Emerging Trends in Fog Computing in Distributed Environments

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Abstract : Futuristic ideas like smart cities and smart healthcare can become a reality soon, thanks to the emerging computational architecture called fog computing. Fog computing is a paradigm for managing a highly distributed environment that provides computation services and network and connectivity services between the edge devices and the cloud. The fog computing paradigm can provide the missing link between a centralized cloud service and the IoT (Internet of Things) at the edge of the network. Fog computing and cloud computing paradigms can work in tandem to build sustainable models for smart environments. We take a brief look at the various fog computing architectures and frameworks. We also look at the emerging advances in fog computing and its architecture and the related impact and applications in our world.

Index Terms *-- Cloud computing, Fog Computing, Edge Computing, Internet of Things*

I. Introduction

The Internet of Everything or the Internet of Things (IoT) as it is called, provides services by interconnecting different physical devices and bringing automation of various activities. IoT is defined as a network of objects each embedded with sensors which are connected to the internet. The idea of IoT is not just connecting computing devices, but everyday objects like a lamp, a refrigerator or even cars. IoT objects are equipped with capabilities like sensing, processing, networking and reacting, thus transforming everyday objects into smart objects. IoT promises a smart world where all objects might be connected to the Internet and function with minimal or zero human interaction.

By 2020, the Internet of Things is expected to connect tens of billions of devices over the world, such as smartphones and wearable devices. Such a distributed environment will be consuming as well as generating huge amounts of data. In a typical distributed environment, the IoT devices communicate with the remote cloud server for executing the respective services. Cloud computing paradigm has many advantages including on-demand self-service, infinite scaling, storing of large amount of data.

The traditional cloud computing paradigm is a centralized model to process data at a remote data centre. It does not address all the needs of the IoT distributed environment and its applications. Several IoT applications require context-awareness, low latency and more importantly, real-time data processing. The centralized cloud services has several drawbacks. The response time of a cloud service in a distributed IoT environment is affected due to insufficient communication resources and high network latency at the base network. There are also privacy and security concerns as IoT devices generate personal data and it has to be stored and processed in a cloud that might be a third-party service. Transferring huge amounts of data generated by IoT devices to the cloud is also a bandwidth bottleneck. Moving computing services closer to the edge of the network nearer to the IoT devices addressed these issues effectively. This led to the emergence of a new computing paradigm called fog computing.

Fog computing is a new set of applications and services using systematic, virtual and secure network integrated platforms deployed close to the data source. It is a distributed computing platform where the edge devices like the routers, gateways, as well as the sensor nodes interplay with cloud servers in order to give services to IoT devices. The versatility of the fog computing paradigm lies in the fact that it can be deployed as fog nodes i.e devices with storage and limited computing capability at the very edge of the network or it can be deployed as cloudlets, a small server that participates in the distributed computing in the IoT network. The fog is a multi-tier architecture that spreads between edge devices and cloud servers.

Some of the characteristics of fog computing are

- Contextual local awareness
- Computational offloading
- Low and predictable latency
- Bandwidth savings
- Mobility support
- Increased privacy of data
- Decentralized decision making
- Interoperability of different IoT platforms, devices, fog nodes and cloud nodes.
- Increased scalability

II. FOG COMPUTING ARCHITECTURE

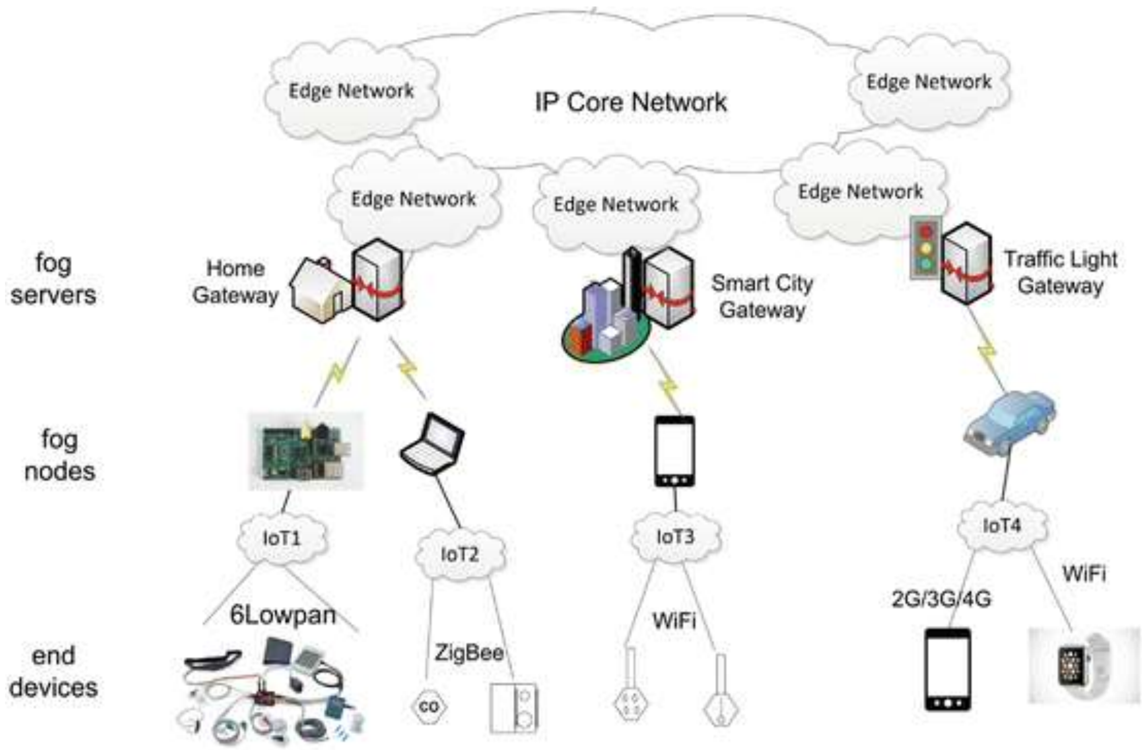

Figure 1: Basic architecture of fog

Figure 1 describes the basic structure and entities of a fog computing environment. IoT is comprised of all smart devices that are interconnected by a backbone network and the internet. The fog nodes are deployed at the edge of the network. Fog nodes are typically devices with storage and minimal computational capability. They are equipped to respond to highly latency sensitive events at the edge of the network. They also deploy applications for the discovery, management and inter-communication of IoT devices. One or more fog servers can also be deployed nearer to the edge of the network that act like cloudlets or mini cloud servers, that provide applications and analytics of data from the IoT devices.

Figure 2: Cloud-Fog-IoT hierarchy

Cloud-Fog-IoT hierarchy is illustrated by figure 2. The end points comprise of IoTs configured with sensors and actuators. The fog points can be deployed both at the same network as the IoT devices and in the edge nodes in the local area network. A core router connected by a regional network higher up in the hierarchy connects the fog nodes to the cloud services. The fog nodes can work in the fluid system of network connectivity. Fog Nodes deployed in the IoT-Fog-Cloud distributed environment perform different tasks depending on their communication bandwidth and processing power as well as their distances from the end devices and the cloud servers. Fog nodes connected directly to the end devices may work as data concentrators, compressors and pre-processors and come with storage capability and minimal computational capability. Fog Nodes in the upper tiers are often endowed more capability and bestowed with data analytic and modeling tasks. On the other hand, reactive responses and real-time computing control often take place in the Fog Nodes close to the end devices while the data-to-knowledge conversion may be performed closer to the Cloud.

The OpenFog consortium has put forth an OpenFog Reference Architecture (RA) for fog computing that describes the eight pillars, which form the core principles of fog computing. Based on these pillars, RA represents the abstract instance of a fog node, which is a composition of multiple views and multiple perspectives in the fog computing distributed environment.

III. Applications of Fog Computing

Fog computing provides a wide range of solutions in both mobile and wired network scenarios. It seamlessly traverses across hardware and software. The fog architecture supports a growing variety of applications. By deploying fog computing at the edge of the network, the quality parameters like latency, performance, security, capacity and reliability can be substantially improved and can create significant new revenue opportunities. Some of the areas of application of fog computing are briefly given below:

3.1 Smart Cities

The concept of a smart city is an urbanized area where multiple sectors cooperate to achieve sustainable outcomes through the analysis of contextual real-time information. The benefits include disaster management, resource management, automated alerts and responses, reduced traffic congestion and minimized energy waste. By 2020, the technology for smart cities is projected to become a massive economic engines.

Several hierarchical fog computing architectures have been proposed as solutions for the realization of smart cities. The geo-distributed big data generated by IoT devices in a smart city is collected and aggregated at the fog nodes before being sent to the cloud data centres for deep analytics. The city corporations can perform city-wide response and resource management in the event of a natural disaster or a large scale service interruption. At the local level, the fog nodes in smart city sub-systems can be enabled to perform localized decisions to avoid potential damage.

3.2 Vehicular Crowdsensing

The fog based Vehicular crowdsensing network is an emerging transportation management infrastructure. The benefits include the study of road surface condition, improved traffic efficiency and road safety and avoid potential accidents and dangers. Fog computing distributed architecture is an effective solution as it provides mobility support, low latency, location awareness support and improved security and privacy of vehicular data.

3.3 Smart Grid

A smart grid will consists of networked subsystems for metering, data collection, filtering and analysis, data aggregation, energy distribution and demand based response across multiple geographic distributed locations. For example, an oil and gas company may need to interconnect hundreds of remote sites such as oil rigs, exploration sites, refineries and pipelines. Fog computing architecture can support and interconnect such a large distributed network, monitor subsystems in the grid, ensure security and privacy of data and enable control and communication among subsystems. The fog system can also be enabled to support several types of storage from ephemeral to semi-permanent. The fog system can interplay with a centralized cloud server to provide global coverage and cloud services like data analytics and data mining to the whole system.

3.4 Video Analytics

Several fog based video analytics solutions and architectures are being proposed. For instance, in a smart city, automated billing of parking requires video analytics and automated license plate recognition system. Transferring video streams to the cloud for analytics is too network intensive. Therefore locally deployed fog nodes at the edge of the network can perform analytics on video streams and manage urban video analytics applications.

The features of fog computing make it an ideal architecture for several other areas of applications including smart health care, airport security, smart buildings, connected cars, self-maintaining trains and wireless sensor and actuators networks.

IV. Emerging Trends in Fog Computing

Fog is an emergent architecture for computing, storage, control, and networking, that distributes these services closer to the edge of the network along the cloud-to-Internet-of-Things continuum. Some of the recent trends in fog computing are briefly discussed below:

4.1 Fog Radio Access Networks (FRAN)

Fog Radio Access Networks (FRAN) has been proposed as an advanced socially-aware mobile networking architecture in fifth generation (5G) wireless communication system. FRANs can achieve spectral efficiency, low latency and high reliability for different IoT applications such as smart homes, vehicular sensing and industrial automation. Several effective caching strategies and other algorithms for FRAN have been proposed in recent times.

4.2 Companion Fog Computing

When mobile IoT devices are integrated into a fog computing paradigm, the fog service has to be migrated in order to be always close enough to the served IoT device. Thus the fog service behaves as a companion to the corresponding application on the mobile device. C. Puliafito et al describe a CFC model that performs stateful container migrations in order to enable companion fog computing.

4.3 Fog Federation

Another emerging trend in fog computing is federation of fogs. Fog resource centres located within the reach can be federated with a primary fog in order to support inter-fog scenarios. Inter-fog scenarios which are cost effective and efficient in terms of resources remains an open research issue. Further study is also needed on the type of service level agreements in inter-fog scenarios.

4.4 Semantic Aware Fog Computing

The cloud computing paradigm is able to support energy efficiency by incorporating IoT nodes that act as an interface to the ad hoc user and able to do real time processing of user requests and aware of user contexts in its vicinity. Context aware or Semantic aware smart city services can become a reality with fog computing. Rahman et al present a fog-cloud hybrid architecture for semantic aware fog computing in the context of multimedia data.

4.5 Mobile Fog Computing

The number of mobile devices is increasing exponentially. Emerging areas that are receiving a lot of research and attention today include smartphones, mobile healthcare, intelligent transportation systems and the Internet of Drones. Fog computing can effectively support mobility of IoT devices and can be co-located with the mobile network base stations or can be a mobile fog (mFog) that is deployed at the edge of the network.

4.6 Fog As A Service (FaaS)

Similar to cloud providers offering cloud Platform as a Service (PaaS) and Software as a Service (SaaS), an exciting prospect for service providers is to offer Fog as a Service (FaaS). The service provider can build an array of fog nodes across its geographical distribution and service many vertical markets that are fog enabled like manufacturing, smart grids, oil and gas companies, smart cities and many more. The fog nodes can host local computation, networking and storage capabilities. The fog software infrastructure might include virtualization, orchestration, sophisticated security and APIs needed to enable a wide range of applications with minimum effort for integration. The service provider can lease FaaS capabilities to several tenants, similar to cloud services.

V. CONCLUSION

Although the fog computing paradigm is a promising extension to the cloud, there are several challenges to overcome. These include infrastructure implementation challenges like compatibility across various geo-distributed IoT devices and protocols, fog nodes and cloud nodes, service level challenges like billing issues, provisioning metrics, etc and security challenges like data privacy, user authentication and data encryption policies. There are other real-time challenges in the form of scalability, end user QoS, content awareness, etc which are critical performance indicators.

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