Fog Computing: A Short Review of Concept and Applications

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Summary
Internet of Things (IoT) makes electronic devices, appliances, medical devices, cameras, sensors, vehicles, as a part of the Internet enabling for smart cities and infrastructure. By the year 2020, it is estimated that 50 billion IoT devices will be connected to Internet. The IoT devices will produce unprecedented volume of data that could be difficult for traditional system and cloud systems to manage. Fog computing is designed to overcome the limitations in the current systems. Fog provides storage, compute, data and application services similar to the cloud computing, at the edge of the network. This paper argues the characteristics that make Fog computing a suitable platform for IoT along with the definitions, applications and related works in Fog and IoT area.

Keywords:
Fog Computing, Internet of Things, IoT, Cloud Computing.

1. Introduction

Fog computing is an emerging technology utilized for the Internet of Things (IoT), a paradigm that extends cloud computing and services to the edge of the network [1]. Fog computing provides data, computation, storage and applications to the end-users similar to cloud computing. What distinguishes Fog computing from Cloud computing is close proximity to end-users, support for mobility and dense geographical distribution [2].

Cloud computing is an efficient, cheap alternative way for customers that require to host web and mobile applications and batch processing compared to managing private data centres (DCs) or centralized server systems. On-demand scalability of computation power, storage and resources along with "pay-as-you-go" cloud computing model make it efficient for customers and could help to meet and scale the IoT requirements. However, the delay in transferring data between cloud and end-devices, especially those in health-monitoring, emergency services and latency-sensitive applications will be unacceptable. In addition to low latency end-devices requires geographical distribution and mobility support [1].

Aazam et al. [3] claims that the number of connected devices or IoT devices has already exceeded the population of earth and by the year 2020 an estimated 50 billion IoT devices will be connected to the Internet [4]. These end-devices will produce large number of data, send to cloud for storage and processing and receive the processed data. This will result in heavy traffic between the cloud and end-devices affecting the quality of service, saturating the network bandwidth. Because Fog is a cloud close to the ground or to the edge of network, it is able to meet the requirements of solving these issues [1].

This paper is organised as follows. The following section is about the Fog Computing paradigm and how it works, followed by the section 3 on the characteristics of fog computing. The next section cover some of the key services and applications that uses Fog computing and discusses why Fog is suitable for those applications. In the next section, some previous related works are discussed and analysed, substantiating the argument in favour of Fog computing and why it is important in IoT, and identifying the gaps in the Fog computing paradigm. Finally, the last section concludes this paper with comments about the state of Fog Computing and its role in the Internet of Things and discussion of future work.

2. Fog Computing Platform

Fog computing can be viewed as a development of the cloud computing paradigm from the core of the network to the edge of the network. Fog computing is a greatly virtualised platform which supply computing facilities, storage services, and networking between users and cloud server or data centres [5]. Fog computing combines the mobile cloud computing (MCC) and mobile-edge computing (MEC), which are of similar concepts [6]. MEC is viewed as a cloud server located at the edge of a mobile network performing dedicated tasks that cannot be achieved by using the traditional network, while MCC is viewed as an infrastructure where both computation of data and storage is done outside the mobile devices [7].

Figure 1 represents and illustrates the role of Fog computing and its support in IoT applications and devices [1]. As shown in the figure, Fog is deployed in between the Cloud and end-devices. Fog servers are geographically distributed and deployed at the local premises such as parks, shopping malls, terminals, etc. This system architecture brings computation, storage and communication resources to a close proximity with the end-devices, thus allowing end-devices to achieve low latency, better and improved quality-of-service (QoS) for streaming and real-time applications. The geographical distribution of Fog servers makes it possible for location awareness and localisation, unlike Cloud servers located in

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a central data centre. In Fog architecture, as shown in the Figure 1, each layer will have different properties in terms of network bandwidth, storage, etc. Because fog nodes or end-devices exist at various layers with interconnected topologies between them, it has the capability to form a connected graph [8]. Fog necessarily does not replace the Cloud, it supplements or act as a middle-man between the cloud and end-devices or fog nodes to provide critical services to the end-devices.

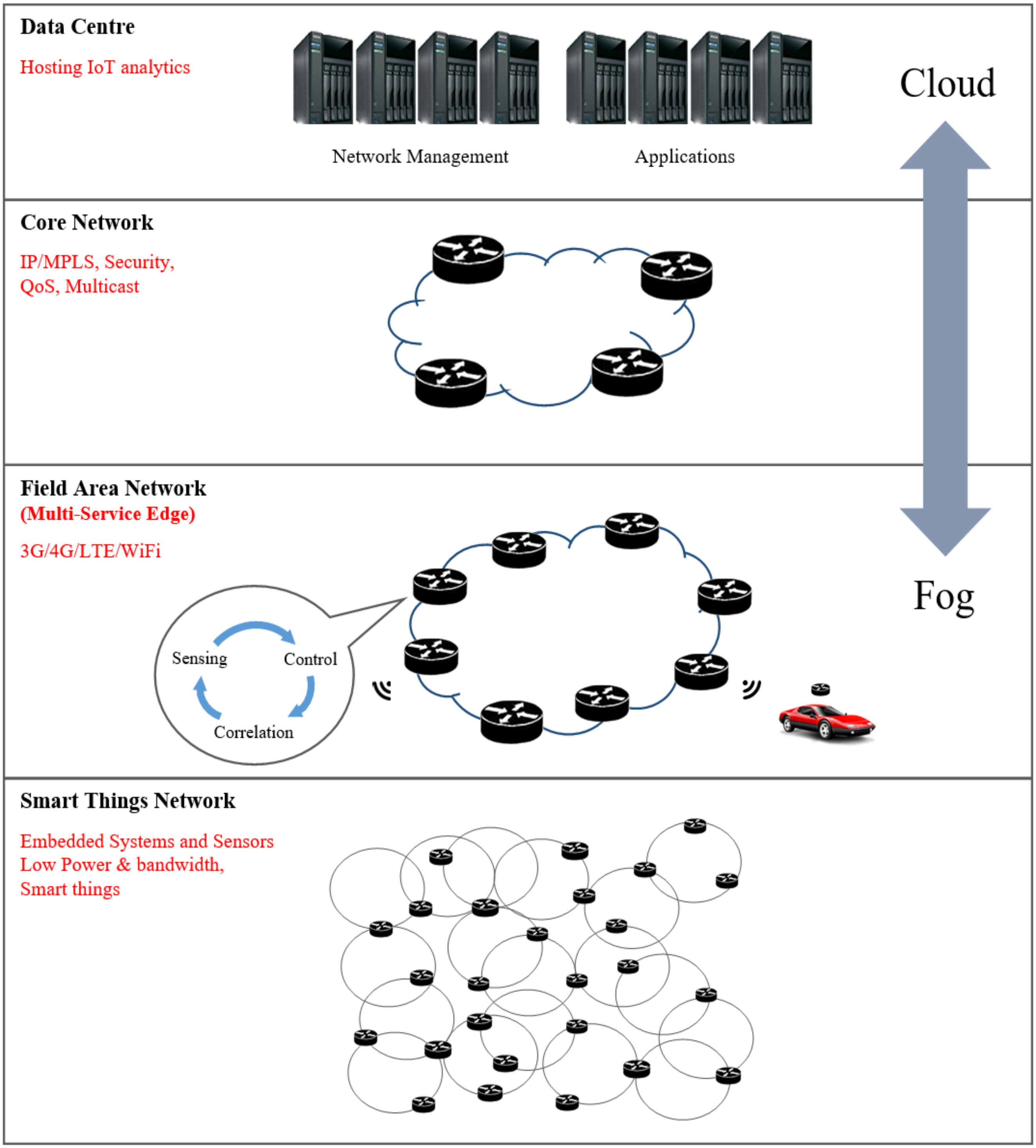
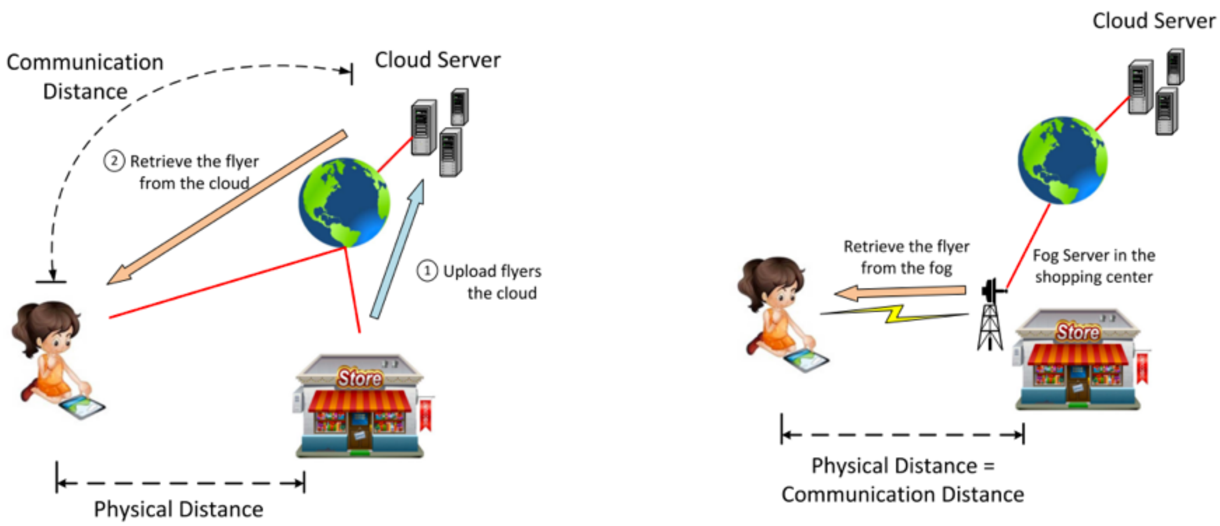


Fig. 1 The Internet Of Things Architecture and Fog Computing [1]

Figure 2 illustrates downloading of a file using both Cloud and Fog. Figure 2 (a) shows downloading of the file from cloud server without a Fog server in between. In this scenario, the localised flyer or file will have to be uploaded to the cloud server first, by the store owner. The user then connects to the Internet and directly download the flyer or file from the cloud server through a long-distance link, even though the user is physically near to the store. Unlike that scenario, in Figure 2 (b), the user retrieves the localised file directly from the Fog server instead of connecting to the cloud server. Because the file is downloaded from Fog server, the back-and-forth traffic between the cloud and the user or end-device helps to save backbone bandwidth and increase data transfer rate, and reduce service latency and response time. The same scenario is applied with IoT end-devices deployed, instead of users, it will be various sensors and IoT compatible end-devices, communicating between the Fog servers. The end-devices can communicate through single-hop wireless connections.



(a) Retrieving the flyer from the cloud (b) Retrieving the flyer from the fog

Fig. 2 Downloading a flyer of a nearby store [9]

3. Characteristics of Fog Computing

Bonomi et al. [1] states that the building blocks of both Fog and Cloud are computation power, storage, and networking components. According to Luan et al [9] the support of location awareness distinguishes Fog computing from Cloud computing. He also claims that cloud computing is often characterised by location awareness, because they are located in a centralized place and have scalable storage space and compute power unlike the Fog server, which has limited storage, computation power and a wireless interface.

IoT devices utilizes and relies on Fog server or layer to carry out compute processes, storage, communication, control, configuration, and management. IoT end-devices are located close to the source of information, the Fog server will reduce the latency and jitter. It can also optimize the latency and jitter so that the end-devices can achieve millisecond-level latency.

The diversity in geographical distribution of Fog servers allows the capability for IoT devices to be aware of their location based on the deployed location of Fog servers. Geographical distribution of Fog servers also allows data to be stored at an optimal depth in the network, allowing caching structures can be optimized [8].

According to CISCO [4], IoT devices will generate huge amount of data and traffic which will overload interconnect links. With the Fog layer or servers deployed, the data associated with IoT devices can be managed closed to the source, thus saving the bandwidth on backbone links and reducing the network traffic [4, 8, 10].

In addition, Fog computing also includes the support for user mobility, resource and interface heterogeneity [10]. The Fog also enables real-time interactions and distributed data analytics to address the requirements of widely distributed applications that requires low latency and provides better security according to CISCO. Furthermore, Fog also provides interoperability for seamless integration of wide range of services such as streaming [11].

4. Applications of Fog Computing

Many important IOT services uses Fog as a suitable platform and applications. Some of these IOT services are briefly discussed below:

4.1 Smart Grid

In order to supply an efficient control and management system for energy distribution, IoT and Fog can be employed. Fog collectors at the edge use the data produced by grid sensors and devices to switch between energies, such as solar, wind and etc. The edge will process this data and perform required action. One of the crucial operations in smart grid is to ensure that protection and control loops are functioning properly [4]. This requires real-time data processing, which can be provided by Fog platform. Through Fog, IoT devices in a smart grid can be achieved in a seamless and effective way.

4.2 Connected Vehicles (Automotive & Smart Mobility)

Today self-driving autonomous vehicles are being tested and deployed by companies like Tesla, Google, GM, Uber and etc. He et al. [12] claims that with connected vehicles and IoT, road congestion can be reduced and road safety can be increased along with better traffic management and parking. Connected vehicles open up new scenarios of connectivity; connection between vehicles to vehicles, vehicles to access points, such as smart traffic lights and roadside units, using protocols such as HTTP, TCP/IP, WAP, etc. Location awareness and support for real-time interaction with low latency and heterogeneity characteristics makes Fog a suitable platform communication between connection connected vehicles or in smart mobility. Audi USA [13] announced Vehicle to Infrastructure (V2I), which communicates with municipal traffic signals to inform the driver when traffic lights turn from red to green. With connected traffic lights and vehicles, the driver knows exactly when the lights will turn green and what speed he should be driving in order to avoid the red light. With this technology possible road collisions can be avoided, where by traffic lights can send signals to approaching vehicles or take immediate action by modifying its own cycle to prevent an accident from occurring. This has to be done in real-time, thus making Fog the most appropriate platform for this. Companies like Mercedes-Benz and Volvo Car Corporation are also exploring technologies like Vehicle to Vehicle (V2V) communication. With V2V, cars will be automatically communicate each other and prevent collisions.

4.3 Wireless Sensor and Actuator Networks (WSAN)

Wireless Sensor and Actuator networks are designed to consume very low power to extend battery life [1]. Each sensor node participates in transferring data to other sensor nodes or to a base station, which are in the range. The base-station then process this data and takes necessary action, such as operating an actuator sensor. For example, in applications where temperature, humidity and various gaseous components in the surrounding are measured in real-time and are used to make decisions on controlling the temperature and opening and closing of the vents. When the sensor reads any abnormal readings, it should be sent for processing and taking immediate actions in real-time. Thus the characteristics, geo-distribution, location awareness, proximity and the low-latency and hierarchical organization makes Fog the platform to support WSNs and WSANs.

4.4 Big Data Analytics in IoT

Fog platform is more suitable for big data analytics in IoT, because it overcomes the drawbacks of cloud, such as high latency and delay [6]. The data will be sent back and forth between the cloud and end-devices which are transmitting data. This takes times and affects the bandwidth and QoS. With Fog platform in use, the data can be aggregated and mined at Fog servers providing timely feedback to the end-devices and to the cloud server. Detailed analytics and intensive computational tasks then can be processed at the cloud server.

4.5 Healthcare

Healthcare services and application are delay sensitive and generates private data of the patients [3]. The data generated contains sensitive and personal information, and location data might be sensitive in some scenarios. Higher jitter and latency can cause several problems in telehealth and telemedicine applications, which makes Fog computing a suitable paradigm in healthcare applications. Stantchev et al. [14] proposed an efficient architecture for healthcare and elderly-care applications using Fog computing, and stated that it can provide redundancy and backup in case of failure between cloud server. Fog computing can provide better management for the flow of data from and to the cloud. Monteiro et al. [15] also developed a Fog computing interface to reduce the data complexity and introduced computational intelligence at the edge, demonstrating how Fog can be used to achieve flexible configuration, computational intelligence, and interpretability in healthcare applications.

5. Related Works

In recent years, various authors have reviewed and discussed the concept and the role of Fog computing in IoT. Bonomi et al. [1] outlined the vision and defined characteristics of Fog computing, which could be used to deliver new services and applications. In his early works, he highlighted three scenarios (connected vehicles, wireless sensor and actuator networks and smart grids), in which Fog computing can be applied. He believes the characteristics of Fog computing make it suitable for the scenarios. The real-time interactions, geographical distribution, support for mobility and heterogeneity and interoperability are some of the key characters that makes Fog computing suitable for those scenarios. This is a valid argument; with Fog computing, low-latency and real-time interactions can be achieved in the scenarios. In the scenario of connected vehicles, if data is not processed in real-time and there are delays, it could result in collision. Bonomi et al. [16] also views Fog computing as a platform for IoT analytics. He believes that data often have different requirements and are used at different time scales, and the geographical distribution of Fog servers can assist in achieving this. The unprecedented volume and a wide range of data generated will increase the data flow. Instead of sending the data to one single point for processing, sending only required data to multiple points or servers for processing will reduce the burden on the network and bandwidth. The author also believes at this early stage of Fog computing, it is hard to address how the providers and users will be aligned. He believes that subscriber models will play a major role and that Fog in applications such as connected/smart cars, smart cities, smart grid, health care etc.

Similar to the work done by Bonomi et al [16], Khan [17] believes Fog computing is a better solution for IoT. According to her, implementation of Fog computing in IoT will eliminate the core computing environment, reducing major block and a single point of failure, reducing the bandwidth used. Fog ensures that processing is done at the edge of the network, reducing the distance of data to be moved. There is argue that this will limit cost of transmission, latency and improving the quality of service (QoS). She also claims that Fog adds an additional layer of security as the data encoded is transferred towards the edge of the network, however there is no data to justify this.

Misra & Sarkar [18] developed a theoretical model to represent the Fog computing architecture mathematically. Their work is the very first attempt in this domain, thus they drew few simplified, yet realistic assumptions for their work. In their mathematical representation, they assumed that the terminal nodes in the network, such as smart phones, smart cars are aware of their location and able to transmit their location via GPS, GIS or GNSS. The second assumption was that Fog computing tier comprises of intelligent devices capable of routing and forwarding data-packets to upper tiers in addition to computing, process and storing. The third assumption was that the networking devices are able to share resources among themselves, and the last assumption was that the fog computing devices are capable of providing optimal support for terminal nodes. By taking the assumptions into consideration, the authors represented Fog computing mathematically, and evaluated the performance in terms of service latency and energy consumption in a scenario where 25% of the IoT applications required real-time services and low latency. It was found that fog computing architecture improved mean energy consumption by 40.48% compared to the traditional cloud computing environment. Latency was also lower compared to cloud-computing, however it was observed that the transmission latency increased when the number of nodes in a cluster or fog server increased. The authors concluded suggesting that integration of IoT and Fog computing will serve as a greener computing platform, which seems to be true by their experimental results.

Vaquero & Rodero-Merino [19] claimed that Fog is nothing but the merging of multiple technologies that have been maturing over the time and will shift many of our current IT tasks, such as app development, network management, provisioning. etc. They highlighted the main challenges faced by Fog computing, in their research work. Having many IoT devices can generate data that could be helpful when processed and analysed. However, the authors stated that managing a network comprising a large number of IoT devices will be challenging and complex. They believe “Softwareisation” of network management is the solution and that Fog computing needs to be handled in a homogenous manner. Use of Network Function Virtualisa-tion (NFV) will provide the ability to dynamically deploy on-demand network services, such as firewall, where ever needed. However, NFV capabilities do not reach end user devices or sensors, and offers only a telco operator’s and vendors of point view, which limits from implementing. In their work, the authors also discussed some challenges of fog computing, such as compute/storage limitation, monetization, security and standardization.

Jalali et al. [20] also proved that fog computing consumes less energy compared to traditional cloud computing architecture and that maybe help to save energy. The author studied energy consumptions by using flow-based and time-based energy consumption models for shared and unshared network equipment, respectively. The author compared the energy consumption of a service provided by a centralized data centre and a nano data centre, which is similar to a fog server. Results shows that the nano data centre consumed less energy and that the type of application running on it and factors such as number of requests made to the nano data centre, number of updates influence the energy cost. The comparison results also found that number of hops between a node and content has very little impact on the energy consumption.

Aazam & Huh [21] discussed a concept of smart gateway with fog computing. The authors believe that the use of this smart gateway will reduce the burden on the cloud server. The authors conceptualized and tested the concept against upload delay, synchronization delay, jitter, bulk data upload delay and bulk data synchronization delay.

The test was conducted between the smart gateway and cloud. The results show that average delay for bulk-data synchronization is 09 seconds for all sizes and bulk-data upload delay is 28 seconds for a 10MB file. For multimedia files the delay was 4 seconds without collaboration, while with collaboration it was 9 seconds. This delay will be increased without the smart gateway and if sensors directly upload data to the server. However, there was no comparison of that data in this work. Later, the authors also proposed a fog computing micro data centre based dynamic resource estimation and pricing model for IoT [5]. Their proposed model addressed the issues of resource prediction, advance reservation, pricing for new and existing customers, and specific type based requirements. Their model uses historic data when estimating resources for returning or existing customers and uses default parameters when estimating for new customers. This model could be expanded or developed in order to overcome the Accountability/Monetisation issue addressed by Vaquero & Rodero-Merino [19].

Daniluk [22] also demonstrated that a smart layer, such as fog is required between the cloud and end-devices. He built an energy efficient multi-hop temperature monitoring system using Wireless Sensor Networks (WSN), to show this necessity. He argues that WSN should be geo-distributed over specific areas in order to get accurate relevant data. By having fog layer, this can be achieved easily. Sensors can be deployed to anywhere there is wireless connection of fog layer. The author also states that by having a smart layer, data can be aggregated and send to cloud server for storage, processing or analytics.

Stojmenovic & Wen [23] in their research discussed the scenarios and security issues in fog computing paradigm. The authors believe that the need for fog computing in IoT is because the current cloud computing paradigm lacks the requirements of mobility support, location awareness and low latency. Having multiple devices connected to a single centralized server could overwhelm the backbone network and will affect the QoS, due to the jitter and delay. However, in this work, the authors pointed out that there are several challenges in fog computing. It is also pointed out that there are security issues, as stated by Vaquero & Rodero-Merino [19]. The authors confirm that main security issues arise due to the authentication at different level of gateways. In addition to authentication, they believe fog computing is vulnerable to Man-in-the-Middle attack, whereby a fog server or gateway is compromised. The authors also believe that fog computing has privacy issues with hiding details and is vulnerable for tampering of data. They cited a method, whereby encrypted data is sent to the fog server and the server acts as data aggregator between the final destination and fog server. However, it is not possible for all IoT devices, because not all sensors and devices are powerful enough to perform encryptions.

Yi et al. [6] believes the above mentioned authentication problem can be resolved by using public key infrastructure (PKI) technique, trusted execution environment (TEE) or by using leverage-measurement-based method to filter fake or unqualified fog nodes. The authors also addressed the issue of privacy in this work, whereby they suggested implementing privacy-premeasuring algorithms in between the fog and cloud, and not between fog and IoT devices as they are resource prohibited. This work surveyed the concepts, applications and issues of fog computing. It is then concluded by suggesting the fog computing will evolve with the rapid development in IoT, edge devices SDN, NFV, VM and Mobile cloud.

Giang et al. [24] believe that developing applications in fog can be challenging due to the heterogeneous devices, widely distributed devices and processing. The authors proposed a Distributed Dataflow (DDF) programming model which utilises both fog and cloud architecture. The proposed model was evaluated using distributed Node-RED, a visual tool that uses flow-based model for wiring the IoT and building applications online. They demonstrated that the proposed model facilitate the development process of building various IoT applications. However, the author also mentions in this work that the biggest issue or challenge they encountered was coordinating the communication of nodes between nodes on different devices.

Usually, every author or researcher implement or use a protocol, which is known to them, instead of sticking to a standard protocol. Thus, in most of previous related works, there is a need for standardization of protocols for IoT and fog computing.

CISCO offers a platform called CISCO IOx for Fog Computing. Using CISCO IOx customers can manage, run and deploy applications [2, 19]. It also provides device management and enables machine to machine (M2M) services in fog computing [25]. According to Dastjerdi et al. [10], CISCO IOx is being used in real-time events and data management by a leading enterprise. Furthermore, it can be used as a centralized tool for a secure tracking and management of automation related asset information, across industrial plants.

6. Conclusion

Fog Computing has the capability to handle the unprecedented amount of data generated by IoT devices. Cloud computing can support IoT by providing on-demand growing services to meet the requirements, however applications that require low latency and high quality of service (QoS) will not be able to perform well, due to congestion in the network. Fog computing develops cloud computing to the edge of the networking to overcome the problems raised, in addition to the other characteristics. The characteristics reduces the burden on the networks, improves latency and performance. Even though Fog makes a suitable platform IoT devices, it lacks standards and there are issues that needs to be addressed and researched on, such as security, privacy, monetization, and provisioning and resource management.

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