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Fog Computing and the Internet of Things (IoT): A Review

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***Abstract*— IoT integration with cloud brings about numerous benefits to devices that operate on heterogeneous platforms. IoT-based applications generate massive data from different sensors. This data is analyzed to make decisions. Fog computing offers advantage by providing data processing capabilities and storage to devices locally rather than sending data to the cloud.**
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***Index Terms*— Internet of Things (IoT), fog computing, cloud computing.**

I. Introduction

IoT reduces human data entry efforts and uses different types of sensors for data collection from environments while allowing automatic data storage and processing [1]. IoT suffers from numerous issues like security, performance, reliability, and privacy. The IoT integration using the cloud, referred to as the Cloud of Things (CoT), presents an opportunity to overcome these issues. CoT facilitates easy flow of IoT data while providing quick integration and low-cost installation for complete processing and deployment of data [2].

IoT's evolution is from the convergence of micro-electromechanical systems (MEMs), wireless technologies, the Internet, and micro-services. This has helped break down the information technology and operational technologies, which allow unstructured data generated by the machine for insights driving improvements [2]. The cloud computing model extension is facilitated by fog computing to the network perimeter, thus boosting new application and service types. The fog computing characteristics include location and low latency awareness, mobility, wide-spread distribution geographically, primary wireless access role, a massive number of nodes, heterogeneity, strong streaming presence, and real-time applications [3]. The above characteristics make fog computing an appropriate and relevant platform for critical IoT applications and services.

IoT comprises internet-connected, smart devices, thus facilitating connectivity to homes, workplaces, offices, and vehicles. However, the over-dependence on these internet-connected devices increases with technology usage and benefits [3]. Therefore, the gateways consistency making the IoT an operational reality must increase, and guarantee uptime. IoT increases usage of current data center and internet infrastructure. It should be noted that fog computing does not replace cloud computing; rather, it works by combining with cloud computing and, in the process, optimize the use of available systems, devices, and resources. Fog computing was a product of seeking to address existing challenges, incoming data action, and real-time processes [2]. It also addresses resources limitation such as computing power and bandwidth. One of the factors assisting fog computing is while attempting to take advantage of the distributed nature of virtualized information technology assets today. This kind of improvement on the hierarchy of data-path is enabled by increasing computer functionality, which manufacturers adopt to build into their switches and edge routers.

II. FOG COMPUTING

Fog computing refers to a paradigm or platform with few capabilities like storage, computing, and networking services, but in a more distributed way between various classic cloud computing and end-devices [2]. The platform provides a reliable solution for applications and devices using IoT but is sensitive to latency. Cisco originally coined the term – "fog computing," but various other organizations and researchers have defined the term based on different perspectives.

Fog Computing Characteristics

Fog computing is highly virtualized, meaning the platform provides storage, compute, and networking services between conventional data centers and end devices. Fog computing also supports mobility approaches, such as the LISP protocol1, which decouples the hosts identity while requiring a distributed system [3]. At the same time, real-time processing is a characteristic of fog computing. Federation and interoperability are synonymous for seamless support of specific services. An excellent example is streaming, as it requires operation of various service providers [3]. Fig. 1 below presents a more idealized computing and information architecture of IoT applications.

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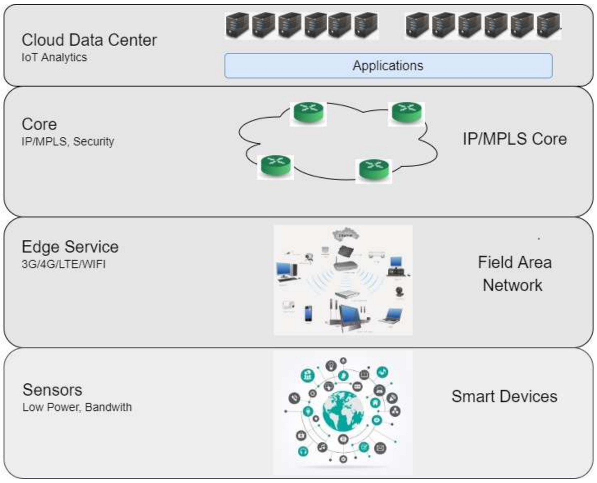

Fig. 1: Fog Computing and IoT [6]

Fog Computing Benefits

The cloud computing model by fog computing is done to the network edge. While the cloud and fog adopt the same resources (computing, network, and storage), as well as share a lot of similar attributes and mechanisms (multi-tenancy and virtualization), fog computing brings about a lot of benefits for IoT-powered devices. One of the benefits accompanying fog computing is that it has greater business agility. Using the right techniques, applications with fog computing can be developed and deployed quickly. Additionally, fog computing-based applications can analyze and program the devices to work based on the machine's needs. Fog computing comes with low latency meaning it can support the functionality and essence of real-time services such as video streaming and gaming [2]. As it relates to large-scale and geographical distribution, fog computing provides storage resources and computing to widely distributed applications.

Fog computing has lower operating costs and saves network bandwidth. Additionally, fog computing has heterogeneity and flexibility. For instance, it allows the collaboration of various infrastructures and physical environments among various services [2]. Lastly, it is known for its scalability, which means the fog computing proximity to end devices enables scaling of services and connected devices.

Fog Computing Architecture

Fog computing avails limited computing, networking, and storing services in a distributed way between the data centers of cloud computing and the end-devices. The main goal of fog computing is to offer predictable and low latency for IoT applications sensitive to time. Fog computing architecture comprises six distinct layers, namely physical and virtualization, pre-processing, monitoring, transport, security layer, and temporary storage [4]. The transport layer facilitates uploading data, both pre-processed and secured, to the cloud. The security layer involves privacy, encryption and decryption, and integrity measures. The temporary storage layer facilitates data distribution, de-duplication, and replication [2]. Other operations include storage devices and storage space virtualization. Accordingly, a pre-processing layer of the architecture involves data filtering, data analysis, trimming, and reconstruction. The monitoring layer involves power monitoring, response monitoring, resource monitoring, and service monitoring [5]. Lastly, the physical and virtualization layer of the fog computing architecture is characterized by virtual sensor networks and wireless sensor networks.

The physical and virtualization layer comprises various "types of nodes" such as virtual nodes, physical nodes, and virtual networks for sensors. The management and maintenance of these nodes are based on the specific types and level of services. Various sensor types are geographically distributed to detect the surroundings or setting before sending the data after collection to the upper layers of fog computing through gateways to process and filter it even further. There is close monitoring of how resources are utilized, the presence of sensors, the network elements, and the fog nodes. There is also monitoring of the nodes performing various tasks in this layer [2]. Accordingly, the status and performance of every application and service deployed on the fog computing architecture are closely examined. At the same time, the consumption of energy by fog nodes is examined; considering fog computing adopts numerous devices with different power consumption levels, the measures for energy management can be effective and timely.

The pre-processing layer in the architecture performs tasks involving data management. The analysis following data collection, including data trimming and filtering, is conducted in the layer to extract important information [4]. When data transmission to the cloud is complete, it is no longer important to facilitate local storage and may be removed from the temporary media of storage. Lastly, the security layer, decryption/encryption of data, becomes relevant at this point. Additionally, measures of integrity are applicable for data protection to prevent possible tampering. In the transport layer, the pre-processed data are uploaded and stored in the cloud [6]. For efficient utilization of data, only a section of data collected is sent to the cloud. This means the gateway device that connects the IoT to the cloud facilitates data processes before sending them to the cloud. This kind of gateway is referred to as the smart gateway [5]. Data collected from the sensor networks, including the IoT devices, is sent to the cloud through smart gateways. The cloud receives data before storing and using it to develop services for users. Given fog computing's limited resources, communication protocols should be lightweight, efficient, and customizable [2][7][8].

Handling Internet of Things (IoT) Data

IoT generates a significant amount of data, which can be useful in various ways, especially for insight analysis. However, the IoT data volume can overwhelm the current storage platforms, including the application of analytics. Cloud computing could assist in providing scalable and on-demand storage, including processing services, which can be scaled to meet IoT requirements. However, for purposes of health monitoring, latency receptive activities and applications, the delay is attributed to data transfer to the cloud and back, which is not acceptable [4].

Simultaneously, this would reduce congestion of the network and accelerate data analysis, including the ensuing production assessment. However, the edge devices cannot handle multiple IoT applications but compete for their limited resources, resulting in the contention of resources and an increase in latency processing [1]. In this case, fog computing seamlessly integrates cloud resources and edge devices while overcoming existing drawbacks. Fog computing avoids contention of resources at the center by leveraging coordination and cloud resources through geographically distributed edge devices [5]. A recommendation to integrate fog computing to push the IoT to the edge is backed up by extensive research, especially in recent years. The expansion of IoT tends to get into every area and device, thus facilitating high-speed data processing and shorter and analytics response times [6][7][8]. There are ways in which fog computing advances IoT intelligence to the network edge as the IoT advances. The high-speed processing of data, shorter response, and analytics are more important than ever. Meeting some of the requirements is, to some point is hard through the current centralized cloud. however, fog computing brings computing application and resource services closer to the network edge [3].

Fog Computing with the Internet of Things

Cisco termed fog computing as a section of cloud computing's paradigm, taking the cloud nearer the network edge. It offers highly virtualized computation models, networking, and storage resources between the classical services of cloud computing and end-devices [2]. To boost the efficiency of applications involving the Internet of Things, most of the data generated by these IoT devices must be processed while analyzing the data in real-time. Fog computing impacts various aspects, for example, bringing cloud networking, storage, and computing capabilities down to the network edge [6][9]. This will address the IoT-based devices' actual issues while providing efficient and secure IoT applications. Accordingly, fog computing offers various applications and services with extensive deployments.

Integrating fog computing with the Internet of Things brings about various benefits: different applications powered with IoT. Fog computing brings about real-time engagement with the intention of reducing latency, more so when it involves time-sensitive applications of IoT. Additionally, one of the significant features includes the ability of fog computing to boost large-scale sensor networks. Fog computing offers specific ways of overcoming challenges associated with computing architectures, which depend on computing in both the end-user and cloud-based devices related to devices powered by IoT. Real-time device applications are characterized by fog computing. This, in turn, resulted in the development of new models of business, including chances for network operators [9]. Bellavista et al. (2019) proposed a framework for better understanding as well as evaluate delays in model service in scenarios involving IoT-based applications. The proposal involved minimizing policy for fog nodes primarily to reduce the delay of services associated with IoT nodes. The proposal for a policy facilitates communication targeted at reducing delay in services. The offloading of computation means the policy considers the queuing and the duration mandated to determine different types of processing. A proposal was made regarding the adaptive platforms of operations to provide end-to-end fog computing manageability regarding the operational demands of the industrial processes. Performance was evaluated based on proposed platform using available cases [3].

Fog computing provides a chance to boost efficiency and reduce latency. It facilitates IoT-based data storage to manage services at the network edge. There are also various cases associated with the centralization of highly proficient computing infrastructure while seeking to manage expenses and scalability. It is the combination of fog and cloud to accelerate IoT applications, more so in the enterprise.

IV. CONCLUSION

IoT integration using the cloud referred to as the Cloud of Things (CoT) presents an opportunity to overcome some issues. CoT facilitates easy flow of IoT data while providing quick integration and low-cost installation for complete processing and deployment of data. Accordingly, various challenges associated with cloud computing facilitated fog computing's adoption as an alternative to implementing IoT. The current approach involves centralizing cloud processing of data in one site. However, this often results in application data security concerns given the data received from distributed sources. This meant that the possible solution focuses on allowing computing, action-taking, and decision-making to take place through IoT-connected devices before only pushing related data to the cloud. In turn, the result would be having IoT-powered devices and systems benefiting from fog computing.

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