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An Experimental Survey of FOG Computing and IOT : Escalate the Cloud to Where the Things Are

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ABSTRACT

Even though the increasing usage of cloud computing, there are still many issues that are not solved due to inherent problems of cloud computing such as unreliable latency, lack of mobility support and location-awareness.Fog computing has been introduced as a technology to bridge the gap between remote data centers and Internet of Things (IoT) devices. Sanctioning a wide range of benefits, including enhanced security, decreased bandwidth, and reduced latency, fog is an appropriate paradigm for many IoT services. Fog computing can address those problems by providing elastic resources and services to end users at the edge of network, while cloud computing are more about providing resources distributed in the core network. This survey discusses the definition of fog computing and similar concepts, introduces representative application scenarios, and identifies various aspects of issues we may encounter when designing and implementing fog computing systems. It also highlights some opportunities and challenges, as direction of potential future work, in related techniques that need to be considered in the context of fog computing.

Keywords: IOT, Cloud Computing, Fog Computing, Abstraction Layer and Orchestration Layer

I. INTRODUCTION

The Internet of things (IoT) is the network of physical devices, vehicles, home appliances vehicles, and other items embedded with electronics, software, sensors, actu ators, and network connectivity which enable these objects to connect and exchange data. The IoT allows objects to be sensed or controlled remotely across existing network infrastructure, [1] creating opportune-ties for more direct integration of the physical world into computer-based systems, and resulting in improved efficiency, accuracy and economic benefit in addition to reduced human intervention.

The Internet of Things represents a remarkable transformation of the way in which our world is soon expected to interact. Much like the World Wide Web connected computers to networks, and the next evolution connected people to the Internet and other people, the IoT is poised to interconnect devices, people, environments, virtual objects and machines.

Users can be anywhere and at any time, day or night; you need to be able to serve them all in a proper way. If you are a worldwide company, you need to be practically everywhere and you can achieve this with cloud computing (if you are a local company, you can use cloud to expand your business).Cloud computing is the best way to share, receive and manage information for the Internet of Things because:

- Cloud providers usually have various data centers covering different geographies, which is ideal for having increased coverage.
- Public cloud providers offer pay-as-you-go services. This means that you can grow for peaks and then decrease, paying only for this time.
- These providers usually have a great infrastructure to serve millions of user connections and they offer different products for shared load balancing, security and more.

Since smart devices are usually inadequate in computation power (CPU), battery (Memory), storage and bandwidth and network connectivity. IoT applications and services are usually backed up by strong server ends, which are mostly deployed in the cloud, since cloud computing is considered as a promising solution to deliver services to end users and provide applications with elastic resources at low cost.

However, cloud computing cannot solve all problems due to its own drawbacks. Applications, such as real time gaming, augmented reality and real time streaming, are too latency sensitive to deploy on cloud. Since data centers of clouds are located near the core network, those applications and services will suffer unacceptable round-trip latency, when data are transmitted from/to end devices to/from the cloud data center through multiple gateways.

Besides this, there are also problems unsolved in IoT applications that usually require mobility support, geo-distribution and location-awareness.

Today's cloud models are not designed for the volume, variety, and velocity of data that the IoT generates. Billions of previously unconnected devices are regenerating more than two Exabyte (10^{18}) of data each day. An estimated 50 billion "things" will be connected to the Internet by 2020. Moving all data from these things to the cloud for analysis would require vast amounts of bandwidth.

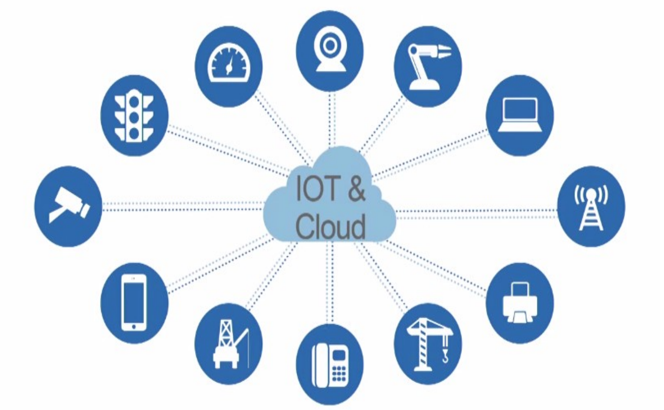

Figure 1: Connecting More and Different Kinds of Things Directly to the Cloud Is Impractical

II. DESIGNING GOALS

Handling the volume, variety, and velocity of IoT data requires a new computing model. The main designing goals are to:

- **Minimize latency:** Milliseconds matter when you are trying to prevent manufacturing line shutdowns or restore electrical service. Analyzing data close to the device that collected the data can make the difference between averting disaster and a cascading system failure.
- **Conserve network bandwidth:** Offshore oilrigs generate 500 GB of data weekly. Commercial jets generate 10 TB for every 30 minutes of flight. It is not practical to transport vast amounts of data from thousands or hundreds of thousands of edge devices to the cloud. Nor is it necessary, because many critical analyses do not require cloud-scale processing and storage.
- **Address security concerns:** IoT data needs to be protected both in transit and at rest. This requires monitoring and automated response across the entire attack continuum: before, during, and after.
- **Operate reliably:** IoT data is increasingly used for decisions affecting citizen safety and critical infrastructure. The integrity and availability of the infrastructure and data cannot be in question.
- **Collect and secure data across a wide geographic area with different environmental conditions:** IoT devices can be distributed over hundreds or more square miles. Devices deployed in harsh environments such as roadways, railways, utility field substations, and vehicles might need to be ruggedized. That is notthe case for devices in controlled, indoor environments.
- **Move data to the best place for processing:** Which place is best depends partly on how quickly a decision is needed. Extremely time-sensitive decisions should be made closer to the things producing and acting on the data. In contrast, big data analytics on historical data needs the computing and storage resources of the cloud.

Traditional cloud computing architectures do not meet all of these requirements. The prevailing approach—moving all data from the network edge to the data center for processing—adds latency. Traffic from thousands of devices soon outstrips bandwidth capacity. Industry regulations and privacy concerns prohibit offsite storage of certain types of data. In addition, cloud servers communicate only with IP, not the countless other protocols used by IoT devices. The ideal place to analyze most IoT data is near the devices that produce and act on that data[2].We call it as Fog Computing

III. CLOUD COMPUTING VS FOG COMPUTING

Requirements	Cloud Computing	Fog Computing
Latency	High	Low
Delay Jitter	High	Very low
Location of Service	Within the Internet	At the edge of the local network
Distance between client and server	Multiple hops	One hope
Security	Undefined	Can be defined
Attack on data enroute	High probability	Very low probability
Location awareness	No	Yes
Geo-distribution	Centralized	Distributed
No. of server nodes	Few	Very large
Support for Mobility	Limited	Supported
Real time interactions	Supported	Supported
Type of last mile connectivity	Leased Line	Wireless

Fog computing keeps data and computation close to end users at the edge of network, and thus provides a new breed of applications and services to end users with low latency, high bandwidth, and location-awareness, and thus gets the name as fog is analogously a cloud close to the ground [3].

IV. OVERVIEW OF FOG COMPUTING

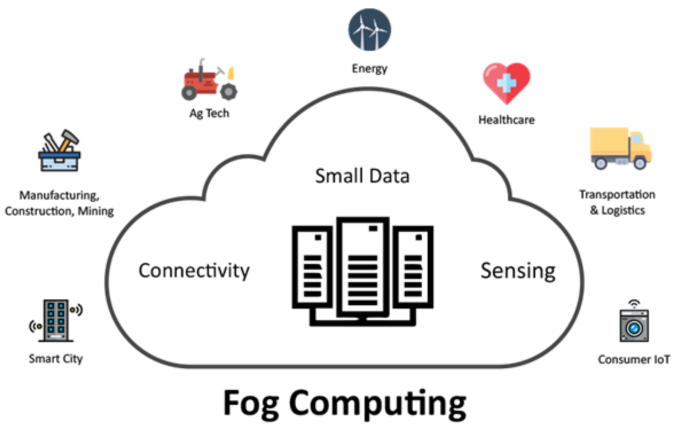

Figure 2: Overview of Fog Computing

Fog computing, also known as edge computing or fog networking or fogging, operates on network ends instead of hosting and working from a centralized cloud. This means that the data can be processed locally in smart devices instead of having to be sent to the cloud for processing. Fog computing basically grew out of the need to address some growing concerns.

A huge concern is the ability to act in real time to incoming transactions and working within set limits of bandwidth. Sensors today are generating too much data to be sent to the cloud. The bandwidth is not enough and costs too much. Fog computing places some of transactions and resources at the edge of the cloud, instead of establishing channels for cloud storage and utilization, it reduces the need for bandwidth by not sending every bit of information over cloud channels, and instead aggregating it at certain access points. Use of this kind of distributed strategy can lower costs and improve efficiencies [6].

It is an decentralized architecture and serves as an extension to **cloud computing** that uses one or more collaborative end-user clients or near-user edge devices to carry out a substantial amount of storage (rather than stored primarily in cloud data centers), communication (rather than routed over the internet backbone), control, configuration, measurement and management[4][5], unlike cloud computing where data needs to access the central mainframe.

Fog computing essentially involves components of an application running both in the cloud as well as in edge devices between sensors and the cloud i.e. in smart gateways, routers or dedicated fog devices. It is distributed paradigm that provides cloud like services to the network edge which leverages the cloud and edge resources along with its own infrastructure. A Fog computing network has two planes,

-Data Plane
-Control Plane

1. Data Plane:
The data plane sometimes referred to as forwarding plane The Data plane determines what happens to the data packets. It allows computing resources to be placed anywhere in the network as they don't have to be centered on a server as they can be distributed on the edge of the network.

2. The Control plane:
It provides an overview of the network and it functions with the routing protocols that run in the architectural control element. Fog computing allows IoT data to be processed in a data hub or smart device closer to the sensor that's generating it.

With cloud computing, you always had to depend on the cloud repository and accessing data required bandwidth allocation and connectivity. Thanks to Fog computing the data can be accessed in between devices locally without complete dependence on the cloud repository. This will help to boost accessibility, ease of use and contextual usability of device data. The emergence of Fog computing will boost collaboration among devices and data centers.

The main idea behind Fog computing is to improve efficiency and reduce the amount of data transported to the cloud for processing, analysis and storage. But it also used for security, performance and business logical reasons.

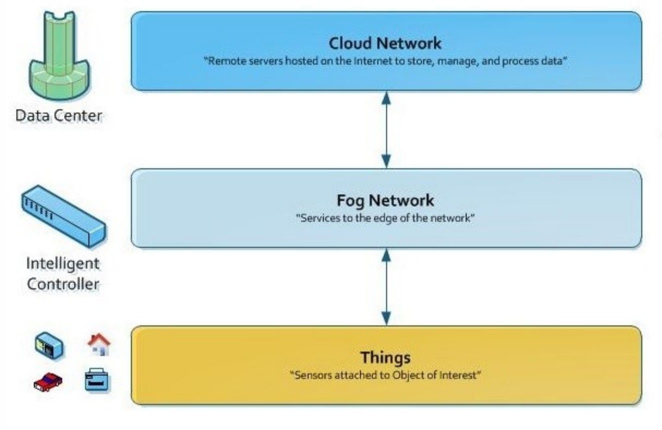

Figure 3: Internet of Things (IoT) Reference Model

The key advantages of Fog computing

Fog computing offers several standout advantages over its predecessor, cloud computing. While it utilizes basic cloud computing technology at its core, it addresses several limitations of the cloud computing and helps to boost usability and accessibility in different computing environments. Following are the key advantages that fog computing offers

- Globally distributed network helps minimal downtime
- Load balancing
- Maximize network bandwidth utilization
- Optimal operational expense
- Business Agility
- Better Interconnectivity
- Enhanced QoS
- Latency Reduction

V. FOG COMPUTING ARCHITECTURE

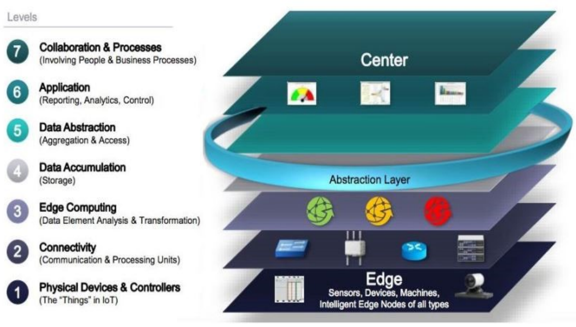

Figure 4: Fog Computing Layered Architecture

Edge devices, sensors and applications generate an enormous amount of data on a daily basis. The data producing devices are often to simple or don´t have the resources to perform necessary analytics or machine-learning tasks. They just produce information to the cloud.

In the Fog Computing architecture, the processing takes place in a smart device close to the source. It can be raspberryPI, gateway or a router. Where the software reduces the amount of data sent to the cloud and takes action depending on the business logic applied in the Fog Node. In order to improve the work of the data source.
Fog system generally use the Sense-process-actuate and stream-processing programming models. Sensors stream data to IOT networks, applications running on fog devices subscribe to and process the information, and obtained insights are translated into actions sent to actuators. Fog systems dynamically discover and use APIs to build complex functionalities. Components at the resource management layer use information from the resource monitoring service to track the state of available cloud, fog and network resources and identify the best candidate to process incoming tasks.

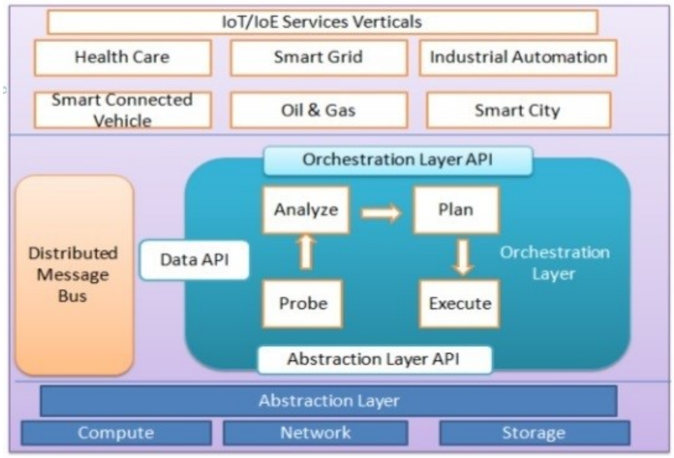

Figure 5: Components of Fog Computing

The key components of fog architecture are as follows:

a) Heterogeneous Physical Resources
b) Fog Abstraction Layer
c) Fog Service Orchestration Layer
1. Foglet software agent
2.Distributed database
3. Policy-Based Service Orchestration

a)Heterogeneous Physical Resources:
Heterogeneous in nature, ranging from high-speed links connecting enterprise data centers and the core to multiple wireless access technologies towards the edge 3G/4G, LTE, Wi-Fi etc

b) Fog Abstraction Layer:
A uniform and programmable interface for seamless resource management and control.
The layer provides generic APIs for monitoring, provisioning and controlling physical resources such as CPU, memory, network and energy

c) Fog Service Orchestration Layer:

- Provides dynamic, policy-based life-cycle management for fog services
- Managing services on a large volume of fog nodes with a wide range of capabilities is achieved with the following technology and components:
  - Foglet Software Agent
  - Distributed Database,persistent storage to store policies and resource meta-data
  - Policy-Based Service Orchestration, provides policy-based service routing i.e. routes an incoming service request to the appropriate service instance that confirms to the relevant business policies

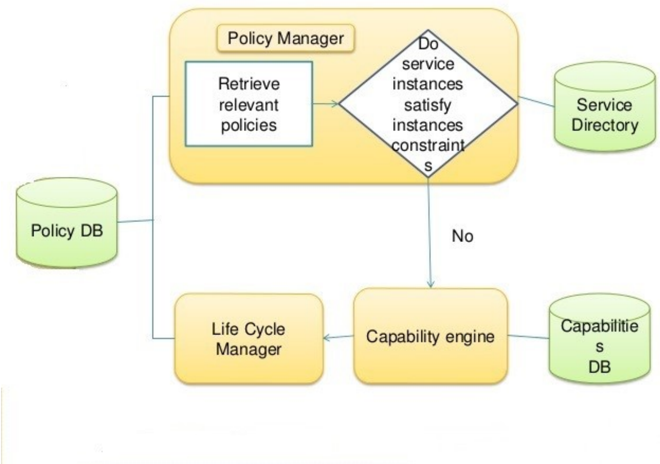

Figure 6 : Policy-Based Orchestration framework

VI. AN EXPERIMENTAL FOG COMPUTING PLATFORM

As illustrated in Fig., each of the fog sub-systems possesses one router and three servers. The routers are connected to the Amazon EC2 cloud through WAN, as well as connected with each other through LAN. The routers are also integrated with Wireless AP function, so that mobile devices can access the fog as well as the Amazon EC2 cloud through them.

In the following, we present some preliminary results based on important performance metrics.

A. Latency and Bandwidth:

First, we compare the latency and bandwidth provided by fog and cloud. We use RTT (round trip time) as the metric of latency, and we measure both uplink and downlink bandwidth. The results are shown in Table I. We can see that fog computing has strong advantages in terms of low latency and high bandwidth for clients.

TABLE I: Latency and Bandwidth Comparison

	RTT(ms)	Up/Down-Link Bandwidth (Mbps)
Fog	1.416	83.723/101.918
Cloud	17.989	1.785/1.746

B. Face Recognition Application:

To further understand the benefits of using fog computing, we implement a face recognition application running across a Smartphone and a fog or a cloud. The application requires to install an app on the user's Smartphone. The user can use the app to capture a face photo of herself or any other people, and the app will transmit the face photo to a remote server, either in a fog or in a cloud. The remote server will then try to recognize the face by matching it in the local face photo database. In our implementation, the app running on the Smartphone takes photos of 384x286 pixels. The face photo database on the remote server consists of 1521 photos, each of which is also 384x286 pixels.

We run the same tasks on our fog as well as on the Amazon EC2 cloud. Table II presents the results.

TABLE II: Fog-based Face Recognition Performance

	Face Recognition time on the server(ms)	Response Time(ms)
Fog	2.479	168.769
Cloud	2.492	899.970

"Response Time" in Table II is the time duration from when the Smartphone begins to upload the face photo to when the Smartphone receives the result from the remote server. Providing the similar VM capabilities, the fog and the cloud consume similar time on the computation task (about 2.5 ms in our case). From Table I, we know that the difference of latency between the fog and cloud is small (less than 10 ms).Therefore; the network bandwidth contributes the most to the big difference in response time (731.201 ms). If we assume the Smartphone can upload the face photo in negligible time to the fog, and then the Smartphone can upload about 167 KB data to the cloud in this 731.201 ms, which is comparable to the average size of uploaded face photos in our experiments (about 110 KB).

VII. FOG COMPUTING USECASE

A.SMART LIGHTING:

One use case for fog computing is a smart traffic light system, which can change its signals based on surveillance of incoming traffic to prevent accidents or reduce congestion. Data could also be sent to the cloud for longer-term analytics. Lighting industries are undergoing a revolutionary transition from wired interfaces to wireless interfaces. Fog computing-empowered edge nodes enable smart lighting OEMs (Original Equipment Manufacturer) to provide a complete solution independent of cloud providers. Fog computing-enabled light solutions enable the OEMs with:

1. Local control, monitoring, and management of end devices.
2. Using localization features along with sunset sunrise data, one can schedule lights to turn on/off.
3. Expand their global reach in the most remote areas.
4. Consolidate reports on energy consumption with per-device granularity.

B.SMART ENERGY:

Smart energy has become a particular interest considering the industry shift in production of energy and conservation of natural resources, constant monitoring of end devices used in wind farms, solar farms, and water and gas distribution networks. When the power of fog computing is coupled with the existing IoT solution in smart energy, OEMs can achieve:

1. Real-time fault detection with low latency.
2. Edge node-enabled data analytics.
3. Geo-distributed networks allowing the pinpointing of fault regions.
4. Demand analysis using M2M interactions.
5. On-demand-based automatic distribution switches.

C.SMART AGRICULTURE:

With the advancements of IoT-enabled devices, smart agriculture has become a niche area of interest for all IoT-centric cloud providers. Farmers are moving toward smart farming practices that generate a huge amount of data from **soil sensors, temperature sensors, humidity sensors, motion sensors,** and **ambient light sensors**. When the power of fog computing is coupled with existing IoT solutions in smart agriculture, solution providers can achieve:

1. Using localization features, fog computing can predict ideal harvesting time.
2. Expanding their global reach in the most remote rural areas without Internet connectivity.
3. Generating crop health analysis reports locally.
4. Livestock monitoring, health analysis, and location tracking.

D.SMART TRANSPORTATION:

Fog computing-empowered smart transportation applications can be achieved by providing inter-fog communication over a distributed network. With inter-fog communication, smart transportation solutions:

1. Edge nodes can independently manage traffic lights in real time based on traffic analysis.
2. Street light control locally based on time and weather.
3. Real-time traffic reports and suggestions for alternate routes in case of congestion.
4. Inter-vehicle communication and connected cars

E.SMART VEHICLE:

Fog computing can be integrated into vehicular networks. Depending on whether extra infrastructure is needed, vehicular fog computing can be categorized into two types [7], *infrastructure-based* and *autonomous*. The former, such as VTube [8], relies on fog nodes deployed along the roadside; fog nodes are responsible to send/retrieve information to/from the driving-by vehicles. The latter, mentioned in [9], utilizes vehicles on-the-fly to form fog and/or cloud to support ad-hoc events; each fog can communicate its client within and other.fogs.There are various applications for vehicular fog computing, no matter the first type or the second type. Popular applications are: traffic light scheduling, congestion mitigation, precaution sharing, parking facility management, traffic information sharing,etc.

F.HEALTH DATA MANAGEMENT:

Health data management has been a sensitive issue since health data contains valuable and private information. With fog computing, it is able to realize the goal that patient will take possession of their own health data locally. Those health data will be stored in fog node such as smartphone or smart vehicle. The computation will be outsourced in a private-preserving manner when patient is seeking help from a medical lab or a physician's office. Modification of data happens directly in patient-owned fog node.

VIII. FUTURE OF FOG COMPUTING

"One very exciting potential is Fog-as-a-Service – FaaS where a fog service provider, which could be a municipality, telecom network operator, or webscale company, deploys a network of fog nodes to blanket a regional service area," Fog computing, in the future, can utilize the power of machine learning and artificial intelligence by leveraging the computing power on local edge nodes and providing precise results and analytics unique to each user. Fog, in the future, will give rise to hybrid computing models where the edge nodes will be used for real-time analysis while the cloud would be used for persistent data storage. With hybrid computing models in place, IoT solutions can target both real-time applications and avoid the bottlenecks of cloud computing.Future work includes full-fledged fog platform implementations and performance optimizations.

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