, embedded systems, ubiquitous computing, cloud computing, communication networks, and Nano electronics will together facilitate achieving the goals of IoT technology. Figure 1 shows the three different communication models of IoT.

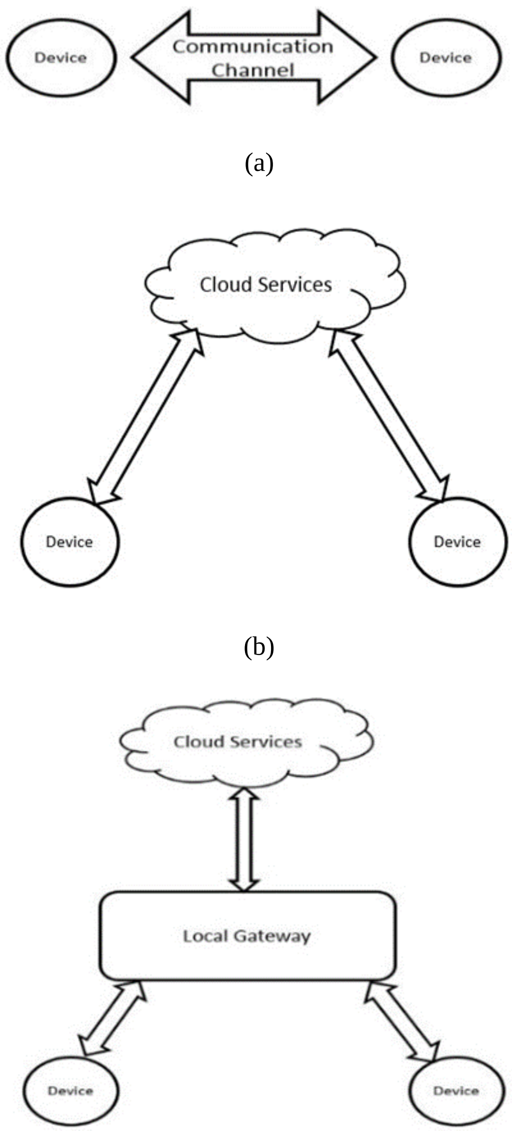


Figure 1: Different types of communication model of IoT.

2.1.1. Device to Device Communication(D2D)

In this communication scenario, IoT nodes are having the capability of exchanging information with each other directly, without involving any other hardware [13].

This Machine to Machine network allows devices to communicate through hybrid protocols in order to support desired quality of services (QoS). This type of model is well suited for many applications as communication is done via packets having small size and at a very low data rate. However, the problem with this model from a user perspective is the lack of compatibility between devices from different vendors such as the incompatibility between Z-wave protocol and ZigBee protocol devices [14]. The type of model is best suited to create ad-hoc wireless sensor networks and is easy to deploy in the environment.

2.1.2. Device to Cloud Communication (D2C)

In this type of communication model, end devices get services like computation and storage from the cloud service providers because of the limited computational and storage facilities of end devices [13]. The advantage of this model is that it utilizes the existing communication network infrastructure and resources. However, with increase in the number of devices bandwidth and other network resources become a barrier to performance. The optimization of the network is an essential step to improve the performance in this type of model.

2.1.3. Device to Gateway Communication (D2G)

In this type of model, the gateway of the network performs functions like data or protocol translation, security scan, etc. Thus acts as a firewall between the IoT nodes and the cloud service provider. In this type of model, the gateway acts as a middleware between the device and the application layer. This type of network provides the benefits of enhanced security and flexibility of IoT devices and also allows the low power devices to operate efficiently. The advantage of this communication model over the other models is that the gateway takes care of various features like security, protocol translation, etc for the IoT devices.

2.2. Basic Architecture of IoT

There are three building blocks in IoT network namely Sensors/Devices, IoT Gateway and Cloud network.

2.2.1. Sensor/Devices

To sense the surrounding environment various types of sensors are deployed in an IoT network. These sensors act as input to the whole IoT system by providing information about the respective environments. The sensor produces large amounts of diversified data which makes the IoT aware of everything. The devices can act as an interface between human and computer. The network of sensors embedded in the end devices allows them to interchange the data to provide the required services to the end-users.

2.2.2. IoT Gateway

IoT gateway interconnects IoT devices with cloud servers. Although IoT devices can have the capability of establishing the network directly with the cloud, but it is better to process the data prior to transmitting it to the cloud servers. IoT

SURVEY ARTICLE

gateway will collect the data from the sensors and end-users, carryout pre-processing in order to remove redundancy and unnecessary payloads. After processing, it will transfer the data to the cloud servers for further processing.

2.2.3. Cloud Network

Using efficient routing schemes (backhaul network), the data from the end-user is received by cloud servers through gateways [15,16]. The cloud servers are having large capabilities to handle the requirements like processing, storage, etc for IoT applications. After complete processing of the data, results are sent back to the end-users for providing the respective services to the end-users.

2.3. Edge Computing

Since the beginning of the concept of IoT, the number of IoT devices is increasing exponentially resulting in generation of a massive amount of diversified data to be processed. The traditional cloud computing structure does not possess capabilities like processing power, storage, bandwidth etc to handle such a large amount of data and hence is unable to maintain quality of service and support real time applications. With the advent of 5G communication technology on the rise, edge computing becomes a prime solution for solving these issues faced by the IoT network [17-19].In edge computing a new layer of computing with processing power, storage and support to good number of the applications is provided very near to end devices. This new layer is called Fog or Edge computing. By using Radio Access Network (RAN), edge computing can provide content-aware services and Quality of Experience (QoE) to the clients [20].The benefit of using edge computing is that it reduces latency, bandwidth consumption and processing load on the cloud server.

2.3.1. Edge Computing Architecture

The basic architecture of edge computing is shown in Figure 2.

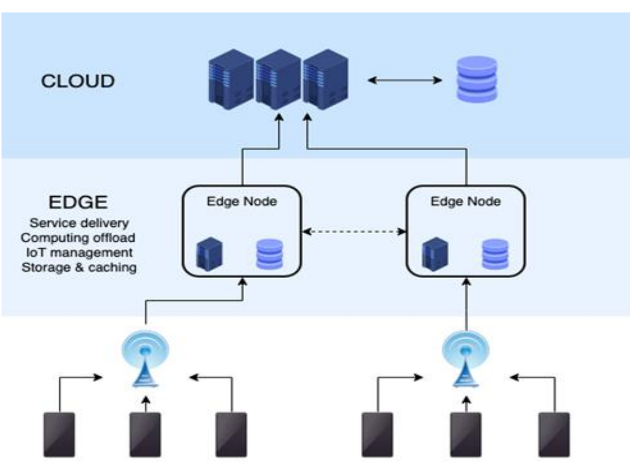


Figure 2 Traditional Architecture of Edge Computing

The edge servers have limited computational power as compared to the cloud server but it lies in the vicinity to the end-user. The edge servers can improve the quality of the network by reducing the latency and bandwidth requirements. The edge computing architecture framework broadly consists three units viz. "Front end", "Near end" and "Far end" as shown in figure 3.

2.3.1.1. Front End

The Front End comprises of the IoT nodes that are placed very close to in the sensing environment. The Front-end devices can provide a better overview of the sensed environment, so as to develop the QoS in real-time applications. As the front-end devices have limited capabilities so most of the service requirements are forwarded to the upper layers for processing.

2.3.1.2. Near End

The near end consist of servers with more processing power, storage etc close to the front end devices. These are called edge servers. The Edge servers placed at the network edge can have capabilities to provide various services like real-time computation, storing and retrieval of data, and edge offloading.

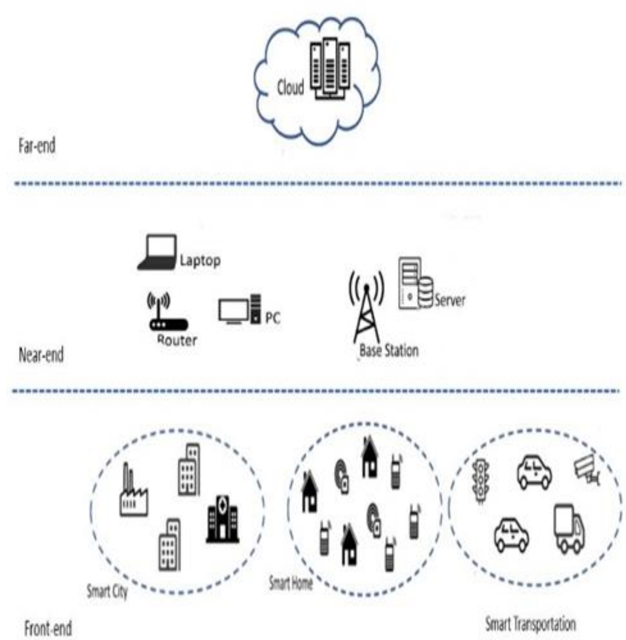


Figure 3 Architecture of Edge Computing

Most of the data processing is therefore shifted from cloud servers to near end servers, thus reducing the load on cloud servers. It also helps in better utilization of network resources like bandwidth etc. Processing at the network Edge improves the quality of service by reducing latency.

SURVEY ARTICLE

2.3.1.3. Far end

Cloud servers constitute the front end of the Iot structure. The cloud servers are much more powerful than the edge servers but the only drawback is that they are more distantly placed than edge servers. The processing of the data that is not time-sensitive can be done by utilizing services of cloud servers. It also provides services which are not facilitated by the edge layer.

The various features of three layer IoT architecture is given in Table 1.

Technology	IoT	Cloud	Edge
Network Deployment	Distributed	Centralized	Distributed
Computation	Limited	Unlimited	Limited
Storage	Small	Very Large	Large
Response Time	N/A	Slow	Fast
Data Processing	Source	Process	Process
Components	Physical Devices	Edge Nodes	Serversand virtual Resources.

Table 1 Characteristic Features of IoT, Cloud and Edge

2.3.2. Edge Computing Implementation:

There are two most prominent ways in which Edge computing can be implemented

- Hierarchical model.
- Software-defined model (SDN).

2.3.2.1. Hierarchical Model

In this model, the edge servers are placed in the networks at different distances and each edge network is assigned a function according to its position in the network and available resources. This model is well suited to meet the peak loads of the network. Various researchers have made efforts in implementing edge computers in a hierarchical way. The authors in [21] proposed the combination of mobile edge computing and cloudlet infrastructure, thus providing the user with the potential to meet the computational requirements. Tong et al [22] propose a hierarchy model that can serve peak load demands for mobile users.

2.3.2.2. Software-Defined Model

The number of IoT devices is expected to rise to 75 billion devices. The management of such large devices will be cumbersome [23-26]. SDN bifurcates the data and control plane, thus becomes a prime factor in managing the edge computing for IoT. Various researchers have proposed software-defined implementation of edge computing. Jarawah et al proposed to combine SDN capabilities and MEC systems. Thus reduces the cost of management and administration [27].

Manzalini et al proposed the edge operating system which allows the use of various open-source software providing an efficient system for services [28]. Elhaj et al. proposed the combination of SDN, MEC, and networks function virtualization (NFV) [29]. Lin et al. proposed the application on SDN based infrastructure which allows the development of various network services and applications [30].

3. PERFORMANCE ANALYSIS OF AN IOT SYSTEM

The performance of an overall IoT system is examined in terms of following

- Transmission time.
- Storage utilization.
- Processing power.
- Bandwidth utilization.
- Energy consumption

The performance of an IoT system improve in all the five areas by incorporating the edge computing technology in the traditional IoT system.

3.1 Transmission Time

The performance of a network depends on the bandwidth, latency, reliability etc. As most of the IoT applications are time-sensitive, using edge computing reduces transmission time [35]. Response time T_R which is sum of Transmission time T_t and processing time T_P also improves Thus, improving the QoS for time-dependent/real-time applications like Human Action classification [36] Vehicle to Motion estimation [37] Vehicle communication, Live video analytics [38].For such systems researchers have proposed use of distributed intelligent edge and cloud technologies[39]. Also, edge computing can improve the network efficiency by offloading the processing and storage. The transmission type can be reduced by factors like

- Minimizing the Latency/Delay.
- Reducing Bandwidth Requirements.
- Reducing Transmission Overhead.

3.1.1 Latency/Delay

For an application, latency depends on two factors i.e. transmission and computational latency. Transmission latency can be defined as the time taken by data from the devices to

SURVEY ARTICLE

the cloud servers. The computational latency is the time taken for the processing of data. The computational latency depends on the capability of the system to process the data. It is obvious that Edge servers have large computational power as compared to the IoT devices, and are at the network edge, thus can reduce both computational time and transmission time. Therefore, an efficient offloading protocol should be developed which can check whether the data need to be transmitted to the edge/cloud server or it can be processed locally. Some of the researchers have proposed schemes like offloading of data to other servers, which in turn reduces the latency/delay and provide efficient resource utilization [40-52].

3.1.2 Bandwidth

IoT uses a large number of sensors, which generate a massive amount of data that results in a number of problems like delay, packet loss, etc. Therefore, data needs to be processed and compressed by the IoT gateways before transmitting it to higher levels. The main objective is to enforce such protocols which ensures lesser bandwidth requirements while maintaining the data integrity.

Researchers have tried to provide solutions to this issue. For example, REPLISOM proposed by Abdel-Wahab et al. in which LTE-optimized memory replication protocol and LTE-aware edge cloud architecture are used for efficient scheduling of memory replication operations [53]. Another scheme called Span Edge is proposed by Sajad et al. in which application are placed in distributed manner, so as to reduce bandwidth utilization [54].

3.1.3 Overhead

As the number of IoT devices is large. The header and trailer added to each data packet in the IoT network lead the massive network overload by using edge servers. Some of the data packers can be transmitted collectively with lesser overload. Several techniques are used to handle this issue. Like the cross-layer scheme which aims to improve the transmission by reducing the overhead [55].

3.2 Energy

IoT devices have a limited amount of power resources and battery capacity. Thus the data computation and uploading should be carefully done keeping in view the limited battery. Embedding edge technology into IoT will in result increasing the life span of devices having limited battery life. The efficient schemes of offloading are incorporated by the edge devices for increasing the overall network life. The reduced transmission time will also help in enhancing the node life.

3.3 Storage Utilization

The service of storage provided by the cloud is very large and severe. This storage is centralized and relies at the top of the network. To improve the storage system of IoT network, there is a need to shift the storage from the centralized storage to edge computing. The storage provided in the edge servers is distributed one and this can be used to provide support to the edge nodes so as to balance their storage demand. These edge computing-based storage should possess the techniques of recovery, offloading and fault tolerance.

3.3.1 Storage Balancing

The total amount of data produced by the IoT devices is massive. Uploading this data to the cloud simultaneously will put a lot of pressure on the network. Considering the scenario of the healthcare sector where the data received from the sensor need to be uploaded to the storage within limited time and analysis of data is to be done quickly.

Sending of data simultaneously to the cloud server will choke the network bandwidth. It is better to use edge computation based storage where the data will be uploaded and analyzed efficiently with less response time.

There are many edge offloading techniques available for balancing the computational and storage demands [56-58]. The primary attribute of these techniques is to remove redundant data packets. Another technique, MM Packing keeps track of storage demands and remove the redundant data [57].

3.3.2 Recovery Policy

The recovery policies in storing the data to the edge computing-based storage systems will be ensure the accuracy and availability of data. In order to make the system more reliable, data availability is made compulsory by making redundant copies of the data at different nodes.

The unavailability of data may result due to many reasons like node crash, maintenance time shutdown/restart, storage error, network error, etc. Only 10% of these failures take rectification time more than 15 minutes [59].

There are techniques proposed by the researchers to handle this issue like the Mean time to failure (MTTF) scheme is proposed in which MTTF is calculated and the probability of each node to remain active is computed [59][60][61].

The Data received by the IoT system is large and for ensuring the availability of correct data, it is needed to be stored at distributed locations.

By distributing the data to multiple locations leads to improved MTTF [62].The data stored in the storage is in the form of fixed code blocks [63].and can be generated /recalculated using physical and logically neighboring blocks [43].The replicating the data to the distributed storage will reduce the risks of data loss.

SURVEY ARTICLE

3.4 Computation

The edge node has limited storage and computational power as compared to the cloud sensors (unlimited computational and storage).The edge computing meets the requirements of the client nodes by offloading computational and storage tasks through efficient task scheduling methods based on the requirements of applying the task scheduling technique are decided on the basis of computational pricing policies and priority of data.

3.4.1 Computation Sharing

To increase the efficiency edge servers are adjusted as per the location of different computational nodes. Today's most IoT devices have limited computational capabilities like M2M communications. These types of communications have a minimum response time.

When the IoT device needs more resource then the tasks are shifted to the edge cloudlet server which provides further support to meet its requirements with minimum latency and bandwidth. When some tasks need more resources available at M2M and edge levels then it is uploaded to the cloud server for the processing. The overall latency will increase by shifting the task or data to the cloud servers. There is a trade-off between the transmission and computational time.

3.4.2 Pricing Policy

The edge computing network provides the nodes with the resource for computation and storage on their request. The allocation of resources to the nodes is done on the basis of subscription with the service provider. Based on the number of service provider two types of services are rendered to the users.

3.4.2.1 Single Service Providers

In this scheme, the nodes get registered under one of the pricing policies provided by the single service provider. This service provider has placed the edge/cloudlet server at different locations with respect to the end-user. The nodes can then subscribe to the desired edge server in order to get services.

Various researchers have proposed schemes for determining the pricing of various edge servers located at different levels in the network [64,65].

3.4.2.2 Multiple Server Providers

As the IoT applications are diversified in nature so the computational and storage services can not be provided by multiple service providers. The pricing policies in these service providers will encourage other parties to give their infrastructure as a service to gain benefits. Further, there will be more competition among the service providers which will be a benefit to users.

3.4.2.3 Priority

InIoT network, priority is a key factor in deciding the task scheduling algorithm. While keeping priority as the primary factor, the efficiency of an IoT application will increase. In this scheme, the application will be given the priority as per their nature. Various researchers have worked in this area have proposed efficient schemes either by prioritizing the tasks (93) or by using the web objects [66]. The application which requires less latency like real-time application will get the highest priority while others will be provided with lower priority.

4. CHALLENGES OF EDGE-BASED IOT SYSTEM

Despite having a number of advantages in the use of integrated edge based IoT architecture, there are few challenges faced by this integrated system which are discussed below:

4.1 System Integration

Edge computing is a complex and heterogeneous system comprising of diversified networks, processing modules, and platforms. Besides providing a number of benefits like diversified and real-time processing environment, it suffers from a number of incompatibility issues arising from the integration of different platforms. From a programing point of view, the applications that are developed on one edge computing experience a lot of difficulties in processing, when they are deployed to different edge platform. There are many efforts made by the researchers to solve the programmability issues faced by the applications on edge computing [67, 68].In some of the proposed schemes, the IoT nodes pre-fetch the information about the edge platform to know the environment. Also, edge nodes face challenges in deploying the cloud side programs on the edge.

As the data sensed by IoT devices is large and is stored in the diversified storage servers. The naming management of data resources like resource allocation, resource naming becomes another issue. The traditional resource naming schemes such as "Domain Name Service (DNS)", "Uniform resource identifier (URI)" are not suited for edge computing and IoT. Further IP based naming schemes is not suited for multi-source and multitasking systems like edge computing because of their cost. The researchers have proposed Named Data Networking and Mobility First naming schemes for edge computing.

4.2 Resource Integration

By integrating the technologies of IoT and edge computing one of the challenges is to make the efficient policies, so as to utilize full capabilities of the system. Another challenge is that the system should have well-established auction policies so that there should be an abstraction level between the users

SURVEY ARTICLE

and service providers, which will preserve the privacy of the users. Securing the credentials of both service providers and users will be a basis for unbiased and fair auction policies.

4.3 Security and Privacy

The heterogeneous nature of edge computing and IoT provides a solution to a lot of challenges. However, like traditional cloud computing there is a threat of security and privacy in this integrated system e.g. Authenticity of the edge nodes, heterogeneity of the edge nodes. Further the distributed nature of the IoT network is another a challenge for privacy and security.

Also, the edge server that serve a cluster of devices puts a threat for data that is stored and processed at the edge server and is more vulnerable than the cloud server [34]. Some of the efforts like local differential privacy [69] and differential privacy with high quality [70] to preserve the privacy are needed to be enhanced for the IoT based edge computing system.

The authentication of the gateways is also one of the major threats to the IoT based edge computing system, as one has to authenticate the system at different levels. Further, the edge servers are managed by different service providers which makes it difficult to implement similar security strategies and policies.

Security of the IoT system particularly the data gets compromised during transmission, storage and processing as enumerated below;

4.3.1 Transmission

IoT based edge computing system is implemented in multiple wireless network environments like mobile wireless networks [73], Ultra-Dense networks [74], and maintaining security in such scenarios without compromising the quality of service is a challenging task.

Ensuring implementation of various security policies during the transmission of data between source and sink nodes is one of the most important steps of every communication system, as it keeps the data, infrastructure safe from any security threats [71,72]. Several techniques such as software-defined networks [75, 24] can be used for efficiently achieving the desired level of security.

4.3.2 Storage

A large volume of data is being sensed by the IoT devices and send to the edge nodes for computation and storage. The storages provided by the third-party vendors, which leads to the threat for the safety of data. To mitigate these problems various techniques like fully homomorphic encryption [76, 77], third party auditor (TPA), resource access control (RAC) techniques can be used to safeguard the data.

4.3.3 Computation

In edge-based IoT computing there is a need to ensure the implementation of security and privacy policies during the processing of data. Researchers have proposed various methods to ensure the safety of the data during computation. Gennaro et al have proposed a concept of verified computing in which the edge nodes are classified as trusted and untrusted groups. The trusted edge nodes are authorized to process the data. The data collected by the untrusted edge node is offloaded to the trusted nodes for computation [78]. Another approach of verified computing is proposed by parno et. al. known as Pinocchio, which uses cryptographic algorithms to verify the computational results [79].

The decentralization of edge networks makes it difficult to manage and secure the data. In [80], the author has proposed a secure box, which is a service-based solution to protect edge nodes. In addition to these techniques, researchers have proposed other techniques like bottom-up foundation stack (BUFS), honey Bot to safeguard the data from any threat [81, 82].

4.4 Advanced Communication

Another challenge of futuristic IoT system is the increasing demand for services having large capacities in terms of bandwidth, minimum latencies, high security and huge device density, etc. The ultra-dense networks, massive MIMO, and millimeter wave communication are cater to the needs of the applications by providing adequate communication features in terms of data rate and bandwidth. Various researchers have studied the benefits of integrating IoT, edge computing, cloud, and 5G networks. For example, in [83] the author proposes a scheme for the management of subscribers in 5G scenarios. In [84] the author proposed a scheme for voice over Wi-Fi (VOWiFi) in the edge based IoT framework, which helps in tracking the user location.

The use of next-generation communication technology (5G), artificial intelligence with the edge based IoT will result in further enhancement of smart infrastructures like smart grid, smart city etc.

5. CONCLUSION

Edge computing offers support to an IoT system by providing various services to the IoT devices at the edge of the network. In this paper a complete analysis of QoS parameters for edge based IoT has been presented. This new environment provides features like support to low power devices and time critical application, which in turn improves the overall efficiency of smart systems. The parameters considered in the survey are transmission time, storage utilization, processing power, bandwidth utilization, and energy consumption. The various challenges faced by this edge based IoT integrated system were also discussed in detail.

SURVEY ARTICLE

REFERENCES

[1] D. Linthicum, ``Responsive data architecture for the Internet of Things," Computer, vol. 49, no. 10, pp. 72_75, 2016.

[2] J. Lin, W. Yu, N. Zhang, X. Yang, H. Zhang, and W. Zhao, ``A survey on Internet of Things: Architecture, enabling technologies, security, and privacy, and applications," IEEE Internet Things J., vol. 4, no. 5, pp. 1125_1142, Oct. 2017.

[3] J. A. Stankovic, ``Research directions for the Internet of Things," IEEE Internet Things J., vol. 1, no. 1, pp. 3_9, Feb. 2014.

[4] J. Wu and W. Zhao, ``Design and realization of internet: From net of things to Internet of Things," ACM Trans. Cyber-Phys. Syst., vol. 1, no. 1, pp. 2:1_2:12, Nov. 2016. [Online]. Available: http://doi. acm.org/10.1145/2872332

[5] J. Lin, W. Yu, X. Yang, Q. Yang, X. Fu, and W. Zhao, ``A real-time en-route route guidance decision scheme for transportation-based cyberphysical systems," IEEE Trans. Veh. Technol., vol. 66, no. 3, pp. 2551_2566, Mar. 2017.

[6] N. Mohamed, J. Al-Jaroodi, I. Jawhar, S. Lazarova-Molnar, and S. Mahmoud, ``SmartCityWare: A service-oriented middleware for cloud and fog enabled smart city services," IEEE Access, vol. 5, pp. 17576_17588, 2017.

[7] S. Mallapuram, N. Ngwum, F. Yuan, C. Lu, and. Yu, ``Smart city: The state of the art, datasets, and evaluation platforms," in Proc. IEEE/ACIS 16th Int. Conf. Comput. Inf. Sci. (ICIS), May 2017, pp. 447_452.

[8] M. D. Cia et al., ``Using smart city data in 5G self-organizing networks," IEEE Internet Things J., to be published.

[9] Y. Yan, Y. Qian, H. Sharif, and D. Tipper, ``A survey on cybersecurity for smart grid communications," IEEE Commun. Surveys Tuts., vol. 14, no. 4, pp. 998_1010, Oct. 2012.

[10] J. Lin,W. Yu, and X. Yang, ``Towards multistep electricity prices in smart grid electricity markets," IEEE Trans. Parallel Distrib. Syst., vol. 27, no. 1, pp. 286_302, Jan. 2016.

[11] L. Catarinucciet al., "An IoT-Aware Architecture for Smart Healthcare Systems," in IEEE Internet of Things Journal, vol. 2, no. 6, pp. 515-526, Dec. 2015. DOI: 10.1109/JIOT.2015.2417684.

[12] “Gartner: Top 10 Strategic Technology Trends For 2013.”0020 [Online]. Available: https://www.forbes.com/sites/ericsavitz/2012/10/23/gartner-top-10-strategic-technology-trends-for-2013/#502d3b29b761. [Accessed: 10-Jan-2019].

[13] F. Wortmann and K. Flüchter, ``Internet of Things," Bus. Inf. Syst. Eng.,vol. 57, no. 3, pp. 221_224, 2015.

[14] A. Al-Fuqaha, M. Guizani, M. Mohammadi, M. Aledhari, and M.Ayyash, ``Internet of Things: A survey on enabling technologies, protocols, and applications," IEEE Commun. Surveys Tuts., vol. 17, no. 4, pp. 2347_2376, 4th Quart., 2015.

[15] W. Yu, G. Xu, Z. Chen, and P. Moulema, ``A cloud computing-based architecture for cyber security situation awareness," in Proc. IEEE Conf.Commun. Netw. Secur. (CNS), Oct. 2013, pp. 488_492.

[16] Z. Chen et al., ``A cloud computing-based network monitoring and threat detection system for critical infrastructures," Big Data Res., vol. 3, pp. 10_23, Apr. 2016.

[17] W. Yu, H. Xu, H. Zhang, D. Grif_th, and N. Golmie, ``Ultra-dense networks: Survey of state of the art and future directions," in Proc. 25th Int. Conf. Comput. Commun. Netw. (ICCCN), Aug. 2016, pp. 1_10.

[18] M. Agarwal, A. Roy, and N. Saxena, ``Next-generation 5G wireless networks: A comprehensive survey," IEEE Commun. Surveys Tuts., vol. 18, no. 3, pp. 1617_1655, 3rd Quart., 2016.

[19] P. Demestichaset al., ``5G on the horizon: Key challenges for the radio access network," IEEE Veh. Technol. Mag., vol. 8, no. 3, pp. 47_53, Sep. 2013.

[20] A. Ahmed and E. Ahmed, ``Asurvey on mobile edge computing," in Proc.10th Int. Conf. Intell. Syst. Control (ISCO), Jan. 2016, pp. 1_8.

[21] Y. Jararweh, A. Doulat, O. AlQudah, E. Ahmed, M. Al-Ayyoub, andE. Benkhelifa, ``The future of mobile cloud computing: Integrating cloudlets and mobile edge computing," in Proc. 23rd Int. Conf. Telecommun. (ICT), May 2016, pp. 1_5

[22] L. Tong, Y. Li, and W. Gao, ``A hierarchical edge cloud architecture for mobile computing," in Proc. 35th Annu. IEEE Int. Conf. Comput. Commun. (INFOCOM), Apr. 2016, pp. 1_9.

[23] G. Wang, Y. Zhao, J. Huang, and W. Wang, ``The controller placement problem in software de_ned networking: A survey," IEEE Netw., vol. 31, no. 5, pp. 21_27, Sep. 2017.

[24] D. Zhu, X. Yang, P. Zhao, and W. Yu, ``Towards effective intra-_ow network coding in software de_ned wireless mesh networks," in Proc. 24th Int. Conf. Comput. Commun. Netw. (ICCCN), Aug. 2015, pp. 1_8.

[25] Y. Jararweh, A. Doulat, A. Darabseh, M. Alsmirat, M. Al-Ayyoub, and E. Benkhelifa, ``SDMEC: Software de_ned system for mobile edge computing," in Proc. IEEE Int. Conf. Cloud Eng. Workshop (IC2EW), Apr. 2016, pp. 88_93.

[26] P. Du and A. Nakao, ``Application speci_c mobile edge computing through network softwarization," in Proc. 5th IEEE Int. Conf. Cloud Netw. (Cloudnet), Oct. 2016, pp. 130_135.

[27] Y. Jararweh, A. Doulat, A. Darabseh, M. Alsmirat, M. Al-Ayyoub, and E. Benkhelifa, ``SDMEC: Software de_ned system for mobile edge computing," in Proc. IEEE Int. Conf. Cloud Eng. Workshop (IC2EW), Apr. 2016, pp. 88_93.

[28] A. Manzalini and N. Crespi, ``An edge operating system enabling anything-as-a-service," IEEE Commun. Mag., vol. 54, no. 3, pp. 62_67, Mar. 2016.

[29] O. Salman, I. Elhajj, A. Kayssi, and A. Chehab, ``Edge computing enabling the Internet of Things," in Proc. IEEE 2ndWorld Forum Internet Things (WF-IoT), Dec. 2015, pp. 603_608.

[30] T. Lin, B. Park, H. Bannazadeh, and A. Leon-Garcia, ``Demo abstract: End-to-end orchestration across SDI smart edges," in Proc. IEEE/ACM Symp. Edge Comput. (SEC), Oct. 2016, pp. 127_128.

[31] F. Bonomi, R. Milito, P. Natarajan, and J. Zhu, ``Fog computing: A platform for the Internet of Things and analytics," in Big Data and Internet of Things: A Roadmap for Smart Environments (Studies in Computational Intelligence), vol. 546. Cham, Switzerland: Springer, 2014, pp. 169_186.

[32] H. Jiang, F. Shen, S. Chen, K.-C. Li, and Y.-S. Jeong, ``A secure and scalable storage system for aggregate data in IoT," Future GenerationComput. Syst., vol. 49, pp. 133_141, Aug. 2015.

[33] X. Yang, T.Wang, X. Ren, and. Yu, ``Survey on improving data utility in differentially private sequential data publishing," IEEE Trans. Big Data, to be published.

[34] G. Ananthanarayananet al., ``Real-time video analytics: The killer app for edge computing," Computer, vol. 50, no. 10, pp. 58_67, 2017.

[35] J. C. Niebles and L. Fei-Fei, ``A hierarchical model of shape and appearance for human action classi_cation," in Proc. IEEE Conf. Comput. Vis.PatternRecognit. (CVPR), Jun. 2007, pp. 1_8.

[36] G. Botella and C. García, ``Real-time motion estimation for image and video processing applications," J. Real-Time Image Process., vol. 11, no. 4, pp. 625_631, Apr. 2016. [Online]. Available: http://dx.doi.org/ 10.1007/s11554-014-0478-y.

[37] J. Liu, Y. Mao, J. Zhang, and K. B. Letaief, ``Delay-optimal computation task scheduling for mobile-edge computing systems," in Proc. IEEE Int. Symp. Inf. Theory (ISIT), Jun. 2016, pp. 1451_1455.

[38] G. Ananthanarayanan, V. Bahl, and P. Bodík. (2017). Microsoft Live Video Analytics. [Online]. Available: https://www.microsoft.com/enus/research/project/live-video-analytics/

[39] J. R. Bergen, P. Anandan, K. J. Hanna, and R. Hingorani, ``Hierarchical model-based motion estimation," in Proc. Eur. Conf. Comput. Vis., 1992, pp. 237_252.

[40] I. Ketykó, L. Kecskés, C. Nemes, and L. Farkas, ``Multi-user computation offloading as multiple knapsack problem for 5G mobile edge computing," in Proc. Eur. Conf. Netw. Commun. (EuCNC), 2016, pp. 225_229.

[41] Y. Liu, S.Wang, and F. Yang, ``Poster abstract: A multi-user computation offloading algorithm based on game theory in mobile

SURVEY ARTICLE

cloud computing," in Proc. IEEE/ACM Symp. Edge Comput. (SEC), Oct. 2016, pp. 93_94.

[42] L. Tianze, W. Muqing, and Z. Min, ``Consumption considered an optimal scheme for task offloading in mobile edge computing," in Proc. 23rd Int.Conf. Telecommun. (ICT), 2016, pp. 1_6.

[43] M. H. ur Rehman, C. Sun, T. Y. Wah, A. Iqbal, and P. P. Jayaraman, ``Opportunistic computation offloading in mobile edge cloud computing environments," in Proc. 17th IEEE Int. Conf. Mobile Data Man-age. (MDM), vol. 1. Jun. 2016, pp. 208_213.

[44] W. Gao, ``Opportunistic peer-to-peer mobile cloud computing at the tactical edge," in Proc. IEEE Military Commun. Conf. (MILCOM), Oct. 2014, pp. 1614_1620.

[45] Y. Wang, M. Sheng, X. Wang, L. Wang, and J. Li, ``Mobile-edge computing: Partial computation offloading using dynamic voltage scaling,"IEEE Trans. Commun., vol. 64, no. 10, pp. 4268_4282, Oct. 2016.

[46] M. Deng, H. Tian, and X. Lyu, ``Adaptive sequential offloading game for multi-cell mobile edge computing," in Proc. 23rd Int. Conf. Telecommun. (ICT), May 2016, pp. 1_5.

[47] Y. Nam, S. Song, and J.-M. Chung, ``Clustered NFV service chaining optimization in mobile edge clouds," IEEE Commun. Lett., vol. 21, no. 2, pp. 350_353, Feb. 2017.

[48] N. Fernando, S. W. Loke, and W. Rahayu, ``Computing with nearby mobile devices: A work-sharing algorithm for mobile edge-clouds," IEEETrans. Cloud Comput., to be published.

[49] X. Sun and N. Ansari, ``PRIMAL: PRo_t maximization avatar placement for mobile edge computing," in Proc. IEEE Int. Conf. Commun. (ICC),May 2016, pp. 1_6.

[50] H. Lee and J. Flinn, ``Reducing tail response time of vehicular applications," in Proc. IEEE/ACM Symp. Edge Comput. (SEC), Oct. 2016, pp. 103_104.

[51] T. G. Rodrigues, K. Suto, H. Nishiyama, and N. Kato, ``Hybrid method for minimizing service delay in edge cloud computing through VM migration and transmission power control," IEEE Trans. Comput., vol. 66, no. 5, pp. 810_819, May 2017.

[52] S. Abdelwahab, B. Hamdaoui, M. Guizani, and T. Znati, ``REPLISOM: Disciplined tiny memory replication for massive IoT devices in LTE edge cloud," IEEE Internet Things J., vol. 3, no. 3, pp. 327_338, Jan. 2016.

[53] H. P. Sajjad, K. Danniswara, A. Al-Shishtawy, and V. Vlassov, ``SpanEdge: Towards unifying stream processing over central and near the edge data centers," in Proc. IEEE/ACM Symp. Edge Comput. (SEC), Oct. 2016, pp. 168_178.

[54] K. Zhang, Y. Mao, S. Leng, A. Vinel, and Y. Zhang, ``Delay constrained of_oading for mobile edge computing in cloud-enabled vehicular networks," in Proc. 8th Int. Workshop Resilient Netw. Design Modelling (RNDM), Sep. 2016, pp. 288_294.

[55] J. Plachy, Z. Becvar, and E. C. Strinati, ``Cross-layer approach enabling communication of a high number of devices in 5G mobile networks," in Proc. IEEE 11th Int. Conf. Wireless Mobile Comput., Netw. Commun. (WiMob), Oct. 2015, pp. 809_816.

[56] D. N. Serpanos, L. Georgiadis, and T. Bouloutas, ``MMPacking: A load and storage balancing algorithm for distributed multimedia servers," in Proc. IEEE Int. Conf. Comput. Design, VLSI Comput. Process. (ICCD), Jun. 1996, pp. 170_174.

[57] A. Singh, M. Korupolu, and D. Mohapatra, ``Server-storage virtualization: Integration and load balancing in data centers," in Proc. ACM/IEEE Conf. Supercomput., Nov. 2008, p. 53.

[58] D. Ford et al., ``Availability in globally distributed storage systems," in Proc. Osdi, vol. 10. 2010, pp. 1_7.

[59] F. Chang et al., ``Bigtable: A distributed storage system for structured data," ACM Trans. Comput. Syst., vol. 26, no. 2, 2008, Art. no. 4.

[60] A. G. Dimakis, K. Ramchandran, Y. Wu, and C. Suh, ``A survey on network codes for distributed storage," Proc. IEEE, vol. 99, no. 3, pp. 476_489, Mar. 2011.

[61] E. S. Andreas et al., ``Proactive replication for data durability," in Proc.5th Int. Workshop Peer-Peer Syst. (IPTPS), 2006, pp. 1_6.

[62] A. Van Kempen, E. Le Merrer, and N. Le Scouarnec, ``Method of data replication in a distributed data storage system and corresponding device," U.S. Patent 8 812 801 B2, Aug. 19, 2014.

[63] T. Zhao, S. Zhou, X. Guo, Y. Zhao, and Z. Niu, ``Pricing policy and computational resource provisioning for delay-aware mobile edge computing," in Proc. IEEE/CIC Int. Conf. Commun. China (ICCC), Jul. 2016, pp. 1_6.

[64] A. Kiani and N. Ansari. (Dec. 2016). ``Towards hierarchical mobile edge computing: An auction-based pro_t maximization approach." [Online]. Available: https://arxiv.org/abs/1612.00122

[65] Y. Zhang, C. Lee, D. Niyato, and P. Wang, ``Auction approaches for resource allocation in wireless systems: A survey," IEEE Commun.Surveys Tuts., vol. 15, no. 3, pp. 1020_1041, 3rd Quart., 2013.

[66] C. You, K. Huang, H. Chae, and B.-H. Kim, ``Energy-ef_cient resource allocation for mobile-edge computation of_oading," IEEE Trans. Wireless Commun., vol. 16, no. 3, pp. 1397_1411, Mar. 2017.

[67] L. Zhang et al., ``Named data networking (NDN) project," Xerox Palo Alto Res. Center-PARC, Palo Alto, CA, USA, Tech. Rep. NDN-0001, 2010.

[68] D. Raychaudhuri, K. Nagaraja, and A. Venkataramani, ``MobilityFirst: A robust and trustworthy mobility-centric architecture for the future Internet," ACM SIGMOBILE Mobile Comput. Commun. Rev., vol. 16,no. 3, pp. 2_13, 2012.

[69] Q. Yang, D. An, R. Min, W. Yu, X. Yang, and W. Zhao, ``On optimal PMU placement-based defense against data integrity attacks in smartgrid," IEEE Trans. Inf. Forensics Security, vol. 12, no. 7, pp. 1735_1750, Jul. 2017.

[70] Q. Yang, J. Yang, W. Yu, D. An, N. Zhang, and W. Zhao, ``On false data-injection attacks against power system state estimation: Modelling and countermeasures," IEEE Trans. Parallel Distrib. Syst., vol. 25, no. 3, pp. 717_729, Mar. 2014.

[71] Y. Huang, X. Yang, S. Yang, W. Yu, and X. Fu, ``A cross-layer approach handling link asymmetry for wireless mesh access networks," IEEE Trans. Veh. Technol., vol. 60, no. 3, pp. 1045_1058, Mar. 2011.

[72] W. Yu, H. Xu, A. Hematian, D. Grif_th, and N. Golmie, ``Towards energy efficiency in ultra-dense networks," in Proc. IEEE 35th Int. Perform. Comput. Commun. Conf. (IPCCC), Dec. 2016, pp. 1_8.

[73] A. Mosenia and N. K. Jha, ``A comprehensive study of the security of Internet-of-Things," IEEE Trans. Emerg. Topics Comput., vol. 5, no. 4, pp. 586_602, Oct./Dec. 2017.

[74] M. Van Dijk, C. Gentry, S. Halevi, and V. Vaikuntanathan, ``Fully homomorphic encryption over the integers," in Proc. Annu. Int. Conf. Theory Appl. Cryptograph. Techn., 2010, pp. 24_43.

[75] D. Li, Q. Yang, W. Yu, D. An, X. Yang, and W. Zhao, ``A strategy-proof privacy-preserving double auction mechanism for electrical vehicles demand response in microgrids," in Proc. IEEE Int. Perform. Comput.Commun. Conf. (IPCCC), Dec. 2017.

[76] C. Anglano, R. Gaeta, and M. Grangetto, ``Securing coding-based cloud storage against pollution attacks," IEEE Trans. Parallel Distrib. Syst., vol. 28, no. 5, pp. 1457_1469, May 2017.

[77] R. Gennaro, C. Gentry, and B. Parno, ``Non-interactive veri_able computing: Outsourcing computation to untrusted workers," in Advances in Cryptology_CRYPTO(Lecture Notes in Computer Science), vol. 6223. Berlin, Germany: Springer, 2010, pp. 465_482.

[78] S. Echeverría, D. Klinedinst, K. Williams, and G. A. Lewis, ``Establishing trusted identities in disconnected edge environments," in Proc. IEEE/ACM Symp. Edge Comput. (SEC), Oct. 2016, pp. 51_63.

[79] J. Tan, R. Gandhi, and P. Narasimhan, ``Poster abstract: BUFS: Towards bottom-up foundational security for software in the Internet-of-Things," in Proc. IEEE/ACM Symp. Edge Comput. (SEC), Oct. 2016, pp. 107_108.

[80] A. Mtibaa, K. Harras, and H. Alnuweiri, ``Friend or foe? Detecting and isolating malicious nodes in mobile edge computing platforms," in Proc. IEEE 7th Int. Conf. Cloud Comput. Technol. Sci. (CloudCom), Nov. 2015, pp. 42_49.

[81] E. Cauet al., ``Ef_cient exploitation of mobile edge computing for

SURVEY ARTICLE

virtualized 5G in EPC architectures," in Proc. 4th IEEE Int. Conf. Mobile Cloud Comput., Serv., Eng. (MobileCloud), Mar. 2016, pp. 100_109.

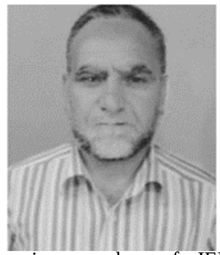
[82] S.-C. Hung, H. Hsu, S.-Y. Lien, and K.-C. Chen, ``Architecture harmonization between cloud radio access networks and fog networks," IEEE Access, vol. 3, pp. 3019_3034, 2015.

[83] W. Em_nger, A. Dubey, P. Volgyesi, J. Sallai, and G. Karsai, ``Demo abstract: RIAPS_A resilient information architecture platform for edge computing," in Proc. IEEE/ACM Symp. Edge Comput. (SEC), Oct. 2016, pp. 119_120.

[84] G. Xu,W. Yu, D. Grif_th, N. Golmie, and P. Moulema, ``Toward integrating distributed energy resources and storage devices in smart grid," IEEE Internet Things J., vol. 4, no. 1, pp. 192_204, Feb. 2017.

Authors

Hushmat Amin Kar (corresponding author) has received his B.Tech. degree in Information Technology from the University of Jammu, J&K, India, in 2012, M. Tech. Degree from National Institute of Technology Srinagar, India in 2014. He has worked as Assistant Professor in Department of Information Technology, National Institute of Technology, Srinagar, India before joining as Senior Research Fellow in Department of Electronics and Communication Engineering in the same Institute. He is a member of IEEE, IETE, IEI and IIETA. His research interests include Wireless Sensor Networks, Internet of Things, Big Data and cloud computing.



Ghulam Mohammad Rather was born in Kashmir, India. He received his B.E. degree in from the Kashmir University, India, in 1981, the M. S. degree (1988) and the Ph.D. degree (1997) from the Indian Institute of Sciences (IISc) Bangalore, India. He is currently Professor in the Department of Electronics and Communication Engineering, National Institute of Technology, Srinagar, India. He has more than 35 years of teaching experience. He is a senior member of IEEE and IETE. His research interests include Communication Systems, Computer Networks, Antennas and Propagation.