Wael Rafea

The effect of edge computing on Iot (5G Perspective)

Metropolia University of Applied Sciences
Bachelor of Engineering
Iot and Cloud Computing
Bachelor’s Thesis
16 Aug 2021

Abstract

Author:	Wael Rafea
Title:	The effect of edge computing on Iot (5G Perspective)
Number of Pages:	32 pages
Date:	16 August 2021
Degree:	Bachelor of Engineering
Degree Programme:	Degree Programme in Information and Communication Technology
Professional Major:	Professional Major IoT and Cloud Computing
Supervisors:	Janne Salonen

Edge computing is an emerging technology that has been enabled to evolve more with 5G networks by bringing closer cloud capabilities to the end-user.
This thesis aims to: explore the concepts of edge computing and its implementation using 5G, define why the edge computing is needed in IoT technology, present the different impacts of edge computing on the Internet of Things (IoT) through the perspective of 5G.
By establishing a taxonomy of edge computing, the existing literature is classified and various essential features are brought out of the edge computing paradigm. By doing so, the requirements which help to succeed the deploying of edge computing in IoT are identified; Further more, the latest 5G advancements in edge computing technology are highlighted, thereby revealing the most standout applications of different edge computing concepts and their impact on IoT.
Finishing off this thesis by discussing the emerging issues that still under research despite of the acceptance of this technology.
To accomplish the study, I relied on the reliable internet websites, e-books, and researches.

Keywords: Edge Computing, IoT, 5G.

Contents

List of Abbreviations

IoT:	Internet of Things
EC:	Edge Computing
MEC:	Mobile Edge Computing
CC:	Cloud Computing
UE:	User Equipment
QoS:	Quality of Service
QoE:	Quality of Experience
MIMO:	multiple-input-multiple-output
SDN:	Software-Defined Network
NFV:	Network function virtualization
Gbps:	Gigabytes per second
RATs:	Radio Access Technologies
3Cs:	Computing, caching, communication

1 INTRODUCTION

Networking technologies advancements have communication between billions of devices globally through IoT technology, these devices will be collecting huge amount of data per month. Data enerated would help increase the productivity and income of relevant organizations. However, organizations that still rely on conventional computing paradigms might find it tough to manage and analyze vast amounts of data hence the emergence of edge computing through IoT that has become the norm in data processing at networks' edges.

Data production at the network edges makes it easy and practical to deal with these data at the edge of networks. The alternatives to cloud computing include recent technologies such as mobile edge computing and fog computing hence reducing data processing in edge computing. The edge computing omputational paradigm has enabled edge servers to provide additional computational capabilities at the network edge and store large amounts of data and perform computationally intensive tasks closer to the user equipment. In other words, edge computing is a term representing micro clouds, cloudlets, and fog computing. Data storage, computing, and processing power are implemented at the network edges to increase availability, reduce latency, and eventually overcome cloud computing challenges. Edge computing brings processing applications that is delay-sensitive and considered the most important matter, closer to the data source.

Although there are several research types on various edge computing concepts, but it is still needed to mention more about edge computing, 5G and IoT technology. Therefore, this thesis highlights the effect of edge computing on IoT as a 5G perspective as the following:

- From an IoT perspective, it is designed to investigate about the latest advancements in edge computing.

- This research classifies edge computing literature.

2 Overview of key topics

This section highlights briefly the backbone of Iot and edge computing architecture, 5G network techniques and the concept of edge computing.

2.1 Iot and edge Computing architecture

Edge computing is perceived to be one of the crucial technologies in the 5G networks communications and IoT. Architecture is a significant point of focus for many organizations, and therefore this section highlights the general architecture of edge computing & Iot by extending cloud services to edge devices.

Below, figure 1 shows edge computing & Iot architecture which contains sensors and controllers, edge computing, and cloud computing layers.

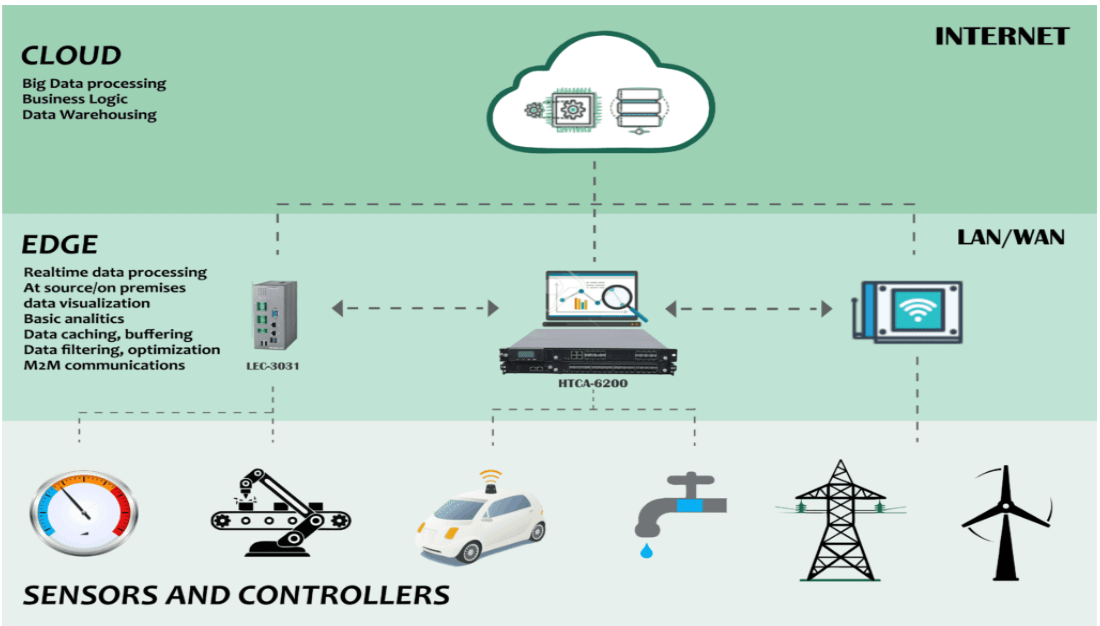

Figure 1: EC & Iot architecture. Copied [1]

First one of the above three layers mentioned is sensors and controllers layer which includes all Iot devices connected to the network's edge, including smart cameras, smart cars, smartphones, etc.; the devices consume data and generate data. Consideration is not on the computational power but perception of various devices within the this layer of the architecture, resulting in millions of devices collecting data and uploading it to the upper layer for storage and calculation. Second one is edge computing layer which is located at the edge of a network and the core of the architecture, it consists of edge nodes equally distributed among clouds and devices in Iot & sensors layer. The layer includes base stations, gateways, routers, etc. This layer's function is to support Iot devices' downward access, connect the cloud, and upload processed data to the cloud. The layer suits applications that require real-time data processing[2]. Third one is cloud layer which is considered the most potent centre for data processing because it contains several robust data storage and processing devices with powerful computing capabilities. Data generated from the edge computing layer can be permanently stored in the cloud and intensely analyzed, something that the edge computing layer cannot handle[3].

2.2 5G network

The exponential growth of IoT (Internet of Things) and other technologies in real-time pushes edge computing which is used to lower the cumulative amount of data sent to the cloud and reduce the gain of inertness.

As figure 2 shows, 5G is the latest advancement model in portable networking organizations that offers a faster web bandwidth, a better resolution, and an advanced ability to accommodate large numbers of information conveyed by various 5 G-backed gadgets. 5G presents characteristics are not seen in the previous cellular networking generations.

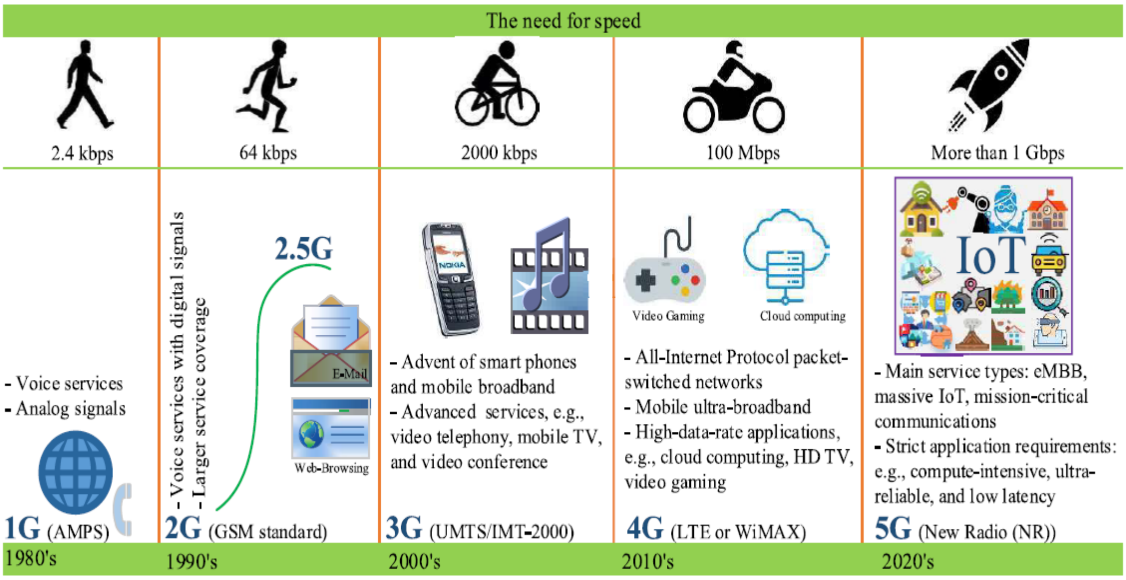

Figure 2 Evolution of wireless communication. Copied(4)

There are three leading technologies in 5G that support high network capacity to face the increasing of user equipments[5]:

- Mm Wave communication – utilizes high-frequency bands to offer high bandwidth.

- small cell deployment – enables the user equipment to communicate through mm-Wave, reducing the range of transmission and interference.

- Multiple-input multiple-output (MIMO) enables the use of more antennas at base stations (more than 15 per sector) to minimize interference, enabling adjacent nodes to communicate simultaneously.

2.3 Edge Computing

With edge computing, data is processed right at the point where it is generated, i.e., at the edge of networks, enabling the computation of data closer to the data source. Processing happens in two streams: upstream and downstream. Upstream is where data travels from the source (IoT device) to the cloud, while downstream, data travels from the cloud to the IoT device. Upstream works on behalf of IoT services, while downstream works on behalf of cloud services. Both streaming types are equally important in the working of edge computing and cloud computing paradigms. In simple terms, edge computing is the link between an IoT device and the cloud[6].

For example, a smartphone acts as a link between a wearable device and the cloud. A home router serves as a link between all smart devices in the home and the cloud. A cloudlet is an edge between a smartphone and the cloud. The significant difference between edge and fog computing is that edge oncentrates on 'things' while fog focuses on the network infrastructure. It is considered that edge computing can significantly affect society in the future, as is cloud computing.

In the edge computing paradigm, the user equipment generates data and consumes the data. These devices include every available smart device such as smartphone, smart TV, smart camera, smart irrigation system, smart lighting control system, smart car park systems, and computers. Devices that act as edge include routers, gateways, micro data centres, and mini servers[7].

Edge devices make data requests from the cloud and at the same time perform data processing tasks. These devices perform service delivery, data storage, caching, processing, and managing IoT devices. The edge should meet the data needs efficiently, keeping in mind reliability, security, and privacy. The cloud is the database, server, and supercomputer to perform all significant computing tasks.

3 Classification of Edge computing in 5G

As figure 3 shows, the classification of edge computing for Iot from a 5G perspective comes under the following titles: objectives, computing platform, attributes, applications, measuring performance, and edge computing roles in IoT.

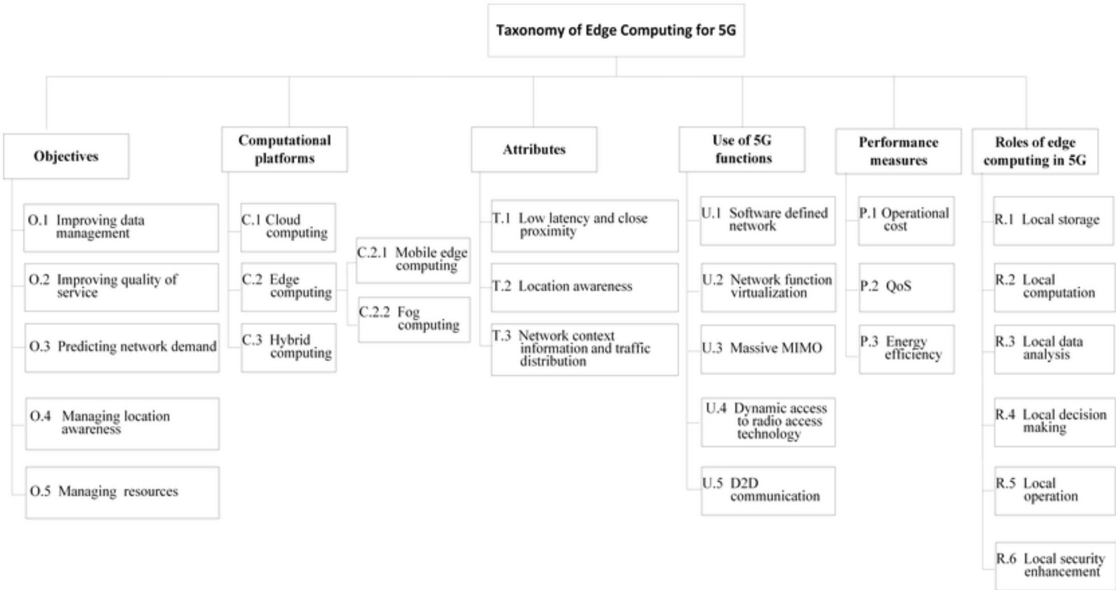

Figure 3: classification of edge computing in 5G. Copied[8]

3.1 Objectives

Edge computing strives to achieve the following objectives in Iot:

- Better data management: user equipment generates vast amounts of delay-sensitive data, which happens locally and in real-time without delay. Let us consider the following example in application today; devices in an autonomous vehicle generate up to 1 TB of data every second. Since communicating with the cloud incurs high latency, edge servers can handle the data locally. Managing data in this way is key to enabling applications to make critical decisions fast through real-time data processing and local functions[9].

- It improves service quality (QoS) to meet the strict edge computing requirements to deliver better quality of experience (QoE). That enables the delivery of on-demand and highly interactive applications such as online gaming and streaming without the provider being necessarily involved with content distribution. Better QoS enables providers to build custom applications that provide a better user experience and ultimately more profit margins[10].

- Predicting the network's needs to provide optimum resources that can handle the specific requirements locally and close to the edge servers. A correct prediction of the network's needs helps determine whether the network demand should be handled network edge or at the cloud to set proper and efficient resource allocation, e.g., network bandwidth, etc[10].

- Location management enables edge servers to determine user equipment's geographical location, infer their location, and provide location-based services. This capability will allow providers that rely on the user equipment's geographical location to provide data and services to edge clouds. For example, the user equipment can use their location information to request data about their interest area. The requests can be many, for instance, in healthcare services or emergency responses[11].

- Better resource management because of the limited resources available for edge computing compared to cloud computing; better resource management ensures optimization and better network performance. However, resource management is complicated as multiple functions are required to handle various applications and user demands[12].

3.2 computational platforms

Different platforms offer different computing capabilities with other characteristics, e.g., processing loads, availability, user equipment proximity, and network infrastructure complexity[13]. Implementation of a computational platform can be either independently or with other media, depending on the type of application or service demands; this section mentions the following three major computational platforms: Cloud computing, Edge computing and Hybrid computing.

First one of the computational platforms is the cloud computing which collects, stores, and processes vast amounts of data from user equipment within a network. Requested data, information, and decisions are sent back to the user equipment upon request. It is, however, not suitable to implement the cloud on user equipment that requires real-time data processing because it is far from the user equipment.

The second one is the edge Computing which Collects, stores, and processes vast chunks of data from user equipment locally. Edge computing is closer to the user equipment than the cloud[14]; hence, it delivers more bandwidth and reduces latency because of the shorter distances travelled by data. There are two types of edge computing platforms:

- Mobile Edge Computing (MEC)

At the edge of a network, MEC provides computational and storage capabilities to improve context awareness and reduced latency. Examples include base stations and radio access networks. Base stations use virtualized environments to access computation and storage services. The MEC orchestrator looks over each host by collecting and providing real-time information concerning a service required by each host, required resources, network topology, and management of MEC applications[7].

In this proposed solution, user equipment decides whether to handle computational tasks or forward them to a MEC server. The process would reduce the energy consumption of the MEC. The user equipment runs various computational and communication capabilities, making them capable of consuming more energy than the MEC servers.

The proposed architecture uses local data storage and local computational capabilities to achieve edge computing objectives, i.e., improving QoS and data management. There is also a use of the 5G function of dynamically accessing the RATs. Proximity and latency are also part of the scheme[7].

Using MEC based solution is by steps as the followings:

A. Classification of the mobile user equipment is according to their energy consumption in the transmission of data, computation, and end-to-end delay in communication between the MEC and mobile user equipment. These are the categories of end devices: first type is user equipment that uses the MEC server for computations, the second type is user equipment that performs individual calculations, and the last type is user equipment decides whether to perform the calculations themselves or offload them to the MEC servers.

B. The different user equipment is given other priorities depending on their energy consumption rates and the quality and availability of channels. Generally speaking, type 1 user equipment enjoys top priorities because of its limitations and the necessity of offloading tasks and storage to the MEC server to meet end-to-end delay requirements.

C. Assigning communication channels to the user equipment happens with different priorities. When there is offloading of user equipment with top priorities, fewer user equipment competes for media. The proposed solution has proved to enable better consumption of energy[15].

The nearest edge server autonomously creates a MEC service to provide a seamless experience in video streaming. The proposed solution strives to achieve improved QoS and network demands prediction using local storage, computation, and decision making. By using edge computing, the proposed solution will offer an uninterrupted video streaming experience[15].

The scheme proposes that an edge server can receive all content from the cloud or part of it and deliver it right to the user equipment with reduced delay. As long as the user equipment is near the edge server, the content quality is always high. In other words, the user equipment receives content from an edge server for purposes of reducing delay and subsequently achieving high-quality streams. It is unlikely that the contents are unavailable at the edge cloud, but if this is the case, the user will have to access the cloud contents, which have lower quality streams because of long delays. The two mechanisms involved ensure seamless streaming: first, migration, which enables seamless streaming even when the user equipment moves from the radar of one edge server to another; then, handover will enable seamless streaming when a user's equipment hands over from one network operator to another to increase streaming quality and reduce delay. The proposed scheme has therefore proved to improve the quality of service[7].

The proposed architecture utilized local storage and local computation to achieve edge computing objectives, i.e., better resource management and improved QoS. Furthermore, the scheme achieves end-to-end delay by bringing edge servers closer to the user devices. The architecture can distribute traffic and acquire network information through the network context-awareness feature, besides having proximity and low latency[16].

The MEC user equipment is classified depending on their computational capacities and links to D2D communication. User devices use the graph matching algorithm to determine whether computations should be performed locally or offloaded to the nodes via D2D to achieve energy efficiency.

- Fog computing

the fog computing that utilizes local fog nodes such as routers and switches to deliver computation locally. As defined by the Open Fog Consortium, it is a system-level horizontal architecture for distributing computing resources anywhere along the cloud line to IoT. It has similar benefits as those of edge computing variants such as real-time data processing and low latency. Fog computing, though, does not have high storage capacities. A cross-layer scheme is presented to manage resources between fog computing and optical network through a fibre network. The proposed system uses local computational capabilities to improve resource management and QoS. Further, it uses the hybrid computational architecture whereby the cloud performs resource-intensive and highly computational tasks while the edge cloud handles real-time data processing applications. Proximity to the data source and low latency are attributes of this scheme[17].

Three layers are involved in performing computational tasks: user equipment layer, fog, and cloud layers. The user equipment layer handles operations locally at the end devices because of its storage and power limitations. The fog layer handles real-time services, and the cloud takes resource-intensive and highly computational services[7]. The scheme has proved to have a lower response delay thus can work well in applications that require real-time data processing.

Various modulation schemes compare performance between fog computing and cloud computing – 64 and 16 phase-shift keying (PSK), quadrature amplitude modulation (QAM), and quadrature phase-shift keying (QPSK). These schemes are used in 5G to test and find the most efficient model for improving throughput and optimizing energy consumption for every user[8]. The system utilizes local computational and operations to improve QoS.

The proposed scheme has proved to reduce energy consumption through a comparison made with cloud computing. The project uses the edge, and fog, in particular, to analyze energy consumption by using the 5G function that includes accessing the RATs dynamically through 3G, 4G, and 5G to serve different user equipment. An energy efficiency model in the fog environment is proposed that analyzes energy consumption levels and throughput.

An architecture known as the 3Cs (computing, caching, and communications) enables service and content providers to deploy their functions efficiently. The proposed architecture uses local storage and computation to better QoS and resource efficiency using regional analysis and local storage. Furthermore, the proposed architecture utilizes fog computing to achieve reduced end-to-end delay. The architecture is further capable of acquiring information about networks and traffic distribution through the network context-awareness feature, besides having proximity and low latency. The architecture works in the following way: the regular extreme node sends information about its available resources to the super intense node, which will assign a task to the regular extreme node for execution[18].

The fog-based solution has satisfied the requirements of improved QoS and reduced end-to-end delay, making it suitable for real-time applications, and Main things has to mention about fog-based solutions: one of them that virtual fog (vFog) is a framework for empowering user equipment with the 3Cs via NFV to enhance flexibility in-network service provisioning. The other thing is that is a collection of vFogs is Hyper fog, enabling the exchange of data and communications between vFogs for providing resources from multiple vFogs.the last thing about fog-based solutions that is a regular extreme node is a piece of user equipment that can process and communicate data, and super extreme node is a piece of user equipment that manages and manipulates the edge node of vFogs.

The third computational platform is a Hybrid which brings together cloud and edge computing so that they can interact. The logic behind it is that the cloud makes non-real-time decisions based on the data collected from the devices, while edge computing makes real-time decisions using real-time data collected from the user equipment[19].

The hybrid type of architecture brings together the core benefits of cloud computing, including more storage capacities and computational power and edge computing, i.e., low latency and real-time responses. Computing is carried out in various layers, i.e., the cloud at the upmost layer, while edge computing happens at the bottom.

Edge computing has transformed working with the cloud because of its reduced latency and increased throughput, which is necessary for developing applications sensitive to delay and services[3]. There is no doubt that a hybrid infrastructure would be more complicated than a separate edge computing or cloud computing platform.

3.3 Attributes

Proximity and low latency is one of the attributes related to edge computing, it overcomes the challenge faced by the traditional cloud by reducing the delay of responses experienced by IoT. The three main components of responses include the following: computational delay that relies on the time to perform computational tasks, communicational delay that depends on data rates and propagation delay that relies on the distance of propagation; Cloud computing has response delays of 160 ms, which is intolerable in real-time response requirements such as remote surgeries and autonomous vehicle systems[9]. Edge computing, on the other hand, has response delays of about 1 ms. Shorter response delays result from placing edge servers closer to the user equipment, decreasing propagation and communication to the user equipment[20].

Awareness of user equipment location is the another attribute related to edge computing, by this attribute edge servers gather and process data generated by user equipment depending on their geographical location, allowing personalized services to the user equipment by edge servers depending on their site without accessing the cloud[11].

Awareness of the network context is the last attribute related to edge computing, by this attribute edge computing edge servers can acquire information about the network context, e.g., radio access network and traffic load requirements information. It also obtains information about user equipment, e.g. assigned network bandwidth and location, enabling customized edge server responses to different networks' conditions effectively and optimizing the allocated network resources. Network information gathered enables the edge servers to handle large network loads and boost network performance in varying conditions[21].

3.4 characteristics of 5G data

Depending on time characteristics, data is categorized into three main categories[7]:

- complex real-time – data that contains a strictly predefined latency. Hence the data is generated by healthcare services, online gaming, and streaming applications.

- Soft real-time– tolerates latency that is bounded even though its latency is predefined. Applications such as smart traffic control systems generate this type of data.

- Non-real-time data is a type of data that tolerates latency and isn't sensitive to time.

There is a significant reduction in latency at edge servers because, in edge computing, servers are close to the user equipment; hence applications are meant to handle hard real-time[2]. On the other hand, in soft real-time data applications, if the cloud and user equipment's response time is above the minimal requirement, tasks are handled by the cloud instead of edge servers. The cloud manages non-real-time data on behalf of applications that generate such data for load balancing[17].

3.5 5G enablers in edge computing

The following are the technologies that have enabled the implementation of edge computing in IoT devices:

- ✓ Software-defined network

SDN is a type of network architecture that divides a network into data planes and controls planes to enable flexibility and agility of networks for simplifying network management and deploying new services[22].

- ✓ Network function virtualization (NFV)

NFV has helped systems to perform virtualized functions in virtual servers that handle large chunks of data to enhance flexibility, automation, and scalability of networks. Network requests happen either at the cloud or the edge. It depends on the type of application or service[20].

- ✓ multiple-input multiple-output (MIMO)

Involves deployment of multiple antennas for increasing the arrays of both transmitter and receiver. According to the Shannon theorem, the ratio of signal-to-noise rises without increasing transmission power, resulting in increased network capacity and boosting efficiency. Using large amounts of MIMO, several user equipment can simultaneously offload tasks on the edge servers, reducing latency[6].

- ✓ Accessing RATs dynamically

Works by providing access mechanisms to conventional radio access technologies like Wi-Fi. 5G NR, an example of RAT, is a current standard for providing connections to most IoT devices that achieve highly scalable and reduced latency networks, allowing extensibility of existing networks.

- ✓ D2D communication

Utilizes ad-hoc links to enable direct communication with adjacent user equipment without passing through base stations. such technique improves energy efficiency, network throughput, and spectrum utilization. Edge servers carry the burn of processing data for the user equipment and ensure that D2D communication of user equipment is successful[23].

4 The role of edge computing in IoT networks (5G networks)

Edge computing will play a significant role in the future operation of IoT networks. Presently, the main research issue in IoT is the function that edge computing plays[24]. Figure 4 shows below the edge computing environment:

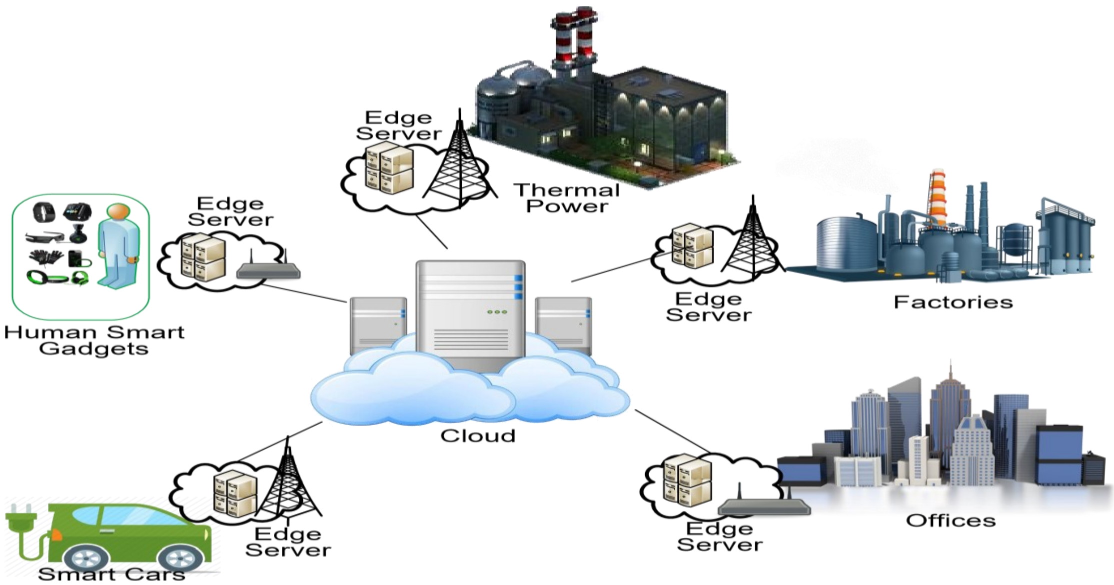

Figure 4: edge computing environment. Copied(24)

Figure 4 shows that edge computing is used for various reasons, mainly reducing latency by limiting loads of data forwarded to the cloud. an IoT environment with edge computing being at the centre of crucial operations. The roles played by edge computing to ensure successful operations are listed as the following:

I. provides local storage.

Edge computing helps user equipment to offload vast amounts of data to the edge clouds. The cloud, however, has more and unlimited storage compared to the edge, whose storage is much lower[25]. Types of data found on the servers are computational data, metadata (e.g., location and timestamps), and monitoring data. The edge servers have different data storage capabilities for supporting a wide array of data types[10]. For example, a type of storage called ephemeral provides temporary storage to given interconnected IoT.

II. performing local computational tasks

Edge computing functions by offloading computational and processing tasks from intelligent devices to the edge clouds. While conventional computational paradigms provide simple computational and processing capabilities, the edge is a smart computational system that brings these capabilities closer to the user equipment independently and autonomously[17].

The outputs from the processes and computations could be valuable inputs to other things, for example, in a smart factory. The mains benefit of this is that an edge cloud acts by performing small computational tasks locally and providing instant responses without accessing the cloud[7]. Accessing the cloud would be pretty costly, and delay-response sensitive applications would not work quite well.

III. Analyzing data locally

Edge computing gathers analyses and performs mandatory data analysis in real-time on large chunks of data collected by user equipment placed closer to the edge clouds. The concept of regional analysis of data has led to the reduced time required to send the data to the cloud and get responses, thereby decreasing latency[8]. Data analyzed locally is used to make valuable decisions.

IV. making decisions locally

Edge computing uses large quantities of data collected from the user equipment to make well-informed decisions and take real-time actions. The capability to process data locally eliminates the need to involve other components such as the cloud leading to the highly available systems, especially the cloud. and higher bandwidth is available therefore enabling more entities to make decisions locally, for example, intelligent factories that have automated processes[7].

V. local operations

Edge computing makes it possible to control and monitor critical remote devices, including those in dangerous environments from safer environments. For example, NASA sent a robot to Mars to search for life[17].

VI. local security enhancements

With edge computing, a layer exists between the cloud and the internet of things to foster network security. The edge clouds serve as secure distributed platforms to secure credentials management, detection, malware, distributing software patches, and verify communications to detect and prevent attacks. Another advantage of placing the edge servers close to gathering data sources is that systems early and counter-measured can detect vulnerabilities and malicious activities[8].

VII. Self Organized

Insights in edge computing will permit standalone frameworks to require nearby choices but too to collaborate with each other to permit the development of worldwide Insights without the required for human administrators.

VIII. Improve the performance of IoT devices

Edge Computing additionally shapes examinations and performs crucial exercises on the collected data locally. Since these shapes are completed in milliseconds, it’s gotten to be fundamental in optimizing specialized data, no matter what the operations may be. Exchanging gigantic sums of data in real-time in a cost-effective way can be a challenge, in a general sense when conducted from more distant mechanical districts. This issue is cured by counting bits of knowledge to contraptions appear at the edge of the organize. Edge computing brings analytics capabilities closer to the machine, which cuts out the middle-man. This setup gives for less exorbitant choices for optimizing asset execution.

IX. Process Data Faster

The Edge computing forms the information speedier which suggests the applications can stack and perform at a much quicker rate. At first, cloud servers took more time, which hampered the client involvement. Now a day's information is handled on edge servers, door, or indeed on a smart phone which engages the company with awesome speed.

X. Reduced Operational Cost

Within the cloud computing demonstration, network, information relocation, transmission capacity, and inactivity highlights are beautiful costly. This wastefulness is helped by edge computing, which features an altogether less transmission capacity necessity and less idleness. By applying edge computing, an important continuum from the gadget to the cloud is made, which can handle the enormous amounts of information generated. Costly bandwidth increases are now not required as there's no have to be transfer gigabytes of information to the cloud. It too investigations touchy IoT information inside a private organization, in this manner ensuring delicate information. Undertakings presently tend to lean toward edge computing. Usually since of its optimizable operational execution, address compliance and security conventions, nearby lower costs.

XI. Smart Homes

Edge computing will introduce high assistance in smart homes. The data produced by these gadgets ought to be processed and expended inside the home environment due to protection concerns and that needs technology like edge computing. The things can be connected and overseen with ease with the assistance of an edge door introduced inside the domestic. This would indeed offer assistance in utilizing keen gadgets when the web association is down[26].

5 Challenges by implementation of Edge Computing

Edge computing got to be a portion of the 5G remote command when engineers realized the same instrument that fortifies information communications arrange can strengthen an information handling organize. And conceivably, the two businesses require not fair coexist, but may at that point combine.

The physical appearance of a 5G edge computing-enabled information center might not see like what you anticipate. Businesses with an intrigued in conveying computing resources in different, farther areas, are contributing to pre-assembled modules that can be transported like shipping holders and dropped in-place onto concrete pieces. Vertiv is one company that builds made-to-order Pre-Assembled Modules (PAM) that come as of now prepared with the chassis and foundation vital to bolster the prescribed hardware for 5G MEC arrangements. Broadcast communications benefit suppliers are as of now recognizable with how to snare up PFMs such as Smart Mod for 5G network[27].

The edge computing now is not adequate to instantly prepare and assess the information produced by IoT gadgets like associated cars and other computerized stages. Edge computing presents very a number of challenges in IoT as the following:

- **Privacy**

Whereas security and protection are improved in edge computing as information doesn't travel over a organize, there are two main issues that can increment arrange vulnerability at the edge of the organization. Firstly, the energetic environment causes the information and arrange necessities of different network substances to shifting quickly. Furthermore, the increasing number of gadgets communicating with each other must require an adaptable arrangement. Subsequently, belief and security management must address the previously mentioned problems in arrange to address organize helplessness; in any case, this may bring about tall complexity and take a toll. Privacy in all angles may be a challenge in edge computing since user’s information must experience security schedules and information encryption sometime recently transmission to ensure client information security[9].

- **Real-Time Data Processing**

The Network among numerous diverse gadgets, for illustration, smartphones, sensors, tablets, and laptops, etc. makes a surge of information generation. In real-time to compute this information could be a major concern[7].

- **Power Consumption**

Vitality productivity decreases the amount of vitality required to supply an item or benefit. Edge gadgets are utilized for diverse capacities in asset assignment and control administration on vitality reinforcements. Edge computing oversees the asset stream to the asset centers and the edge hub is dependable for handling the computations within the Edge.

- **Need more storage space**

Edge computing does take significantly higher capacity space on your gadget. Since the capacity gadgets are getting to be more compact this will not really be an issue. In any case, it could be a point to keep in mind when creating an IoT gadget.

- **Data incompletion**

Edge computing as it formed and analyzes halfway sets of data. The rest of the information are fair disposed of. Due to this, the companies may conclusion up losing parcels of profitable data. Subsequently, sometime recently utilizing edge computing, the organizations must choose what sort of data they are willing to lose.

- **High investment cost**

Edge framework can be expensive and complex. Usually due to their complexity which needs extra hardware and assets. In expansion to that, the IoT gadget with edge computing comes with the need for more local equipment for them to operate. This will generally lead to more effectiveness but critical speculation is required.

- **Increase Maintenance Cost**

Not at all like a centralized cloud design, edge computing may be a conveyed framework. This implies that there are more different organized combinations with a few computing hubs. This requires higher upkeep costs than a centralized foundation[28].

6 Conclusion

This thesis has investigated, analyzed, and reported recent advancements in edge computing and their impact on 5G networks. It carefully defined the taxonomy of edge computing literature and made particular classifications based on characteristics to unmask its key features that enable the working with IoT networks.

Then highlighted some essential requirements for deploying edge computing in IoT, including reliability, high data rates, local processing, and real-time interaction. This work further presents the state of the art solutions that have caught the eye of the modern world of edge computing applications in IoT (including fog computing, MEC, and hybrid solutions). Finally the some challenges of implementation of Edge Computing are presented.

To accomplish the study, I relied on the reliable internet websites, e-books, and researches.

7 References

1. Sittón-Candanedo, I., Alonso, R., García, Ó., Muñoz, L. and Rodríguez-González, S., 2019. Edge Computing, IoT and Social Computing in Smart Energy Scenarios. Sensors, 19(15), p.3353.

2. Sittón-Candanedo I, Alonso RS, Rodríguez-González S, García Coria JA, De La Prieta F. Edge Computing Architectures in Industry 4.0: A General Survey and Comparison. In: Advances in Intelligent Systems and Computing. 2020.
   URL:
   https://www.researchgate.net/publication/332795578_Edge_Computing_Architectures_in_Industry_40_A_General_Survey_and_Comparison

3. Hamdan S, Ayyash M, Almajali S. Edge-Computing Architectures for Internet of Things Applications: A Survey. Sensors. 2020;20(22):6441.

4. Quoc-viet pham, Vu Nguyen Ha, Long Bao Le, Zhiguo Ding. A Servey Of Multi-Access Edge Computing in 5G and Beyond: Fundamentals, Technology integration, and State-of-The-Art. vol(8); 2020.

5. J. Andrew Zhang, Y.Jay Guo, Peng Cheng. Towards 5th generation cellular mobile network. Journal of telecommunicationa and the digital economy. 2014.
6. Hafeez I, Antikainen M, Ding AY, Tarkoma S. IoT-KEEPER: Detecting Malicious IoT Network Activity Using Online Traffic Analysis at the Edge. IEEE Trans Netw Serv Manag. 2020 Mar 1;17(1):45–59.

7. Abbas N, Zhang Y, Taherkordi A, Skeie T. Mobile Edge Computing: A Survey. Vol. 5, IEEE Internet of Things Journal. Institute of Electrical and Electronics Engineers Inc.; 2018. p. 450–65.

8. NAJMUL HASSAN, KOK-LIM ALVIN YAU, CELIMUGE WU.Edge computing In 5G: A riview. IEEE. vol(4); 2016.

9. Qiu T, Chi J, Zhou X, Ning Z, Atiquzzaman M, Wu DO. Edge Computing in Industrial Internet of Things: Architecture, Advances, and Challenges. IEEE Commun Surv Tutorials. 2020;22(4).

10. Wang S, Zhao Y, Huang L, Xu J, Hsu CH. QoS prediction for service recommendations in mobile edge computing. J Parallel Distrib Comput. 2019 May 1;12 7:134–44.

11. Satyanarayanan M. The emergence of edge computing. Computer (Long Beach, Calif). 2017 Jan 1;50(1):30–9.

12. Khajeh-Hosseini A, Greenwood D, Sommerville I. Cloud migration: A case study of migrating an enterprise IT system to IaaS. In: Proceedings - 2010 IEEE 3rd International Conference on Cloud Computing, CLOUD 2010. 2010.

13. Wu C, Peng Q, Xia Y, Ma Y, Zheng W, Xie H, et al. Online user allocation in mobile edge computing environments: A decentralized reactive approach. J Syst Archit. 2021 Feb 1;113.

14. Nitinder Mohan. Edge Computing Platforms and Protocols. researchgate; 2019.

15. Wu C, Peng Q, Xia Y, Ma Y, Zheng W, Xie H, et al. Online user allocation in mobile edge computing environments: A decentralized reactive approach. J Syst Archit. 2021 Feb 1;113.

16. Jackson KR, Ramakrishnan L, Muraki K, Canon S, Cholia S, Shalf J, et al. Performance analysis of high-performance computing applications on the

Amazon Web Services cloud. In: Proceedings - 2nd IEEE International Conference on Cloud Computing Technology and Science, CloudCom 2010. 2010.

17. Svorobej S, Endo PT, Bendechache M, Filelis-Papadopoulos C, Giannoutakis KM, Gravvanis GA, et al. Simulating fog and edge computing scenarios: An overview and research challenges. Vol. 11, Future Internet. 2019.

18. Weinhardt C, Anandasivam A, Blau B, Borissov N, Meinl T, Michalk W, et al. Cloud Computing – A Classification, Business Models, and Research Directions. Bus Inf Syst Eng. 2009;

19. Sotomayor B, Montero RS, Llorente IM, Foster I. Virtual infrastructure management in private and hybrid clouds. IEEE Internet Comput. 2009;

20. Mansouri Y, Babar MA. A review of edge computing: Features and resource virtualization. J Parallel Distrib Comput. 2021 Apr 1;150:155–83.

21. Minoli D, Occhiogrosso B. Blockchain mechanisms for IoT security. Internet of Things. 2018 Sep;1–2:1–13.

22. Touch J, Poste J. Network Infrastructure. In: The Grid 2. 2004.

23. Wang W, Bhargava B. Visualization of wormholes in sensor networks. In: Proceedings of the 2004 ACM Workshop on Wireless Security, WiSe. 2004.

24. Hassan N, Gillani S, Ahmed E, Yaqoob I, Imran M. The Role of Edge Computing in the Internet of Things. IEEE Commun Mag. 2018 Nov 1;56(11):110–5.

25. Shi W, Cao J, Zhang Q, Li Y, Xu L. Edge Computing: Vision and Challenges. IEEE Internet Things J. 2016 Oct 1;3(5):637–46.

26. Wu C, Peng Q, Xia Y, Ma Y, Zheng W, Xie H, et al. Online user allocation in mobile edge computing environments: A decentralized reactive approach. J Syst Archit. 2021 Feb 1;113.

27. Sittón-Candanedo I, Alonso RS, Corchado JM, Rodríguez-González S, Casado-Vara R. A review of edge computing reference architectures and a new global edge proposal. Futur Gener Comput Syst. 2019;99.

28. Sotomayor B, Montero RS, Llorente IM, Foster I. Virtual infrastructure management in private and hybrid clouds. IEEE Internet Comput. 2009;