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Fog Computing: An Extended Version of Cloud Computing

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Abstract: The advancement in technology and its impact has revolutionized every aspect of human life. The high demand and scalable distributed computing is a network-based computing paradigm where resource sharing is being performed remotely in a distributive fashion. Cloud computing is part of this domain where computing resources (CPU, Memory, Network, Software, and Servers), various applications and services are offered to the Clients on feasible rent plans. Cloud, although is capable of holding voluminous data and it is treated to be the solution to every internet based problem. But with ever-increasing services, data congestion, bottle neck situations, Cloud is not enough as the data volumes generated by the edge devices is unpredictable and not easy to maintain, and is out of the functionalities of cloud computing, that is where Fog is a handy tool to handle the voluminous data generated and act as a bridge between cloud and IoT. Fog computing is an exciting extended version of Cloud, it extends the cloud computational capabilities to the edge of the network and enables various applications and services to act in real-time scenarios. Fog is the solution to the various flaws that are arising in cloud computing. Its characteristics are paving ways for the real-time sensitive applications. The main idea in this paper is to highlight the various Fog computing features that will give an indication in real sense Fog is the future of cloud paradigm and also will relate it with various IoT-enabled (CVs, SGs, SCs, WSANs) time-sensitive applications in real life scenarios. Fog is extending the cloud capabilities to the next level and hence regarded to be the future of cloud computing and to meet the challenges and solve the problems of the organizations.

Keywords: Cloud & Fog Computing, IoT-enabled Time-sensitive Applications, Computing Resources

I. INTRODUCTION

In an era where distributed technologies have revolutionized the Information arena. Cloud computing evolved as a blessing of it, from its initial phases until now, the technology is becoming everyone's first priority, immense potential to carry out the bulk workloads. The voluminous data centres, allows the cloud to store the unpredictable massively high datasets, for better availability and performance parameters, it offers the clients better services and highest utilization without affecting the performance of the system, by this, an organization can maintain its capital & operational expenses. It is not merely a technological platform which offers the services to the large-scale industries but also becomes vital for small-scale industries to compete in the economic market. Cloud even if of its popularity, still faced some catastrophic challenges, like availability, interoperability, scalability, and securities issues. The bottleneck situations were demands are higher than the data availability, the time delay responses, makes cloud an insufficient computing platform, the latency issues with time-sensitive application in IoT environment became a challenge for cloud to fulfil the demands from the front end side, the IoT enabled tagged gadgets require mobility, reduced latencies and location awareness to run smoothly in a distributed cloud environment. So the shift in Technological advancement leads the various future cloud-enabled platforms to evolve, the important and popular one that take IT to the newest phase of computing is the Fog or Foggy (Edge)computing paradigm, it is a blessing in disguise. Fog computing is an emerging trend in Cloud domain which indirectly is a mini-cloud with proximity to ground level. Fog computing offers a platform to various applications and services to run in a real-time environment. Here in this article we define Fog computing, describe in brief its characteristics, and the Fog supportive platforms. Highlight some of the areas where Fog is beneficial and serve as the backbone for their smooth functioning, and will continue to be the future of the cloud in real-time sensitive IoT enabled platforms [1], [2], [23].

II. DISTRIBUTED TECHNOLOGIES: BACKBONE OF FOG COMPUTING

Fog computing is not the solo technology but an extended version of various existing technologies, Fog on its own can't be everlasting, for its smooth functioning, collaboration and convergence with existing computing paradigms are important. Here we define the participating computing technologies which lead to the emergence of Fog [3], [4].

- **Distributed Computing:** The collection and collaboration of much autonomous computing clustering define the distributed, each having its own private memory and other resources necessary for communicating through inter-networks. Here the solution to the particular task is being done in a distributive manner, where the different parts of a particular problem are being conducted by different individuals in a collaborative manner [1], [4].
- **Cloud Computing:** Cloud computing is a distributed platform and primarily based on already existing computing paradigms i.e. Centralized, Parallel, Grid and Distributed Cloud computing. It inherits characteristics from the pre-existing computing models. The services and applications are accessible to the different clients using proper internet protocol suite and networking standards. Its key characters, different service and deployment models makes it quite unique and offer various features like cloud agility, improved costs, scalable infrastructure with flexibility and resources and services are being offered on-demand basis [1], [6], [10].

- **Web of Internet of Things:** Web of the Internet of Things where every entity is connected with smart gadgets, communication is taking place in a sophisticated manner. RFID plays the crucial role in it, the tagged entities generate the data in Fog environment, the Fog nodes, and various network routers direct the workloads to the particular node in the edge network. The connected devices can communicate in three ways, the human-to-human, machine-to-machine and machine-to-human, from smart households, cities, healthcare systems, traffic, different sensors and actuators are embedded in or attached to the objects, by this whole forms a web of the internet of things. In Ubiquitous IoT environment things get connected within fraction nanoseconds, the proliferation of human as well as machine interventions increases rapidly. The number objects participate in IoT, the more is data generation and need more storage space to store it. In order to meet the required demands, the integration of Internet of things along with cloud computing form a platform known as Cloud of Things [7].

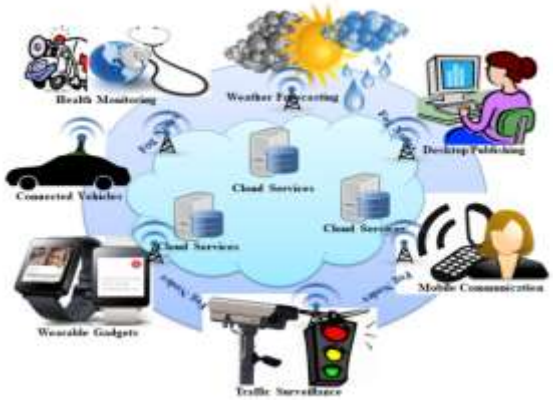

Figure 1 Cloud of Things

- **Big Data:** Big data (4V's) are the large data sets, being stored in cloud data centres, data analysis leads to results of information, the data generation of various organizations like money transactions, social media, digital marketing, giant e-commerce sites continuously generate data both in the form structured or unstructured. While it is becoming a heck of a problem for companies to handle the vital data in traditional processing techniques like RDBMS and other data analytical tools, big data analysis carried out its data operations by using high-quality software concurrently running on servers in a cloud platform [4],[22].

Figure 2 Big Data

- **Edge Computing:** It optimizes the cloud computing by bring the applications, data and various cloud services away from cloud's core network to the extreme of edge network which where all the physical gadgets like handheld devices, sensors, actuators, routers, switches are in contact with the live network, the data generated by these devices, the data analytics is performed on it over the edge network itself rather sending to core cloud network. Edge computing pushes the intelligence, processing power and communication capabilities of an edge gateway or appliance directly into devices like programmable automation controllers (PACs) [6],[7]

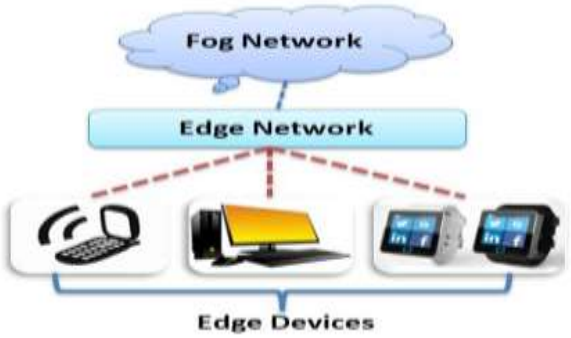

Figure 3 Edge Devices

III. FOG COMPUTING

Fog computing offers the functionalities that of cloud, like data storage space, networks, compute processing power but with greater extent and proximity as Fog nodes reside near to the edge devices of the end users and leverage the resources and decrease the latency. It extends the cloud capabilities, processing computational power to the edge of the network of an edge device [4], [6], [9].

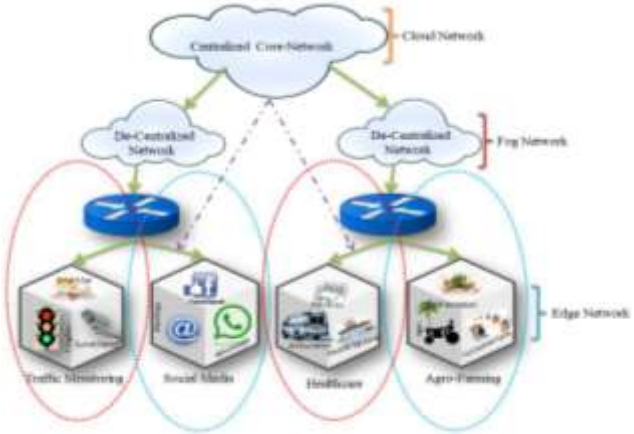

Figure 4 Fog Computing Layered Architecture

- **Fog Computing Characteristics**

Fog computing is offering the various services like computational power, data storage, networking among the edge devices and cloud-centric entities participating in collaborative fashion. Although Fog is not a solo technology, has to depend on the cloud for full functionalities and smoothly running of the services and applications in IoT environment. The services are taken from core cloud computing to the edge network for better execution. Some of the characteristics of the Fog computing that define its feature

to be the next biggest evolution in Information technology [8], [9], [11], [20].

- Geographical Distribution, compared to the cloud, a centralized platform, for offers the services geographically wide dispersed for distributed deployment models. Fog is playing a vital role in delivering the highly enhanced high quality to the Fog connected Vehicles through Fog nodes and smart gateways. The sensors/actuators monitoring the distributed computing systems and various data storage resources like microdata centres, cloudlets [12].
- Large Fog nodes, spatially network, make it possible for edge devices to communicate in coordination.
- Mobility support, it is one of advanced feature of Fog that differentiates it from cloud computing, it is important for many Fog applications to communicate directly with an edge in real-time scenarios. It provides the location awareness as well, to locate the communicated edge, with mobility, it provides essence to the entities to follow proper pursuit to accomplish the various tasks in IoT environment.
- Real-time interactions, the processing mechanism in Fog domain is not like to that of batch processing rather it is real-time interaction, the process of communication between the edge and Fog node is taking place in real-time as it bypasses avoids cloud interference in communication.
- Supports heterogeneity, Interoperability, since in IoT environment, different sensors, network routers of different manufacturer company did not have to face the interoperability heterogenic issues, the edge devices and Fog nodes interact with one another without hardware compliance issues as well.
- Fog proximity plays a significant part in the data processing as it is close to the source
- Lightweight applications that required low and predictable latencies and response time in the IoT environment.
- Energy efficiency, being dispersed geographically, various Fog nodes on concentration generate less heat as compared to cloud data centres, cloud servers, and will be an important tool for optimal energy management policies

IV. FOG COMPUTING: A PLATFORM FOR IOT ENABLED PARADIGM

Some Fog scenarios where it is crystal clear that its involvement enriches the user experience to adopt them. Fog plays a vital role in their smooth functioning. Some of the scenarios here to mention are important like Connected Vehicle, Smart Grid, and Wireless Sensor and Actuator Networks [18].

- **Connected Vehicle (CV):**The connected vehicles like fully loaded GPS enabled cars with interactive cabin system, where interaction among the various participants in IoT platform make it a rich experience among the RFID tagged entities like a driver, a car and network connection. The data generated by these entities is huge and need real-time operations. The various networking i.e. Wi-Fi Hotspots, 4G, RSUs, traffic light system, the connectivity is being maintained throughout the interactions. With Fog provides the Space Construction Vehicle (SCV) an ideal platform for entertainment, safety and traffic management system and data analytics on the go. Mobility support and location awareness, with enhanced reduced latencies, is what need for the real-time interactions in IoT. The nodes connect in smart traffic lights communicate locally, it will be continuously updating traffic situations by sending the signal to the nearest network towers. The smart connected systems, will are excellent to detect any unfavourable situation like accidents and may act in advance and will avoid, it will provide safety to both pedestrians and drivers. Since the smarts devices connected with smart vehicles can't store the data for long and has to send to the core cloud network for long-term data analysis [6], [7], [12], [13].

Figure 5 Connected Vehicles

- **Smart Cities**: a rapid proliferation in population, changes in lifestyle standards, and shift from rural to urban leads to urbanization. Most of the population of every nation is making continuously moves to cities, as these are equipped with the availability of modern technology in sectors like education, health, commerce than the rural areas. Urban population is using various electronic gadgets embedded with RFID sensors, actuators, and are being used efficiently to manage the various available resources. Each and every intellectual are connected with each other through the network, continuously generate and manage the data traffic (power, transportation, water, recycle management) [7], [8], [13].

Figure 6 Smart Cities

- **Smart Grid:** the smart grid is another use-case and making way for the green computing and removing the ageing effect of the old infrastructure when electricity was limited to customer utility. As more machines interact continuously, smart grids will help the electricity demands which would work in cooperation with the cloud, it will be going to benefit the society unprecedently and will provide the various opportunities and offer them the reliable and efficient means of energy, and its availability will benefit both the commerce as well as health systems. Some of its advantages here is important to mention

- Efficient data transmission, better energy utilization
- Flawless data services between the utility and clients.
- Fewer energy disturbances and better restoration methods.
- Improved cost operations, clients will be offered utility services at feasible and affordable prices
- On-demand as per requirement will lower the energy costs
- Scalable integration of renewable energy resources.
- Secured and improved security protocols.

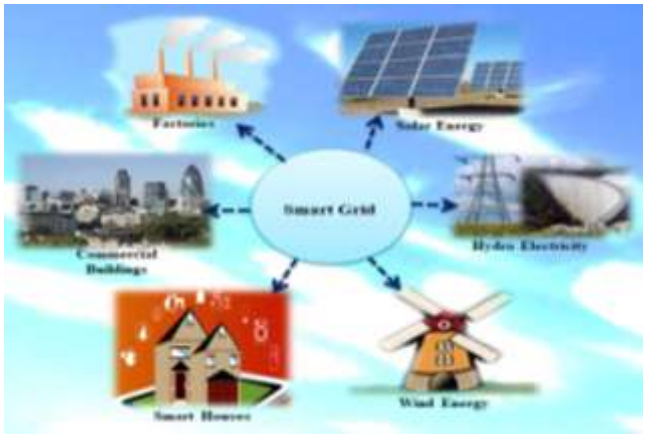

Figure 7 Smart Grid

- **Wireless Sensors and Actuators Networks:** The Motes (WSNs) are delicately designed to be the energy efficiency and extend the battery consumption while in data transmission from edge devices to Fog micro-data centres. These sensors and actuators light weighted and are embedded with low memory, energy, bandwidth, computational power. The Motes are embedded with a de-facto operating system known as TinySO2. These are mostly used to collect the data like weather updates, humidity, Loo, wave intensity, measuring the rainfall, drought and floods warnings[7], [13].

Healthcare Systems: Fog computing plays a vital role in bringing the changes in the healthcare system, it provides the dynamic architecture by reducing the latencies, and offers the mobility support to perform better operations in real time scenario. Since IoT-healthcare devices are producing enormous data at consistently, storage and security becomes matter of concern, cloud computing with Fog technology is proving to be the backbone for the smooth functioning of healthcare systems. Cloud computing, offers high storage and computational processing capabilities. Health wearable gadgets, like smart watches, monitoring sugar level, heartbeat rate and blood pressure level, for these real-time operation, cloud is not feasible because of latency issues, so Fog is the best platform to operate in real-time scenario [14]

V. COMPARISON OF FOG COMPUTING WITH CLOUD COMPUTING

As Fog has its root in cloud computing, so inherits all the features of cloud computing. While cloud computing being centralized distributed paradigm, Fog, in contrast, is a de-centralized paradigm, will offer reduced latencies, quick response time and location awareness of the devices in IoT enabled environment. Both technologies require functioning in coordination as many applications require the attention of both locally as well as globally especially for real-time data analysis. Fog computing is not becoming a universal platform for real-time interactions (machine-2-machine, human-2-human and human-2-machines), the sensors and actuators will act once any interaction is happening, data will be collecting and processed in real-time without further delays or latencies. The sensors at local accessible points of edge network generate the data continuously, the actuators filter the data which can be processed locally and rest of it is sent to the highest core network data storage for further filtration. The core network is the highest level of computing, the geographically wide dispersed large scalable resources. Cloud can be treated as a data repository for Fog where data can be stored for longevity and permanent basis. In below table shows some of the comparisons of the two growing paradigms. With flexibility and elasticity, Fog computing may be delivered as a single node or a large system, it will continue to enhance cloud user experience, bring the services near to end users and seamlessly bring combined Fog-cloud-IoT (Cloud of Things) framework to make the computing accessible from anywhere with better performance. The coordination among various Fog nodes smart gateways provides the platform for the real-time applications to function in Fog-Edge Network [7], [12], [15].

Fog computing is termed to be the future of cloud, but the fact is that Fog is having some serious issues like scheduling and is very difficult and cumbersome tasks than cloud, heterogenetic Fog nodes, owned and maintained by different organizations thus may be prone to the malicious attacks. Fog will be going to benefit the cloud of IoE, will be a much-anticipated platform for low latency applications, edge analysis, will reduce data delay jitter and will be cost efficient, moreover, Fog computing will address the most exciting features and enable to achieve the scalable, flexible, relievable, dynamic and efficient IoE systems.

Table 1: Comparison between Fog & Cloud Computing

Characteristics	Cloud Computing	Fog Computing
Latency	High	Low
Delay Jitter	High	Low
Location of Server Nodes	Within the core network	At Edge of Network

Distance between Client and Server	Multiple Hops	One Hop
Security	Undefined	Can be Defined
Attacks and Vulnerabilities	High Probability	Low Probability
Location Awareness	No	Yes
Geographical Distribution	Distributed Centralized	Distributed Decentralized
Number of Server Nodes	Few	Large
Mobility Support	Limited	Supported
Real-Time Interactions	Supported	Supported
Type of Connectivity	Leased Line/Wireless	Wireless

VI. SHIFT IN CLOUD PARADIGM TO THE FOG-EDGE NETWORK

Cloud computing is a vast form of distributed computing and is being adopted everyone everywhere. However the proliferation in IoT enabled peripherals leads to some of the problems like network congestions and bottlenecks data accessing. It is a concern for various companies, organizations, institutions to shift from centralized to decentralized domain. Fog computing is not here to replace the cloud computing completely but to enhance and improve its various feature. Fog computing was developed to address applications and services that do not fit the paradigm of the cloud computing leads to the shift in technological domain. Fog is the solution to short comings of cloud computing [15], [16], [17]

- **Bottleneck & Network Congestion**: are the issues in centralized cloud computing that can be addressed properly in decentralized Fog-cloud computing, since processing, and intelligence of decision making needs to be closer to the source of data generation than the core cloud network, Reduction in data movement across the network resulting in reduced congestion.

- **Hops Count:** As the number of hops increase in cloud computing so are the high chances of data tempering. Security violations are so high in it, since the adaptation of Fog computing, security is less compromised than ever before, the data stay near to edge device of the end users leads to the minimal chances of security threats.

- Existing **Data Protection Mechanisms** in Cloud Computing such as encryption failed in securing the data from the attackers, In Fog Computing data is kept right on the queue where the Internet of Everything needs it, maintaining it security within the edge device

- **High Latencies**: in cloud is the biggest challenge for the time-sensitive applications. Fog computing reduces the short comings like latency, high bandwidth, security of cloud computing.

- **Intelligence:** For better results, computational operations, decision making, Fog is pushing the intelligence closer to the edge device rather than the cloud computing.

- The **Quality of Service** parameter in cloud computing is an cumbersome task and is always neglected during the service level agreements among the various parties in cloud, Quality of Service is one among them, and is always compromised. But with Fog, which is an enabling technology for the real-time latency oriented applications, QoS might find its feet for betterment, with location awareness, mobility edge support, scalability, reliability and security features of Fog computing. Fog will be the suitable platform for mission critical, real-time bounded, live streaming content application to enhance and improve the QoS parameter [8], [14]

VII. CONCLUSION

Fog computing is still in embryonic stage, slowly and gradually it is conquering every aspect of human life, proving to be the future of distributed cloud computing and act as an intermediate between the core and edge network, It is the solution to the short comings of cloud like high latencies, and is becoming backbone technology for the real-time sensitive applications running over the edge network in IoT-enabled environment. Locality awareness of various spatial edge devices is making it possible to adhere the mobility support for various real time IoT based applications such as Smart Traffic Light Management System, Smart Healthcare Monitoring Systems, GPS connected Vehicular cars, Smart Cities. Data generated by the end user devices are being processing at Fog network rather than sending it to core network, removing the network congestion leads to better resource provisioning. Being an advantageous extension of cloud computing, one can easily predict that both will complement and work in coordination, trying to eradicate the own respective issues and challenges. Fog computing, regarding as the future of cloud will enhance and empower the emerging computing paradigms that need the real-time interactions with minimal delays and jitters. Cloud computing will be at the backend of Fog to function smoothly and met the business demands and reduced costs and high throughputs. In near future Fog will be first priority due to its agility and versatility and safety features.

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