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Fog computing in Industries: Practical applications and future directions

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Abstract- **Internet of things (IoT) services have been accepted and accredited globally for the past couple of years and have had increasing interest from researchers. Fog architecture has been brought up in IoT for enhancing its competence in a variety of applications. Fog computing is an emerging concept that transforms centralized Cloud to distributed Fog by bringing storage and computation closer to the user end. The aim of this paper is to highlight the fundamental Fog three-tier model and emphasize its advantages, challenges and possible attacks. This paper will also focus on Fog computing models pertaining to IoT scenario that have been developed over the period to conquer the challenges of existing Fog computing architecture. This paper also highlights Fog's real importance which will include a review of scenario-based examples. Moreover, open issues have also been discussed to be worked upon in future.**

Keywords— Internet of things · Cloud · Fog computing · Fog challenges · Fog models

I. Introduction

In recent years, Internet of Things (IoT) has gathered considerable attention, as it provides various IoT services in almost all fields of life. IoT is an interconnected network of large numbers of IoT devices, each having the capability of sensing and communication, through which they report their sensed data to the main server. This enables the control centre, based on received data, to take decisions intelligently [1]. Like small wireless devices used in S-band sensing technique [2], IoT uses small sensor devices. The increase in usage of IoT devices has led to requirement of resource and computing paradigms which may work efficiently in collaboration with IoT environment. The major paradigms are Cloud computing, Fog computing and Edge computing. This paper will primarily focus on Fog computing in IoT environment. 1.1 IoT (Internet of things) The interconnected IoT devices perform Internet Protocol (IP) based communication. In IoT system, data is collected from the interconnected end devices, which is then distributed in a network with cost-effective implementation and operation [3]. The initial interest in IoT had been of industry and business but now it has developed emphasis towards homes and offices as well. The reason for this shift is usage of smart devices in our everyday life. These devices are easy to use and have the capability to work in relevance with almost every environment. Figure 1 shows the statistics of increase in IoT units installation from 2016 till 2020 [4]. Apart from reliable data collection and communication between end devices, IoT faces a major issue of data storage [5]. Another main challenge in executing and achieving a global IoT system, is the integration of IoT services to only specific type of sensors. In addition, it also faces issues regarding efficiency, security, latency, privacy preservation with respect to integrity of data and bandwidth [6]. To deal mainly with storage issues, Cloud computing was introduced. Afterwards, Cloud was combined with IoT, which resulted in a reduction of challenges associated with it. 1.2 Cloud computing Cloud computing describes a novel method of designing, developing, deploying, testing, running and maintaining applications over the internet [7] (Fig. 2). Cloud computing is a utility model providing storage and computation resources. These services can be accessed over the internet where the central server manages IoT sensed data as well as users' request for services. Moreover, it can support a large number of requests due to its significant storage capabilities. Its payment is based on time and services utilized by the users [8].

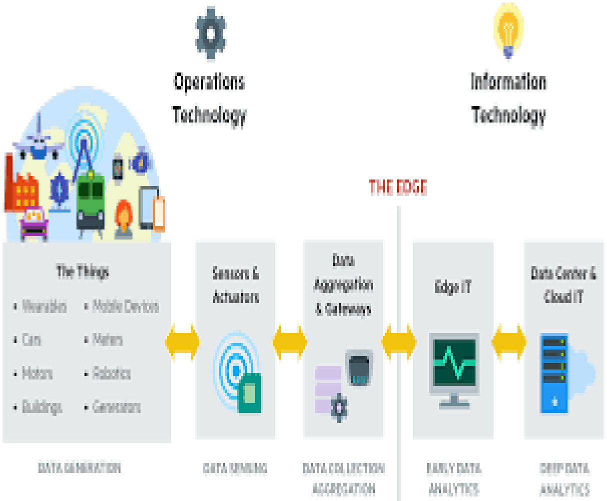

Fig. 1

It consists of three service models [9] i.e. Software as a Service (SaaS), Platform as a Service (PaaS) and Infrastructure as a Service (IaaS). – SaaS provides consumers the capability to access the providers' application on the Cloud infrastructure. – PaaS allows the consumer to deploy their own application on the Cloud infrastructure using various tools and programming languages. – IaaS provides consumers the capability to acquire computing resources from Cloud infrastructure so that they may deploy their applications and networks. Cloud computing has its advantages, nevertheless, accelerated increase in ubiquitous mobile and sensing devices coupled with developments in technology, the upcoming IoT ecosystem confronts the traditional Cloud computing architecture. As in Cloud environment, the central server must manage the data of all the IoT devices, which leads to response latency. It may also face difficulty in managing a large amount of data. Various requirements of IoT such as scalability, privacy, enormous bandwidth requirements, energy consumption, efficiency in network computations and delay-sensitive communication, were not managed efficiently by Cloud.

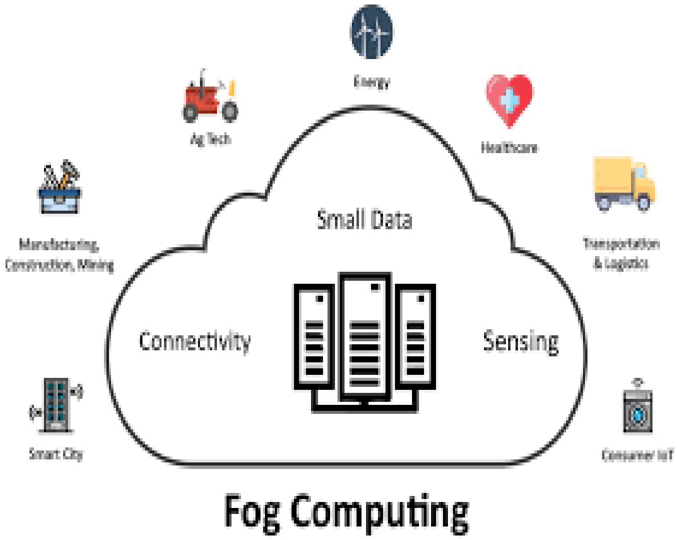

Fig. 2

Therefore, to meet the dynamics of IoT, these factors have given rise to Fog computing infrastructure [10]. Fog computing tackles these challenges well as compared to Cloud computing. It is a novel framework which brings the traditional Cloud at the edge of network (Fig. 3). It has a decentralized environment, thus reducing the overall load from Cloud computing. Introduction to this architecture has resulted in fewer delays in IoT environment. It has been acknowledged widely in the literature through rigorous testing that Fog computing is a much better alternative for Cloud computing in IoT environment. Our motivation towards this specific topic and how our survey is different from other surveys and tutorials available, has been highlighted in next section.

II. Related Work

This section describes existing work related to different aspects of fog computing. Fog computing is a widely spread domain and many researchers are exploring it nowadays. We categorize these contributions according to the issues faced in foglet resource management. The authors in [1], have proposed FOCAN (multi-tier structure) for energy consumption, resource utilization, and latency. Low energy usage, response time reduction, and reduced network overhead are achieved while load balancing, security, and privacy are not considered. In [3], the authors proposed definitions for mobile edge computing and motivation of mobile edge computing by considering different applications. This is done to bring cloud services, resources, and mobile edge computing. The authors resolved the issue regarding WAN latency for delay sensitive applications in accessing the cloud resources; however, the problem of traffic overhead is not addressed in this paper. The problem of load balancing in cloud computing is discussed in [4]. Load balancing algorithms and techniques are used to serve the purpose. Response time is decreased with VM. In [5], a previous allocation state of VM is not saved and the algorithm is executed each time when new request for VM allocation is made. Hence, round robin with server affinity is proposed. With the proposed algorithm, the authors are able to reduce the response time and processing time. The authors in [6] address the problem of response time and processing time. A combination of two algorithms is used: ESCE and throttled algorithm. A comparison of ESCE, throttled algorithm, and round robin is done. From the results, it is clear that ESCE and throttled algorithms performed well, then round robin and time and cost are reduced by using these two algorithms. The goal of [7] is to locate user demand and to minimize the tremendous growth of mobile traffic. Higher bandwidth cost and energy consumption are considered. The author uses a three-tier mobile fog cloud architecture to achieve the goal. By using this architecture, fog computing absorbs intensive mobile traffic and relieves good data transmission. Data storage, security and privacy issues, and costly and energy Khattak et al. EURASIP Journal on Wireless Communications and Networking (2019) 2019:91 Page 3 of 12 application areas discussed in [8]. Maintaining and operating sensors directly from cloud servers are non-trivial tasks. Multi-layer telemedicine architecture is proposed using Intel Edison, Raspberry pi, case studies on various types of physiological data and body sensor networks. Reliability is achieved with reduced traffic overhead, and the overall performance is enhanced. Data trimming and resource utilization are the application areas discussed in [9]. The authors presented smart gateway focused communication. A single-hop gateway and multi-hop gateway are used. Efficient resource utilization for better data trimming and pre-processing, and reduced traffic head are achieved. In [10], the authors have proposed the hierarchical model and application architecture, information system infrastructure framework, and resource management mechanism for data backup, data management, and system monitoring. Burden is reduced on network traffic, and system efficiency is also improved while security is not considered. In paper [11], the authors have considered the security issues faced in fog computing paradigm. The authors have studied a real typical attack (man in the middle attack), analyzing memory consumption and CPU. Data security is more as compared to other SOTA. Real-time scheduling algorithm is proposed in [12], to recover connection failure and to retain services for vehicles that lose the fog server. Control overhead and failure recovery time was decreased by 55%. The paper [13] deals with three challenges. (1) Design of information sensing nodes in body sensor networks. (2) Collection, storage, and analysis of large amounts of heterogeneous data. (3) Energy efficiency of edge devices. The authors propose a service-oriented fog computing architecture to overcome these challenges of data reduction, low power consumption, and high efficiency. Dubey et al. built a prototype using Intel's Edison in order to show the efficiency of the proposed architecture. Achievements of the authors include reduction in storage and power along with the reduced logistics requirements. The main focus of the authors in [14] is to enhance the IoT-based health monitoring systems used for diversified environments.

The authors proposed an IoT-enabled healthcare system architecture to demonstrate the efficiency of bandwidth utilization, emergency notification, and quality of service assurance. To determine the efficiency of fog computing in healthcare applications, it is implemented on a case study of ECG. This paper implemented different fog computing services like location awareness, interoperability, graphical user interface with access management, distributed database, and real-time notification mechanism. The authors in [15] are dealing with the problem of resource management. A methodology for management and estimation of resources is proposed which is known as relinquish probability. How many resources are going to be used and whether all the requested resources are consumed or not, this cannot be predicted. With the model proposed by Aazam et al., one can determine the right amount of resources required which results in reduction of resource wastage and profit-cut for CPS and fog. Authors in [16] proposed the new fall detection algorithm as early algorithms for fall detection have too much false alarm rate and missing rate. However, with the proposed algorithm, high specificity and high sensitivity is achieved with a minimum response time and energy consumption. The paper [17] presents the fog computing architecture for emergency alerts. A lot of work has already been done on emergency management despite that the architecture proposed in this paper is simple and efficient. By a single button click, users can send alert and then the application decides on its own which department should be informed [18]. Moreover, it automatically informs the patients family by sending them a message. Overall delay with fog computing is reduced six times than other cloud cases. In paper [19], iFogSim is introduced, modelled, and simulated in IoT, edge, and fog environment. In particular, the authors described two case studies and demonstrated effectiveness of iFogSim. A framework is proposed in [20] for supply chain management on the basis of IoT technologies, in order to deal with the incomplete information effectively. In [21], a whale optimization algorithm along with local search strategy is proposed for dealing with the scheduling problems. A new variant of whale optimization algorithm is proposed in [22]. Experiments are performed to prove the proficiency of the proposed algorithm. The authors in [23] have presented the selection criteria for suppliers. Quality is proved to be the most important criteria in the selection of the suppliers. To deal effectively with vague, imprecise, and inconsistent information, the neutrosophic set concept is applied to the linear programming problems [24]. Two-level clustering algorithm is proposed in [25] for the detection and localization of duplicated areas in a digital image. The study revealed in [26] have provided solutions for quadratic assignment problems. Three-way decisions on neutrosophic sets are applied in [27]. The effective and efficient rule of the neutrosophic set for supplier selection is also illustrated in this work. The state of the art work is given in Table 1 which clarifies that only Aazam et al. in [9] and [4] are dealing with load balancing. Likewise, other parameters are also considered by many researchers. The aim of this paper is to efficiently utilize the resources so that cost of utility can be reduced along with the improved QoS

III. EVALUATION PARAMETERS

This section gives a brief description of the different evaluation parameters along with their importance in the healthcare domain.

3.1 Load balancing

It refers to the distribution of application or network traffic among different servers in order to enhance the capacity and reliability of the applications. It is the distribution of the task performed by a single computer into multiple computers so that more work gets done at the same time. By this distribution of workloads and the computing resources, we can manage the workload demands in a better way by allocating resources (requests in this case) among multiple servers and will serve users rapidly [28]. This will lead to a high availability and increased performance rate. The aim of this research is to efficiently utilize load which can be done by distributing workload among different servers. If one server is too busy in handling requests from the clients and other servers are idle or have a less amount of requests, then it will transfer some of the load on the nearby server which has no or less requests. Hence, by this distribution of workload, we can achieve efficient utilization of energy and resource consumption.

3.2 Latency/response time

Latency refers to delays which usually occur when any component of the system waits for another component to complete the task. Basically, it is the time taken by the processor to handle the request, i.e., from the moment of transmission till the time it is received back to the client after all the processing [29]. In case of any delay in this processing time, it is considered as latency. It is among one of the drawbacks of the cloud computing which is handled by fog computing. In the scenario discussed in this paper, delays can not be tolerated as in life-threatening situations delays may cause any mishap.

3.3 Quality of service

It is the ability to provide better services to network traffic over different technologies. The goal of QoS is to allocate the lead containing dedicated bandwidth, managed and controlled latency, and jitter. QoS is not a one time deployment in a varying network environment, rather it is an ongoing and fundamental part of a network design.

3.4 Bandwidth

It is the volume of information that can be transmitted per unit of time. The maximum amount of data that can be transmitted over a specific network or internet in a given amount of time that the transmission medium can handle is termed as bandwidth. It only describes the speed of the network and does not tell how fast data is moving from one location to another. The amount of bandwidth required depends on what you are planning to do with your internet connection. The higher the bandwidth, more data are transmitted, and hence, in a particular time, more processing of data can be done due to the large amount of data transmission. One can also limit the bandwidth for a certain task. This control of bandwidth is set by an internet service provider to limit particular traffic during a certain period of time in order to reduce traffic congestion.

3.5 Traffic overhead

It refers to the amount of extra resources that do not have any direct relationship with the production. The amount of processing time required by the system including the operating system, the utility which supports the application programs, and the installation of any of the particular feature will add to the proportion already needed by the program. It is also defined by Martin et al. in [30] as the processing time of a processor in which it is engaged in the transmission or reception of each message; during this period of time, the dedicated processor cannot perform any other operations.

3.6 Energy consumption

This is the amount of energy used in a particular process or system, or energy consumed by an organization or a society. It is the total amount of energy required to provide the services to the end users. Energy conservation will lead to more efficient systems thus reducing the wastage of resources.

3.7 Security

It refers to securing the data, most probably sensitive data, of the end users or clients of the system. The protection of the data to make sure that only authorized personnel have access over the data or services provided by a certain system and to ensure the safety against attacks. It is one of the biggest challenges which fog computing is facing, and in order to overcome this access, control should be applied.

3.8 Privacy

Utilization of data while protecting the privacy of the individuals. It refers to the anonymity of an individual and determines whether the data or information of any individual or organization can be accessed by third parties ornot, and when, how, and to whom this information is to be revealed.

3.9 Support of mobility

To facilitate traffic forwarding from one node to another which results in change of location of the information. It is useful to handle and allocate resources efficiently among fog nodes [31]. In this work, it is referred as the abilityto transfer some load from an over burdened fog node to the idle one. The mobility has an important influence on communication as well [1].

3.10 Interoperability

It refers to the ability of system or software to use the information even after exchange of the data or information. This use of the same tool or software on a variety of platforms is considered as interoperability. In this scenario, if we move or exchange data from one foglet to another, then it would be usable and useful for transmitting the same information.

3.11 Data storage

Recording of information in a storage medium for future use is termed as data storage. With the increasing demand, data storage and data processing in the IoT have become an issue. To resolve this problem, utilization of cloud computing was introduced which was later replaced by fog computing.

3.12 Network management

It refers to monitoring and managing a wide range of computer networks which might be a burden for fog computing unless some of the techniques are applied on it. Applying these techniques on fog computing may be a challenging task and may lead to mismatch with the goals of efficiency and latency.

3.13 Resource management

It is the efficient and effective management of all the available resources in a best possible way. It is responsible for allocation of resources and maintenance of resource pool in a distributed fashion. 3.14 Jitter It is the delay between the received packets. It is considered as the variation in the data flow between two systems which might occur because of network congestion. Jitter can be reduced with fog computing

IV. Proposed System Design

This section describes a model of IoT architecture which takes advantage of SDN and Fog computing paradigms. The proposed solution is inspired by recent works on these topics [1, 17–20]. However, while each of them is either focused only on one of the technologies or considers their application in VANET (Vehicular Ad-hoc NETwork) networks, we analyse the generic IoT scenario where features of both technologies are combined together in one integrated system. Figure 4 shows the system structure which involves: end devices with multiple wireless communication solutions, SDN controllers, heterogeneous

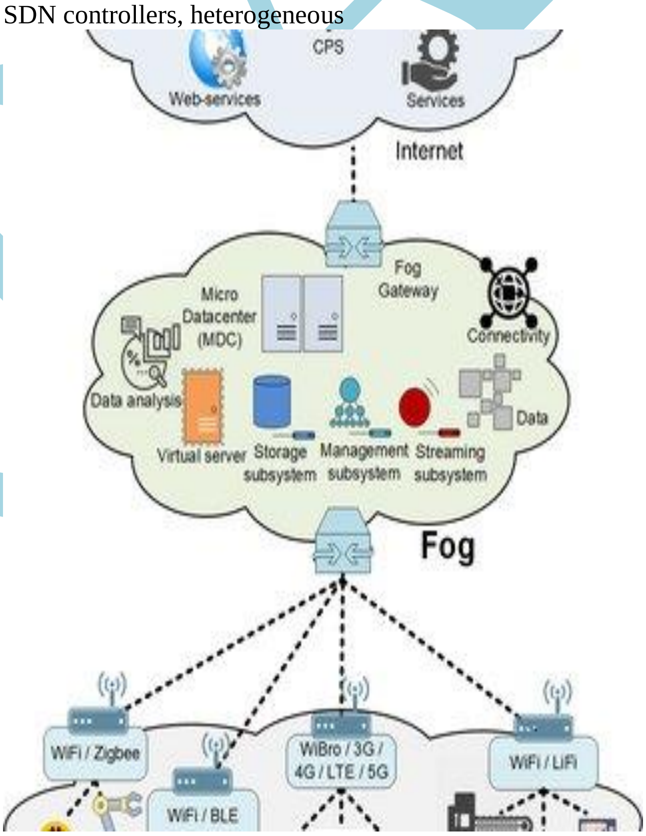

Fig. 3

Fog infrastructure (virtualized servers, routers, access points, etc.) and Cloud in the network core. Since IoT applications may be geospatially distributed, we assumed hierarchical deployment of Fog network. As illustrated in Fig. 5a, Fog nodes expose a set of APIs (Application Programming Interfaces) for application deployment and development, resource management and control. These APIs allow seamless access to hypervisors, various operating systems and service containers on a physical machine [1]. Also, they enable remote monitoring and management of physical resources such as CPU, memory and network interfaces.

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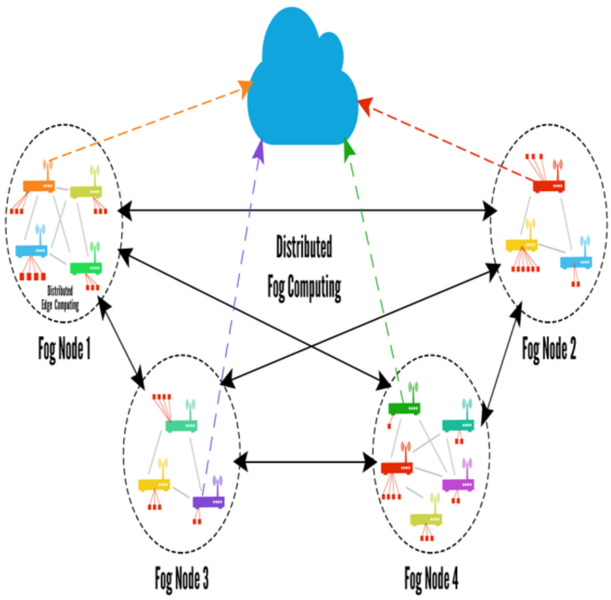

Fig 4

Development of IoT applications using hierarchically deployed and heterogeneous Fog resources could be simplified by adopting Mobile Fog programming model [20]. Mobile Fog runs the same application code on various devices of the heterogeneous Fog infrastructure. The application consists of multiple processes that perform different tasks with respect to the device capabilities and position in the network hierarchy. For example, tasks of large-scale video surveillance application may be organized in three levels: motion detection at IP camera, face recognition at edge Fog nodes and aggregation of identities at Cloud server [20]. It is assumed that each of the devices has information about its geophysical location. Thus, although all of them run the same code, each one is aware of its particular tasks. A major challenge imposed by Fog concept refers to service orchestration. The orchestration involves automated instantiation, replication and migration of service instances on a large volume of Fog nodes with a wide range of capabilities. As discussed earlier, many IoT applications deal with dynamic workload due to periodic or event-driven data delivery models. In an ideal case, applications should be transparently scaled at the runtime without resource over-provisioning. In order to achieve that, we propose logical centralization of orchestration functionality at SDN controller. The design of SDN controller is modified compared to traditional one used in DC networks. As illustrated in Figure 5b, its role in IoT system is threefold: 1. Fog orchestration. 2. Injection of routing logic into SDN-enabled network elements. 3. Optimal selection of access points for IoT devices (i.e. radio access network management). To perform above tasks efficiently the controller needs an up-to-date view of the system. For this reason, it collects and maintains information about: – Features of Fog nodes in the controlled domain, such as: available RAM, secondary storage, running Operating Systems and software applications [1]. – Capabilities, state and interconnectivity of the network elements, including: wireless technology of the access points (e.g. 3G/4G, LTE, Wi-Fi etc.), links capacity and residual bandwidth, the flow table content and neighbour list of each network node..

V. CONCLUSION

Fog computing has applications in a wide range of applications, ranging from civilian (e.g. healthcare settings such as the context in this paper) to military (e.g. battlefields in fog-of-battlefields). Thus, the capability to ensure security and privacy of a fog-driven deployment will be increasingly important. In this paper, we proposed a three-party AKA protocol with bilinear pairings, and proved its security in the random oracle model. The performance evaluation was also presented, which demonstrated its potential to be deployed in a real-world healthcare organization. Future work includes exploring ways to improve the efficiency of the scheme, in order to be more suited for other lightweight applications.

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