A SURVEY ON FOG-EDGE CLOUD COMPUTING: A DISTRIBUTED IOT DATA COMPUTATION PARADIGMS

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Abstract: In today's information technology environment, more and more devices connected to the internet and generating data for multiple purposes over Internet of Things (IOT). Cloud computing might not be able to handle all the data processing at the need of users, especially at the speed required for certain uses and users. Edge computing is distributed computing paradigm in which computation is completely performed on distributed nodes such as edge devices. Edge computing enables data to be computed closer to where it is created. Edge computing has become the potential to address the concerns of response time requirement, bandwidth, cost saving as well as data safety and privacy, also reducing the data transmission time between Data centers(DC's) and intermediate nodes over IOT.

***Index Terms*: Internet of Things, Fog – Edge Computing, Cloud Computing and DC's**

INTRODUCTION

In the development of information technology, processing methods used to compute data in IOT places an important role in our daily activities. In modern communication network architecture millions of devices connected to each other (D. Linthicum, 2016.) (J. Lin, W.Oct.2017.),(J. A. Stankovic9, Feb. 2014.) (F. Bonomi. 2011.). The nodes on IOT collects and exchange the different data and here are varieties of application can provide network services for users. In conventional cloud computing all data is processed at the data centers and after the data processing the report needs to be sent back to the devices and users based on needs, this creates lot of network traffic, pressure especially in the transmission bandwidth and resources. There will be a performance drop in the network with increasing data size. The routing of massive scales of network traffic towards the data centers can leads to be bottle- neck in terms of latency and thus in turn the Quality of Service (QOS) and Quality of Experience (QOE).To address the above mentioned issues in this paper summarizes existing works and present our view on the Edge computing role in IOT and comparison between edge computing and cloud computing.

I. WHAT IS FOG COMPUTING

Fog computing bridges the gap between the cloud and end devices (e.g. IoT nodes) by enabling computing, Storage, networking, and data management on network nodes within the close vicinity of IoT devices. Consequentially, computation, storage, networking, decision making, and data management not only occur in the cloud, but also occur along the IoT-to-Cloud path as data traverses to the cloud (preferably close to the IoT devices)(Tao Zhang.).In addition to facilitating a horizontal architecture, fog computing provides a flexible platform to meet the data-driven needs of operators and users. Fog computing is intended to provide strong support for the Internet of Things.

II. REVIEW ON THE ROLE OF EDGE COMPUTING IN IOT

Need For Fog Computing In IoT

Fog computing is highly virtualized plant form that provides data processing, storages & network services between end nodes and data centers in the cloud computing typically, but not exclusively located at the edge of network. Figure 1 presents the idealized information and computing architecture supporting the future IOT applications, and illustrates the role of Fog Computing. Compute, storage, and networking resources are the building blocks of both the Cloud and the Fog. "Edge of the Network", however, implies a number of characteristics that make the Fog a non-trivial extension of the Cloud.

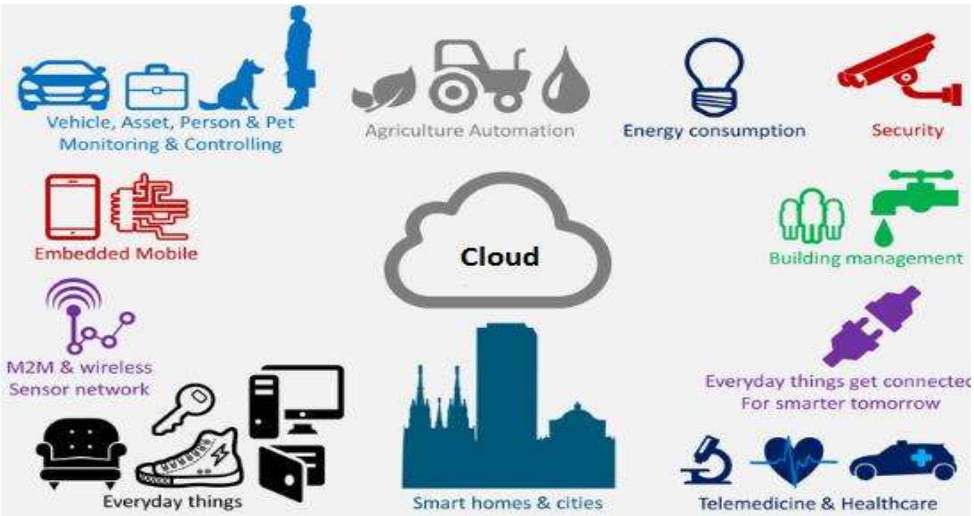

Figure 1 presents the idealized information and computing architecture

Fog Computing has been introduced as a practical and efficient solution to fulfill the need of IoT (Qaisar & Riaz, 2016).The characteristic features of IoT which necessitate the use of Fog Computing are given below (Chiang& Zhang, 2016):

• **The Huge Volume of Data:** The magnitude of data produced by trillions of devices or 'things' connected to the Internet is astronomical. Managing and transferring this voluminous data to Cloud can incur issues like bandwidth consumption, network congestion and latency. In automation process, all the data need not necessarily be sent to the Cloud for processing but can be processed and analyzed locally, near the source of the event with only relevant information is sent to the Cloud.

• **Geo-Distribution and Need of Cooperation:** IoT applications are evolving and its applications have been widespread globally across different domains like Industrial production, mining, traffic management, building and home automation, elevators, transportation and logistics, retails market etc. The rise of IoT applications has increased the use of sensors or IoT nodes globally in trillions. The sensor has limited resources need a platform which can manage and control the different IoT application and further maintaining consistency.

• **Latency Minimization:** As the distance between data/event source and processing platform widens, the network latency also increases. IoT applications based on real-time systems are stringent to network latency for less than a fraction of a millisecond. Increase in network latency may lose the instantaneous interaction requirement of the user or other applications. This issue can be eliminated by processing data at the network edge, removing the need of sending data to a distant location (Cloud). Processing data close or locally to the data source or user would eliminate network latency.

• **High-Mobility Applications:** Mobile IoT application requires sensing, processing, and analyzing data on transit or move. For example, the driverless automatic car produces huge sensory data at the very high speed and demand instant decision making. Application of Cloud to wirelessly acquire and process the huge and high-velocity data is far beyond the effectiveness of Cloud. These types of mobile IoT applications demand virtual Cloud kind of service on the move which can process data and make a decision with or without Internet connectivity (in absence of Cloud).

• **Security Issues:** Security issues are the prevailing concerns for all Internet-based applications. The security vulnerability of data increases with multiple hops. As the data crosses multiple network nodes and goes away from the user, chances of data corruption, cyber-attack, etc. also increase. Thus, it is necessary that data processing should be carried out as close as possible to the user to prevent the chances of cyber-attack. Computing on the network edge close to the data source can evade most of the security vulnerabilities.

• **Scalability:** Another characteristic of IoT-based application is scalability. With changing and expanding business requirement, the number of devices or 'things' connected to the Internet may increase. With growing number of IoT application, the IoT network widens horizontally. The increasing sensors or 'things' demands software updates regularly to support data encryption/decryption and communication protocols. It becomes quite unrealistic for Cloud to take care of each node and manage them. Thus, it is necessary for a new architecture which would locally and closely manage the scalability factor of IoT.

III. IOT DATA PROCESSING ARCHITECTURE IN THE FOG

IoT produces an enormous amount of data. To maintain the quality regarding real-time data processing, probably Cloud is not the best solution for IoT. It is very clear that IoT needs a different kind of architecture which addresses the IoT's latency and mobility issues. In this regard, Fog Computing architecture typically suits IoT data processing. Fog has extended Cloud Computing, bringing it closer to IoT's. The computing services which have been upheld by the Cloud will be carried out locally by numerous other computational devices near IoT's. Network devices like routers, switch, modem and other control devices have a good amount of processing speed and memory. These devices can act as data processing unit for IoT's, thereby offloading data processing burden from the Cloud. These Fog devices, capable of producing and processing IoT data, are termed as Fog nodes. The Fog nodes may include a range of devices having the processing and storage capacity like industrial controllers, set-top boxes, Switches, routers, embedded servers and video surveillance cameras etc.

Fog is the virtualizations of Cloud making 'things' assume it as Cloud. Fog Computing evolved from the research experience of many other similar computing paradigms, and do "balance" well the centralization and decentralization issues of IoT computing. In this view, the architecture on how IoT data is processed is significant. Fog provides data service to IoT data; the data service includes (Figure1):

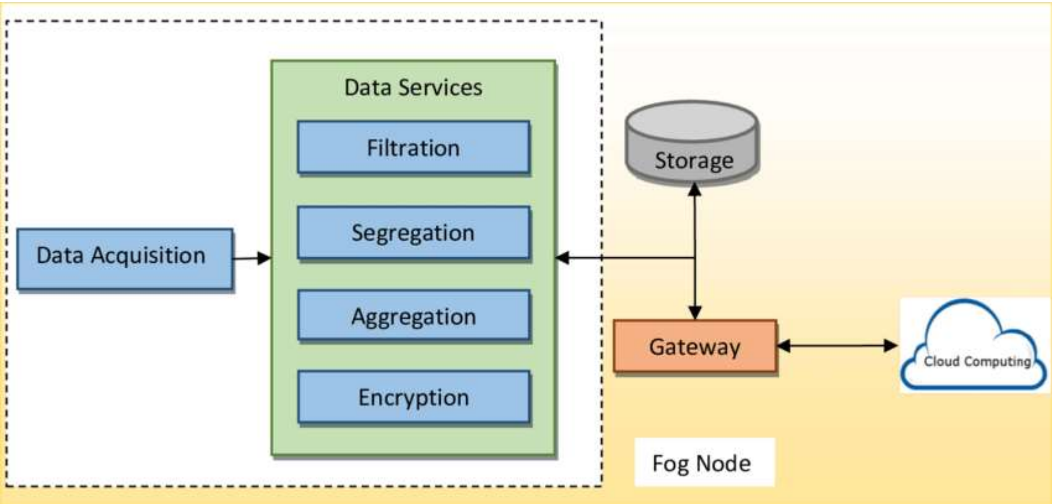

Figure1: Data processing architecture in the Fog

- **Data Filtering:** Removing noisy data and other irrelevant data and thus separating the data of interest.
- **Segregation:** Since Fog allows a multi-tenancy model, multiple IoT application shares the same resources. Segregating involves distinctly identifying and separating which data belong to which application
- **Aggregation:** Aggregation involves collecting or gathering the same application data over a time span to get the data insight.
- **Data Encryption:** To maintain privacy and security parameters, plain raw data obtained from the sensor/'things' are encrypted.
- **Caching:** Fog provides enough amount of storage space; this allows data to be stored near user rather at a remote/distance data centre.

Fog is a natural extension to the Cloud, where both are interdependent on each other. Fog connected to Cloud can take the advantage of the highly capable services and application tools of the Cloud. Fog collects and aggregates data for Cloud. Fog sent the relevant/critical information to the Cloud for further processing and storage. Fog pre-process the data before it is sent to Cloud.

IV. COMMUNICTION BETWEEN THINGS, FOG, AND THE CLOUD

Fog is an extension of Cloud, prevailing data processing in a continuum ranging from network edges to core of the Internet. It basically bridges the gap between the Cloud and the 'things' bringing the services closer to the consumer. Since Fog resides on the edge of the network, it is advantageous to IoT in terms of locality-based computation, low bandwidth consumption and near-to-zero network latency, and flexible management and control of 'things'. Fog has its own limitation too, as a reason all the data are not analyzed in Fog some is sent to Cloud for further analytics and storage. To get over the limitation of Fog, the assistance of Cloud services is taken into consideration. The selection of Cloud and Fog is not binary. These two technologies together make mutually beneficial and interdependent continuum. Fog devices over a network, for the same IoT application or different, may collaborate with each other for data intelligence and sharing resources like processing power and memory. The architecture of IoT application decides "who does what and what time scale" (Chiang, 2015). Basically, three kinds of interactions are found in an IoT-Fog-Cloud model (Figure 2):

1.Fog-to-Thing Communication: Fog provides most of the services to 'things' in resource efficiency and secure way. Among the services include data filtration, segregation and aggregation. Besides this, it provides storage, analyses and decision making. The different tasks which Fog nodes perform for IoT application are:

- **Data Processing:** Data filtering, segregation, and aggregation.
- **Intelligence:** Data analysis and decision making.
- **Storage:** Fog allows data to be stored for a long or short time, depending upon the application requirement.
- **Control and Management:** Fog communicates with different 'things' for data gathering, feeds and firmware update by using suitable protocols.
- **Encryption and Decryption:** Data collected by 'things' are vulnerable to security threats and hence raise concerns for data protection. Fog node ensures data protection by encryption technology, data are encrypted before it is stored and sent to other places.

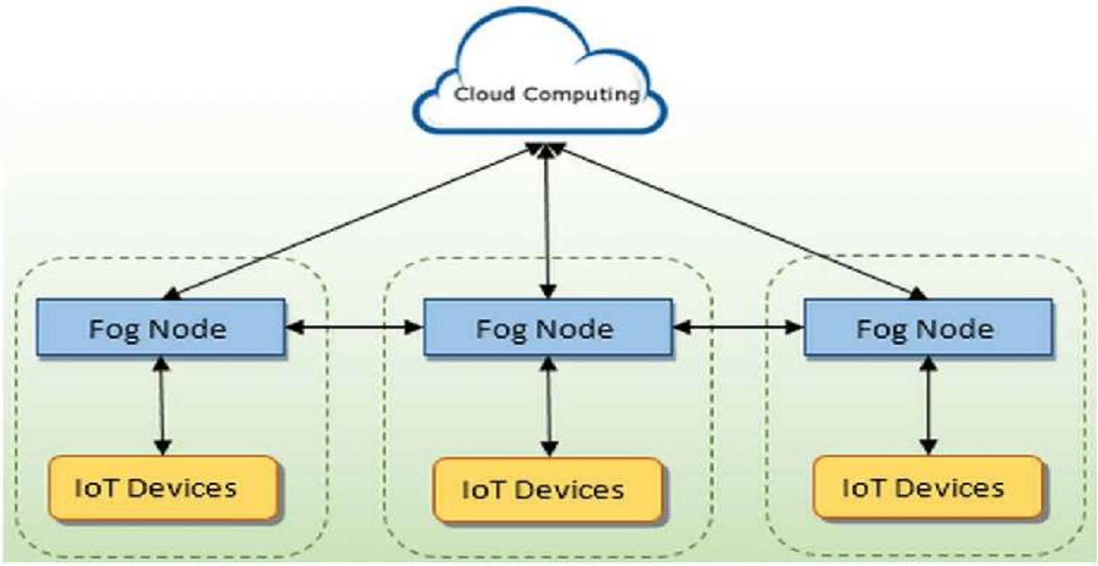

Figure2. Communication between IoT, Fog, and Cloud

2. Fog-to-Fog Communication: Fog to Fog interaction leads to data sharing, data backup, a collaboration of software and computations among the Fog nodes. Fog nodes are often resourced poor with limitations seen in terms of processing power, software capabilities, and storage capacity. The Fog of Fog interaction, leading to Fog to Fog cooperation for resources (software and hardware), may help to overcome individual node's limitations. For example, the Fog nodes over the network edges for an IoT application may collaborate with each other to share the data storage and processing capabilities. Data gathered from a node with low memory is relayed to other nodes having high storage capacity. Similarly, nodes having high processing capacities collaborate with each other to provide an aggregated form of local data processing platform.

Furthermore, while talking about the location-based application running over an IoT network, the data resources are often distributed or scattered. Collective data gathering for data analysis job will be accumulating data from scattered nodes. Fog of Fog interaction allows multiple Fog systems to share the data storage, software service and other computing tasks for one or multiple users or applications. Through the mutual collaboration, they serve as a backup for each other.

3. Fog-to-Cloud Communication: Fog is a virtualized version of Cloud, sustaining all the features of Cloud. Fog is a kind of job handler of Cloud. It cannot substitute Cloud, as it has its own dependencies on Cloud in terms of software and Infrastructural support. Fog and Cloud exchange data with each other. The critical data gathered from 'things' are sent to Cloud and the then processed information is returned from Cloud; in a way Cloud services are availed to 'things' (end users) through Fog.

V. FOG COMPUTING APPLICATIONS ON IOT

Fog Computing endeavor to fully realize IoT's potential has an open new horizon for real-life applications. Fog Computing is well suited for IoT applications which demand real-time action. The Fog and IoT find its way in different areas like industrial automation, transportation, energy, mining, and oil & gas (Milunovich, Passi, & Roy, 2014). Some of the present and future applications are discussed below.

- **Environment Monitoring**: IoT applied for environmental monitoring will be helpful in early detection of natural disasters. The appliance of Fog Computing to IoT over a geographical region can detect events like volcanic explosion or earthquake by assessing the real-time data. Different sensors connected through a wireless network capable of measuring strain, temperature, light, image, sound, vibration, pressure, chemical changes etc. can be used detect environmental changes. Fog nodes process and analyses the real-time data produced by these IoT sensors, the exception in readings are calibrated and necessary alerts are raised (Alamri, et al., February 2013).

- **Transportation:** One of the biggest real-time applications of IoT and Fog Computing would be intelligent transportation. In the forthcoming years, the number of vehicle on the road going to be high. The increase in vehicle count would bring new challenges in monitoring and control of transportation on road. The application of IoT and Fog Computing would help to ease of the situation. Different types of sensor are available to monitor the traffic condition on roads and cities. These sensors categorical of two types: Road sensors and vehicle sensors. The road sensors like a video camera, road tube, inductive loop, capacitive mats and the piezoelectric sensor would help to measure vehicle speed, type of vehicle and vehicle count. Whereas vehicle sensors like onboard camera, GPS, speedometer, proximity sensor etc. would enable to locate vehicle location, detect vehicles in near proximity and any road blockage. As the sensor continuously monitors the situation, they produce a huge amount of data. Furthermore, sensors are heterogeneous, producing a different type of data which need real-time analyses. Fog nodes alleviate this issue by providing a platform which uniformly aggregates data from different devices, storage space to keep past data and real-time analyses based on present and stored data. Sensors communicate with the Fog nodes wirelessly. This particular kind of information, in addition to the regular vehicle, would be helpful for other important and emergency services like a police car, ambulance, fire brigade, utility vehicle etc. Of course, the vehicle is fitted with onboard GPS, but they are not helpful for dynamic traffic condition when traffic condition changes rapidly like accident and road blockage, a sudden rush of vehicle etc. This situation demands continuous monitoring of traffic condition and instant decision taking locally as incorporated by Fog Computing.

- **Crowd Control**: Crowd control is one of the big challenges for police, volunteers and administration. Public functions, festivals, sports & game, concerts, parades, outdoor celebration welcomes a lot of crowds causing an outburst of the crowd in short time. The increase in the crowd may cause vandalism, accidents and mishap etc. Sensors can detect the rise of the crowd at certain places. In addition, the GPS in mobile devices allows for real-time tracking of individuals, their movement pattern and concentration in an area. It helps in resolving the contextual issues by taking a necessary decision like opening parking lots, closing and opening some roads or street and posting police in a critical area. Furthermore, crowd analyses may able to predict places of accidents, thus initiating new response methods including clearing routes, dispatch of emergency response vehicle etc.

• **Object Tracking:** Camera installed on road and street not only able to monitor traffic and mass movement but also tracks for objects. A large number of video surveillance camera deployed on roads, streets, building, airport, railway station and hospital. The camera produces a huge stream of data. Fog Computing provides enough storage and processing capabilities for processing real time videos to look for objects captured in the video. The biggest security application is recognizing the object and tracking them. In crowded places, objects are often lost. Similarly, unoccupied objects in crowded places may be very dangerous and thus demand to identify and tracking them. Fog computing process and analyses video frame in real time can track objects. Based on the relevancy it may raise alerts (Yi, Li, & Li, 2015).

Smart Buildings: Today's buildings like shopping malls, railway station, business enterprises, and hospitals have multi-functionality services such as cooling system, electricity, water, sewage and garbage system, elevator and escalators, fire system and others. These systems provide cyclically and, sometimes, on-demand operation. Failure of any of these systems may turn down the building operations. These services consume huge energy and resources; moreover, their steady operation demands high maintenance. Application of IoT would enable these services to function in an optimal manner and thus saving energy as well as resource consumption. Furthermore, real-time and regular monitoring of these services will be a utility for scheduled maintenance. Applications of IoT would bring a sense of automation, sensor attached to functional units may help to monitor, control and coordinate the services. Sensors can be used in for temperature regulation. Presence or absence of people in the room can switch on or off the light or AC. Tap fitted with the sensor can regulate the water flow based on requirement, thus saving wastage of water. Garbage can, fitted with a sensor, can notify if the can is filled. Fog Computing that provides a virtual Cloud will be useful in low latency solution, a platform for integrating independent devices and flexibility in terms of computation and storage (Khan, 2015; Yi, Hao, Qin, & Li, 2015).

• **Health Data Management**: One of the pioneering issues in the personalized health system is how one's personal health data is gathered, managed and subsequently used for diagnosis. In a typical health monitoring and data management scenario, the sensors fitted or observing patient continuously stream the data to Fog nodes like smart phones or other devices. Fog nodes analyse the data and raise alert for any anomaly found. The summarized data are stored and outsourced when the patient seeking help in hospital, doctor or medical lab (Yi, Hao, Qin, & Li, 2015).

VI.ADVANTAGES OF FOG COMPUTING OVER CLOUD FOR IOT

Fog computing in comparison provides real advantages to what is a need for IoT to work effectively. The Fog Computing advantages are (Chiang & Zhang, 2016):

- Real-time processing.
- Homogeneous support to all varying kind and make of IoT device. Support rapid scalability.
- Secure IoT data while in transit from network edge to Cloud using sophisticated encryption algorithm.
- Rapid development and deploy of Fog applications. Fog Computing provides a pool of resources locally, near IoT.
- Fog computing can balance the network load and computing by taking a decision where to best analyze the sensor data. Based on time sensitivity, privacy requirement and business policies, Fog Computing can decide whether sensor data need to be stored locally or on Cloud.
- Fog Computing automatically controls and manages IoT nodes dispersed geographically apart (Cisco, 2015).

VII. Cloud and Fog Computing: a Comparison Chart

Table 1 Comparison between Fog & Cloud

Parameters	Cloud	Fog
Architecture	Centralized	Distributed
Communication with devices	From a distance	Directly from the edge
Data processing	Far from the source of information	Close to the source of information
Computing capabilities	Higher	Lower
Number of nodes	Few	Very large
Analysis	Long-term	Short-term
Latency	High	Low
Connectivity	Internet	Various protocols and standards
Security	Lower	Higher

VIII. FINAL REMARKS

With the development of IoT, edge computing is becoming an emerging solution to the difficult and complex challenges of managing millions of sensors/devices, and the corresponding resources that they require. Compared with the cloud computing paradigm, edge computing will migrate data computation and storage to the “edge” of the network, It utilizes the local rather than remote computer resources, making performance more efficient and powerful and reducing bandwidth issues. Companies should compare cloud vs. fog computing to make the most of the emerging opportunities and harness the true potential of the technologies. Thus, edge computing can reduce the traffic flows to diminish the bandwidth requirements in IoT. The Internet of Things is a constantly growing industry that requires more efficient ways to manage data transmission and processing.

CONCLUSION

As the data processing happens near IoT devices, the real-time applications can be experienced more quickly. The proliferation of Fog has abstracted the heavy weighted cloud, bringing powerful computing close to the user. The features like support for mobility, geographical distribution and locality awareness has supported much context-aware computing, which was otherwise would be very challenging in Cloud Computing. Even though Fog Computing has many challenges in terms of load distribution, supportability to heterogeneous devices, handling huge data and limitation to computing power and memory capacity, its advantages are overwhelming. In this spirit, many vendors like Cisco, Dell, HP, etc. are working hard to bring suitable solutions. Fog Computing would also be the other stepping stone in realizing Cognitive IoT, whereby physical world and the virtual world would blend together as one.

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