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Edge Computing: A Review on Architectures and Its Applications

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ABSTRACT

Along with the rapid advancement of technology, the number of devices connected to the internet is increasing. This fact can cause several problems in traditional cloud computing like delay, bandwidth load, security and storage problems. This is the reason the edge computing model comes into the picture. The purpose of the edge computing concept is to deliver distributed processing and storage at the network's edge. This review presents the recent edge computing architectures highlighting the different sectors like industry and healthcare. This survey covers different architectures of edge computing like Fog Computing (FC), Mobile Edge Computing (MEC), and Cloudlet Computing (CC) [1],[2]. Similar paradigms and numerous real-world applications, including smart healthcare and vehicles are also explained. All the highlighted insights of this review will hopefully lead to increased efforts toward edge computing for future applications of different sectors.

Keywords—Edge Computing, Fog Computing, Mobile Edge Computing, Cloudlet Computing

1. INTRODUCTION

Due to the expansion of the Internet of Things (IoT) and the widespread deployment of wireless networks, the number of edge devices and the amount of edge data have been growing significantly in recent years. [1]. Moving storage, processing, and network management operations to centralized data centers have become popular over time. There is a requirement for data to be processed close to where it is produced to reduce delay and efficiently distribute the network load due to the continuously growing volume of data received from underlying IoT devices [1]. Edge Computing (EC) makes an effort to get around the problems mentioned. This is a new approach, places an edge server's resources close to the data source, or at the edge of the Internet i.e. near the data source [1]. Edge computation is becoming more and more popular in both industrial and educational sectors due to its ability to successfully provide enormous machine-type communication with very low latency and outstanding spectral efficiency [3]. According to a prediction by International Data Corporation (IDC), by 2025, 70% of the data created by the Internet Of Things will be handled at the network's edge. [4]. Because of this, edge computing is necessary for effective performance. Edge computing can be implemented between end devices and the cloud in different ways such as Fog computing (FC), Mobile Edge Computing (MEC), and Cloudlet computing (CC) using devices like drones, sensors, robots, etc. that serve as intermediary edge nodes [4, 5]. A type of computing called fog computing makes use of IoT gateways and networking equipment like wireless routers. These are known as "Fog Computing Nodes" (FCN) and are used to process and store data locally by the end devices before transmitting it to the cloud [4]. MEC allowed real-time, computationally expensive applications to be run directly at the network edge on the billions of portable devices like mobile devices [6]. Small data centers called cloudlets are situated at the Internet's outer edge. Thus, deploying cloudlets allows for the processing of resource-intensive operations, reducing latency, bandwidth load, and time consumption.

The paper is organized as follows. The fundamentals of edge computing are presented in section 2. Section 3 represents different edge computing architectures. Section 4 and Section 5 describes the different architectures of edge computing for different sectors like healthcare, and Industrial IOT (IIOT). Section 6 concludes the paper.

2. EDGE COMPUTING

Edge computing refers to a network of local cloud services that processes or stores crucial data close to the data source and sends all other data received to a centralized cloud storage system for storage [30]. This method of cloud computing system optimization involves processing of data near to data source at the edge of the network. By doing so, analytics and knowledge generation can be done at or close to the data source, reducing the amount of communications bandwidth required between sensors and cloud [31].

2.1 Need for Edge Computing

The cloud-based computing paradigm is experiencing a bottleneck due to the increasing amount of data being generated at the edge and the speed at which it is being transmitted. Think of an autonomous vehicle as an

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illustration. Real-time processing is necessary for the car to make informed decisions because it will generate 1GB of data per second The processing time would be significant if each piece of data had to be uploaded individually to the cloud. Additionally, the current network's bandwidth and stability would be compromised if it is able to service a large number of vehicles at one time. For a faster response time, more reliable processing, and minimal network load in this case, edge data processing is required [7, 32, 33].

Edge computing devices typically act as data consumers in the cloud computing model. One example is watching the YouTube videos on a smartphone. But nowadays, individuals are also producing data on their mobile devices. More function placement at the edge is necessary from data consumers to data producers and consumers. For instance, it is quite common for people to capture images or film videos today, and then share the content through a cloud service like YouTube, Facebook, Twitter, or Instagram. Additionally, Facebook users share nearly 2.5 million pieces of information, Twitter users tweet nearly 300000 times, and Instagram users post nearly 220000 new photographs every minute. This is in addition to the 72 hours of new video content uploaded by YouTube users every minute. However, if the image or video is large, then uploading requires a lot of bandwidth. Before uploading to the cloud, the video clip in this situation needs to be demised and adjusted at the edge to the proper resolution. A wearable medical device is the another example. Since the physical data gathered at the network's edge is typically private, processing the data there may offer greater user privacy protection than uploading raw data to the cloud [33].

2.2 Edge Computing vs Cloud Computing

The term edge computing refers to a specialized computing infrastructure that exists at the boundaries of data sources like industrial equipment, auto-cars, smart homes, and other smart devices that envision incorporating many sensors and operating with their data. In other words, it shifts the edge of computing applications toward the network rather than the centralized nodes. Edge computing, therefore, requires utilizing device resources to reduce the need for constant network connectivity [33].

The alternative strategy, known as cloud computing, is linking everything to a central data storage system, where enormous amounts of data are processed to identify optimized solutions or make business-related decisions. Cloud computing is typically related to complicated data processing tasks that demands a lot of processing power. In some particular fields where the results of computation must be applied immediately, data accumulation and processing are not fast enough to be used [33].

In case of edge computing, first a large portion of transitory data is processed at the network's edge but not all of it is transferred to the cloud, thus reducing the load on the network's bandwidth and the electricity needed by data centers. Second, processing data close to the data source eliminates the need for a network response from the cloud computing facility, dramatically reducing system latency and improving service response time. Finally, edge computing prevents network data leakage and safeguards security and privacy by storing users' sensitive data on edge devices rather than uploading it [7, 33].

3. EDGE COMPUTING ARCHITECTURES

3.1 Fog Computing

In fog computing, data and computation are placed close to the end user because the name "fog" refers to a cloud that is near the ground [8]. Fog computing architecture allows the distribution of processing, storage, control, and networking functions near the user. As a result, it serves as a link between end devices and the remote cloud [3, 8]. Using a fog model, data can be processed close to where it is generated rather than being sent to a cloud or internal data center. This causes a reduction in overall network congestion as well as lower latency for mobile and IoT devices. To support the integration of potential future technologies and services such as smart grids, smart vehicles, and smart cities, fog computing provides a hierarchical distributed architecture [9, 10]. The general architecture of Fog computing is shown in Fig.1 which contains three layers: the device layer, the Fog layer, and the Cloud layer.

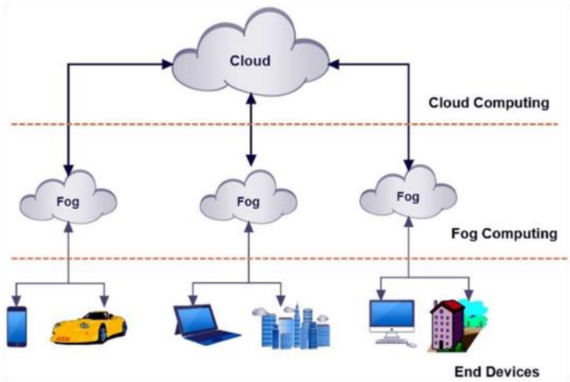

Fig. 1 Fog Computing Architecture [9]

The device layer is made up of various IoT devices as well as end devices like computers, smart automobiles, smart homes, tablets, and smartphones. The data generated by devices must be gathered and sent from this layer to the fog devices in the fog layer for additional processing and storage [8, 10]. The fog layer functions as a bridging layer between the cloud and the end device layer [10]. At this level, the fog devices process the data that is received and send it to the cloud for storage. The fog layer is made up of networking equipment like routers, gateways, switches, security cameras, etc. Fog devices monitor the process, gather data from endpoints, and temporarily store detected data. The fog server can manage latency-sensitive information and real-time analytics [8, 11]. The analysis and long-term storage of data are done by the Cloud layer,

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which is the top layer of the fog computing architecture [10, 11].

3.2 Mobile Edge Computing

Mobile edge computing is a cloud computing infrastructure, which supports delay-sensitive, context-aware applications is situated in the radio access network (RAN) close to mobile users. [4]. Mobile edge computing's primary objective is to lower latency by moving to compute and storage capability from the core Wireless Area Network (WAN) to the network edge [12]. Mobile edge computing offers radio access network data in real-time to application developers, including user location and available bandwidth. By offering context-aware services to mobile users using this real-time network data, user satisfaction is improved. The use of a mobile edge computing platform improves edge responsibility and enables the hosting of computation and services at the edge, which lowers user network latency and bandwidth usage [12]. Fig. 2 shows the architecture of Mobile Edge Computing.

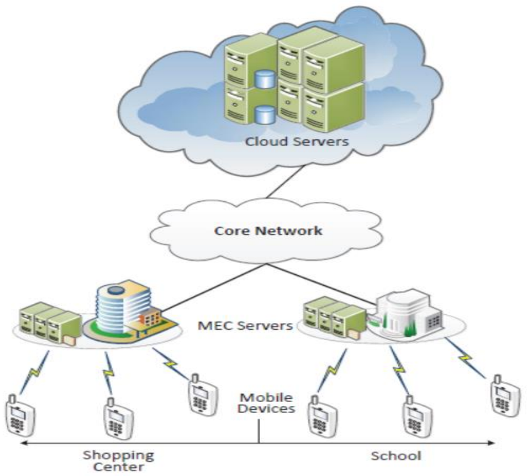

Fig. 2 Mobile Edge Computing Architecture [11]

The architecture is composed of these three fundamental parts: Edge devices, the MEC layer which acts as an edge cloud, and the cloud layer. Mobile phones and IoT devices that are connected to the network are both considered edge devices. The less inventive edge cloud is the one that is installed in each mobile base station. The Edge cloud manages traditional network traffic, including both forwarding and filtering, and contains a range of mobile edge apps, including smart healthcare, smart monitoring, and others. The cloud layer is a centralized system responsible for data storage [12, 13].

3.3 Cloudlet Computing

Our daily lives now cannot function without mobile gadgets, but they have limited storage, processing, and battery life. To extend battery life, expand storage capacity, and increase processor power, resource-intensive operations can be effectively offloaded to the cloud [15]. For applications like image recognition, requires high computing power and long battery life, the performance of mobile devices drastically reduces when used in hostile situations [14]. To overcome this limitation, the researcher developed a solution called cloudlets. By using a cloudlet, user can perform computational tasks in the cloud more conveniently [15]. Cloudlets computing intends to bring cloud services, capabilities, and applications closer to users and the network edge. Cloudlets have many advantages, including reduced communication latency and enhanced connection [16]. It uses Wi-Fi connections to transfer computationally heavy operations to a cloudlet for processing, extending the battery life of mobile devices. Combining cloudlets with an enterprise cloud, like Google, is an advantageous since it gives users access to applications and services [15].

Fig. 3 represents the cloudlet architecture. According to Fig. 4, each Base Station (BS) is connected to a cloudlet, which is composed of several physically connected units. For its local mobile users, each cloudlet offers significant computing resources [17, 18]. The location of cloudlets is flexible, allowing several BSs to share the computing resources in a single cloudlet by connecting it to an edge switch or directly to a BS via high-speed fibers. The introduction of the SDN-based cellular core establishes an efficient routing path between two BSs [17, 18]. As MUs may access computing resources with little network delay thanks to the supplied architecture, it is simpler to offload the MCC application workload [17].

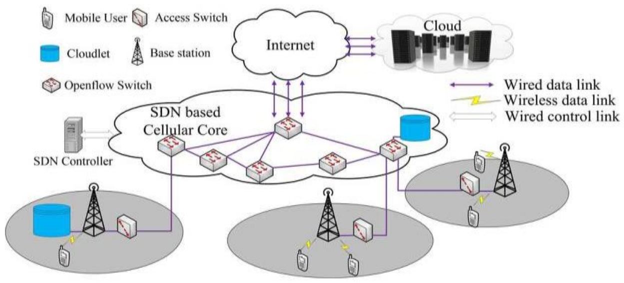

Fig. 3 Cloudlet Computing Architecture [18]

4. INDUSTRIAL INTERNET OF THINGS AND CLOUD COMPUTING

The term "Industrial Internet of Things" (IIoT) refers to an environment in which information is received from numerous sensors, actuators, and equipment in an industrial setting and made available and accessible via the Internet [19]. The Internet of Things (IoT) enables access to the Internet for any "thing," although it only allows those "things" to exist in the context of an industry [19]. IIoT extensively relies on machine-to-machine (M2M) connections and is primarily focused mainly on the transmission and control of crucial information and responses [19, 20]. For a variety of applications in the industrial setting, including the maintenance of hightension power lines, the inspection of underwater pipelines, the production and monitoring of jet aircraft, mining, and the operation of large cranes, a minor error or delay that exceeds the permitted limit may cause some catastrophe. Fog computing acts as a middleware system capable of tackling urgent and complicated tasks locally and promptly, and can in this situation offer the necessary support [19, 20]. Fog can provide many benefits, such as reducing human error, lowering health risks to people, improving operating efficiency, lowering costs, increasing productivity, and improving maintenance quality. Fog will be able to unload the sensors and carry out difficult tasks on their behalf. Similarly, fog can keep track of how much power each sensor uses and adjust the data generation frequency accordingly. Fog can also investigate and control various energy sources like solar, thermal, and others. In nearly every industry sector, fog computing has a significant potential use. The industry is typically divided into three sectors: primary, secondary, and tertiary, which are related to extraction, manufacture, and services respectively e.g., mining, vehicles, and transportation [19].

4.1 Vehicular Edge Computing

The improved processing and communication capabilities of the vehicle are expanding quickly along with the rapid advancement of technology. Automobiles are being developed as vehicles of the internet, able to do navigation, remote car diagnosis, multimedia entertainment services, and even AI-based automatic driving services, with the help of promising electronic control units (ECU) [22]. However, the ECU's restricted functionality and the unsteady vehicular network continue to have an impact on the service's quality. Therefore, their service capacity is increased when edge computing and regular vehicular networks are integrated. The edge computing infrastructure for automobiles consists of computation nodes connected to Base Stations (BS) and a range of computational hotspots with Wireless Local Area Network (WLAN) access technology, such as cloudlets in structures and smart roadside devices. Each of these computational nodes can do duties for the driving vehicles along with the nearby vehicles [22].

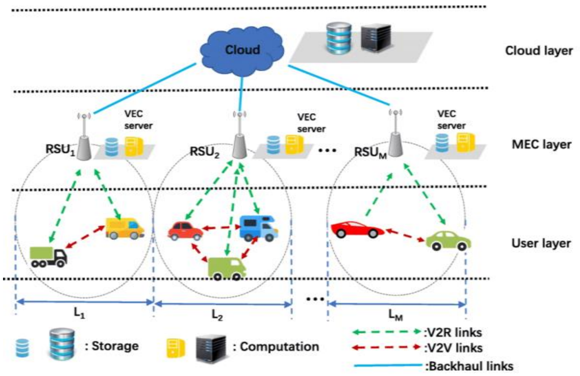

Fig. 4 Vehicular Fog Computing Architecture [25]

The wireless access points are placed with the cloudlet edge computing servers at intelligent roadside units like the street lamp, crossroads, stores, or buildings. These nodes use limited transmission coverage communication technologies to offer the vehicles a variety of local capabilities and services, such as computing, networking, and storage [22, 23]. The vehicular nodes can also be viewed as edge computing nodes because the user can use the features of the adjacent vehicles to carry out some service [24]. The architecture of Vehicular Edge Computing is shown in Fig.4 which consists of three layers: The user layer, the MEC layer, and the cloud layer [25].

The user layer consists of vehicular terminals represented by vehicles that can perform different functions. Vehicles equipped with cameras, radars, Global Positioning Systems (GPS), and other sensors can collect a wide range of data. They can also exchange information with other vehicles or RSUs. Vehicles can do some calculations locally rather than sending them to edge servers or the cloud. Vehicles can be used to cache popular information for data sharing [25]. RSUs, which are distributed along the road in a city, frequently serve as edge servers in VEC. They have enhanced communication, computing, and storage capabilities in comparison to vehicles. Receiving the data transmitted by the cars, analyzing it, and even uploading it to the cloud are the responsibilities of RSUs. RSUs are useful for fulfilling high-performance requirements because they use compute offloading and caching technologies. They can also provide a range of services for vehicles, such as traffic management, route guides, and video streaming [25].

Remote clouds are used to deploy cloud services. They can access edge servers to obtain the uploaded data. In terms of processing and storage, cloud services are significantly more capable than edge servers and have a much larger geographic reach [25].

Fog computing is thus one of the greatest ways to prevent erroneous or irrelevant data from propagating throughout the entire network, which will reduce latency and free up storage space. Low latency and improved memory storage are necessary for real-time services and decision-making processes in industrial automation. In the future, solutions for more effective, efficient, and controllable communication channels for the wide range of smart IoT devices will be provided by fog computing [26].

5. HEALTHCARE AND EDGE COMPUTING

Information and communication technologies (ICT) have lately been employed in the field of healthcare to create intelligent systems that speed up the process of anomaly detection in humans and deliver an accurate and effective diagnosis. The entire healthcare system has been automated through the Internet of Medical Things (IoMT), including data collection and diagnosis. A powerful technology during the COVID-19 pandemic was IoMT. It made it possible to detect, diagnose, monitor, and treat patients remotely, which helped to stop the virus spread [27, 28]. But as IoMT increases, a significant amount of huge data is produced, which needs to be analyzed instantly. Due to their constrained CPU and storage capacities, IoMT devices cannot process massive data in real time. Centralized cloud computing with excellent computational and storage resources was the initial solution. However, because transferring data to the cloud depends on network speed and congestion, processing data on cloud servers are subject to significant delays. [28]. Transmission of data for cloud-based analysis may result in some people's deaths. Therefore, processing time-sensitive data close to patients, possibly at the network edge, is a realistic approach. To achieve this, Mobile Edge Computing, also known as small cloud server distribution, is required at the edges of the network or mobile base stations [28].

5.1 5G Mobile Edge Computing –based IoMT healthcare system

The emergence of MEC enhanced this environment by adding a middle component at the network edge, which resulted in the creation of a new model for software development with three locations: devices, edge servers, and cloud [28]. One of these architectures, which enables smart healthcare systems with 5G IoMT and uses mobile edge computing servers as a middle-ware layer, is shown in Fig.7 This architecture consists of four layers: the sensor layer, which primarily serves the purpose of data collecting; the communication layer, which offloads computing activities; the MEC layer, which handles edge processing; and the cloud layer, which handles remote processing and storage [28].

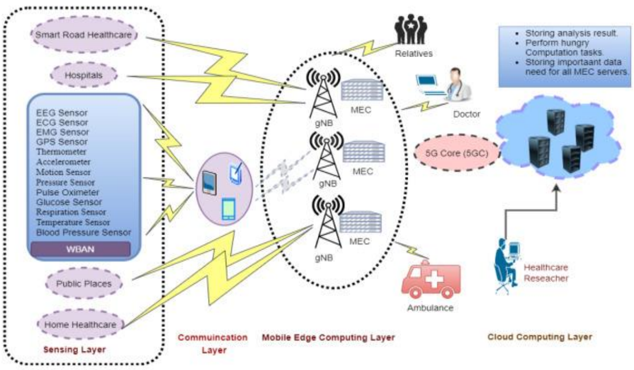

Fig. 5 5G MEC-based IoMT Healthcare System Architecture [28]

The sensing layer consists of a group of wireless medical sensors placed in various body parts to track psychometrics like blood pressure, heart rate, body temperature, insulin, and oxygen levels. The IoMT devices capture medical data and transmit it to a nearby node for transmission, such as a smartphone, or nearest node. The local node can examine data using small machine learning tools and other minimal processing tools, and then only upload the relevant data to the edge server i.e. MEC servers or the cloud. A coordinator, such as a doctor, ambulance, or medical professional, is notified of the analysis's findings via a gateway [28]. In public spaces and on smart highways, IoMT sensors, like smart cameras, are used to identify emergencies and accidents and alert the closest emergency services. The third use involves using wearable smart sensors to monitor elderly and chronically ill patients at home. To track the state of hospital resources, IoMT sensors are also used in hospital management systems. The communication layer comprises sending information and tasks via wireless local area networks to the surrounding MEC servers. A decentralized computing environment is offered by MEC, which is situated at the edge of the mobile network. It can set up medical software or medical application to process and store data close to mobile users and Internet of Things devices. MEC can be utilized for local caching to lower queries to remote clouds. In the healthcare industry, cloud computing is used to manage processes that need a lot of processing power and to store huge amounts of information produced by IoMT devices. Time-insensitive, computationally expensive jobs are sent to centralized cloud computing for processing. Additionally, it keeps track of data from all MEC servers, including pandemic sites and the number of cases of various diseases. [28, 29].

Higher-level healthcare services are provided by MEC-based healthcare systems, including real-time data processing, quick computing, local storage, and many others. By delivering computing resources to mobile users in close proximity to mobile networks, MEC lowers latency, which can help save many lives.

6. CONCLUSION

Many industries, including telecommunications, manufacturing, transportation, utilities, and many more, are currently using edge computing. By avoiding bandwidth restrictions, reducing transmission delays, limiting service issues, and improving control over the movement of sensitive data, edge computing can lower the network cost. By keeping all of that computing power local, edge computing further lowers the risk of exposing sensitive data and enables enterprises to implement security procedures or adhere to legal requirements. Utilizing edge computing in the IIoT can analyze a portion of large amounts of real-time sensing data near the data source, resolving the main issues of limited transmission bandwidth and longer latency when making decisions from cloud platforms. This technology will advance in the future to improve patient care, help them stay healthy, and prepare for any pandemic of the COVID-19 variety. Edge computing is quickly becoming a necessary tool for healthcare practitioners as the industry turns more and more to digital solutions to improve patient care. The promise for quicker, more effective, and more secure data processing and analysis makes the use of edge computing in industry and healthcare as bright prospect for future analysis. This survey presents a critical understanding of various edge computing methods concerning their benefits. In the domain of edge computing, a large pool of work has been explored in the application of industry, healthcare, and many more different sectors. Both industrial IoT and Smart Healthcare approaches have yielded significant results in edge computing.

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