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The Fog Computing Paradigm for the Internet of Things

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Abstract
Nowadays, the Internet of Things, alongside with other phenomena like Big Data, become technology trends. The industry predicts that by 2020 there will be 50 billion devices of IoT. The Internet of Things itself remain hard to define. Moreover, there are many technologies and paradigms involved, which makes the last task harder. In this paper, we investigate the relationship between the Internet of Things and an emergent concept of computing: the Fog. We will present the reference framework to understand the Internet of Things (IoT). We also introduce the concept of Fog computing and discuss its relationship to Cloud computing and the IoT. We also present the reference framework to understand the Internet of Things paradigm. The components of the fog computing are also discussed. A presentation of the reference architecture RA for Fog computing introduced by the biggest company of the industry will be given in this paper.

Keywords
Internet of Things, Fog Computing, Cloud Computing

1. Introduction

The Internet of Things (IoT) is considered as the new big thing [1] for technology not only for researchers and practitioners, but also for industry and markets. In 20110, Cisco systems forecasted that the number of IoT devices would reach 50 billion by 2020 [2]. Whereas an estimation made by Gartner [3] claimed that where too far from this number, and said that 6.4 Billion Connected "Things" are in use in 2016. Nevertheless, IoT device population is exponentially increasing.

Many concepts and technologies are involved in the IoT, and one of them is the Fog computing. In addition, many applications and architecture [4, 5] are based on the IoT paradigm, where the fog computing plays an essential role.

In this paper, we try to investigate this technology by understanding its relationship to IoT. In addition, we will try to clarify a big confusion about fog computing and cloud computing. Finally, we will present the major components that enables the fog computing and ensure the best implantation of IoT.

2. Internet of Things

2.1. Overview of Internet of Things

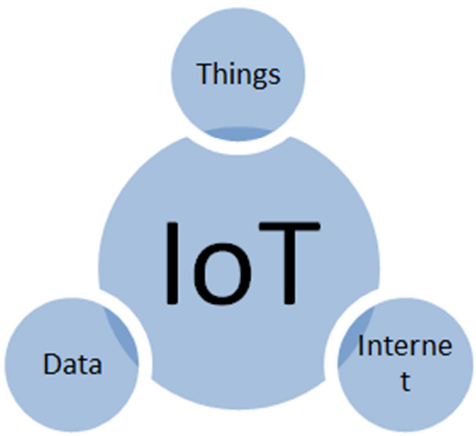

Figure 1. *IoT elements.*

Kevin Ashton coined the term Internet of Things (IoT) in 1999 in a presentation that he made at Procter and Gamble [6]. Its first purpose was to link and apply RFID (radio frequency identification) technology to supply chain management. The concept has shifted the world of IT to cover much wider technologies and applications [7–11].

The simplest way to define the Internet of Things is to determine its essential elements. The IoT can be seen as the combination of Internet, Things (devices) and data. Also, it's called the Internet of Everything [12–14]. Things are devices connected to Internet via various types of connectivity (wired and wireless). They can be sensors or/and actuators. Sensors collect physical information (temperature, pressure, movement …)

2.2. Internet of Things Reference Framework

Researchers and the industry involved in the development of the Internet of Things Applications produced various results in this field, but their all focused on the applications side and they're product-centric [15]. Some works tried to focus on the standardizations of IoT, architectures and its related technologies [16, 17].

In order to explain the role of the fog computing in IoT, we have to adopt a reference framework. The most simple and relevant one [18] is based on four levels: IoT devices (things or objects), IoT network (the infrastructure that will handle data transportation), IoT services platform (a management software that ensure the connection between things and provide an overview of the system), and IoT applications (the application domain that differ from one field to another).

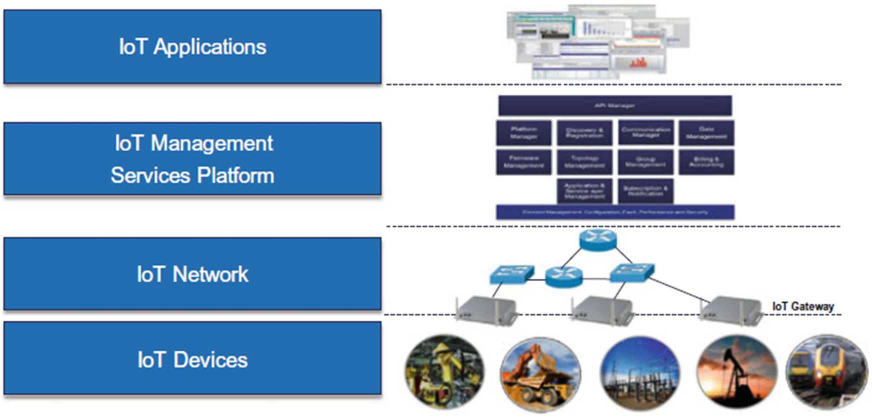

Figure 2. *Internet of Things reference Framework [18].*

This reference framework facilitate the understanding of the different actors involved in IoT. Also it helps to decouple each layer and developed separately.

3. Fog Computing

A platform that integrates computing, storage, and network services (highly distributed and virtualized) referred as Fog computing (sometimes only Fog). To have a clear idea about it, we will consider the following domain decomposition of the Internet of Things: User, Cloud, Network and Device domains. Fog domain is the aggregation of two sub-domains: Network and Device. There is no exact location for this platform but it can be extended to the local entourage of IoT devices and gateways all the way to cloud data centers. Typically, the most relevant location for it is the network edge.

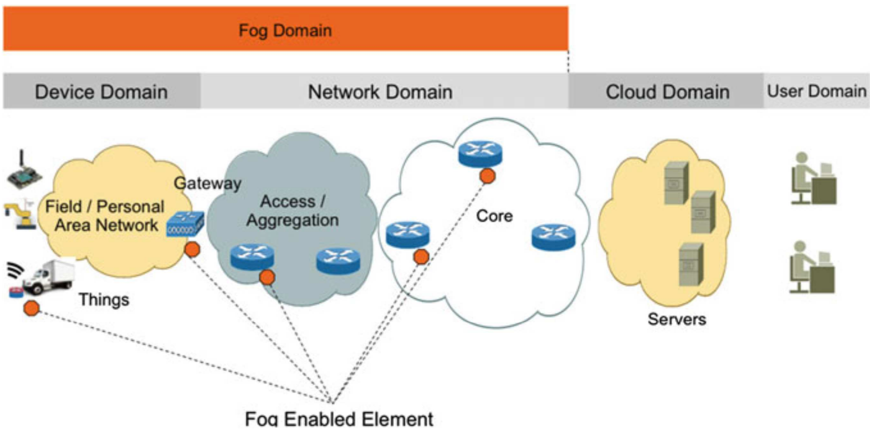

Figure 3. *Fog computing localization [18].*

Fog computing, according to OpenFog consortium, is a "horizontal, system-level architecture that distributes computing, storage, control and networking functions closer to the users along a cloud-to-thing continuum" [19].

Fog computing is not an alternative for cloud computing. The Fog Extends the Cloud Closer to the Devices Producing Data in order to react instantly.

Figure 4. *Fog computing.*

It can be seen as a brining the computing closer to where data is produced or consumed [20]. Analyzing data close to where it is collected minimize latency and very beneficial to critical applications (health monitoring, traffic accidents …).

The applications of fog computing diverse and can be general or specific to a context. An example of fog computing application is the monitoring or the analyzing of real-time data from things (connected to a network) and then triggers an action. The action can involve machine-to-machine (M2M) communications or human-machine interaction (HMI). Examples include opening a door, changing AC settings, zooming a video camera on a suspect or sending an alert to a doctor to make a preventive treatment. The possibilities are diverse and unlimited.

3.1. Fog Computing vs. Cloud Computing

The term Cloud computing is a paradigm that offers ubiquitous access to shared pools of pre-configurable resources (servers) and services. Generally, these resources are accessible via internet, and can be rapidly exploited with minimal management effort. Cloud computing is similar to public utility in the context of IT (It can be public or private).

The difference between the two terms of fog computing and cloud computing cloud be hard form for many users. There is a tendency to consider the fog as an extension of the cloud. Others consider the fog just another term to describe the cloud. Table 1 compares the features of both technologies of computing [21].

Table 1. *Fog computing and cloud computing comparison [21].*

Feature	Cloud	Fog
Latency	High	Low
Access	Fixed and wireless	Mainly wireless
Explicit mobility	NA	Lispmob [22]
Control	Centralized / Hierarchical (full control)	Distributed / Hierarchical (partial control)
Service access	Through core	At the edge / on handled devices
Availability	99.99%	Highly volatile / highly redundant
Number of users/devices	Ten / hundreds of millions	Ten of billions
Main content generator	Humans	Devices / Sensors
Content generation	Central location	Anywhere
Content consumption	End devices	Anywhere
Software virtual infrastructure	Central corporate servers	User devices

3.2. Fog Computing Components

The fog-computing reference architecture can be viewed as six layered architecture (figure 5):

i. Applications
ii. Programming models
iii. API and service management
iv. Multitenant resource management
v. Edge and cloud resources
vi. IoT sensors and actuators

The sense-process-actuate and stream-processing programming models are the main core of Fog computing based systems. The streamed data from objects (sensors) through IoT networks to applications. The fog devices assigned to these applications process the information and the data collected. Then the resulted insights are translated into actions performed by objects (actuators).

Fog systems and their functionalities are dynamically built as needed by the discover mechanisms that uses APIs. The resource-management layer track the state of all available components such as cloud, fog, and network resources and identify the best candidate elements to process incoming jobs. Resources communication between Edge and cloud uses machine-to-machine (M2M) standards [23] such as MQTT [24, 25] (formerly MQ Telemetry Transport) and the Constrained Application Protocol (CoAP) [26, 27].

The fog computing systems relies also on the Software-defined networking (SDN) concept that helps dealing with the management of heterogeneous fog networks, especially in the Internet of Things [28, 29].

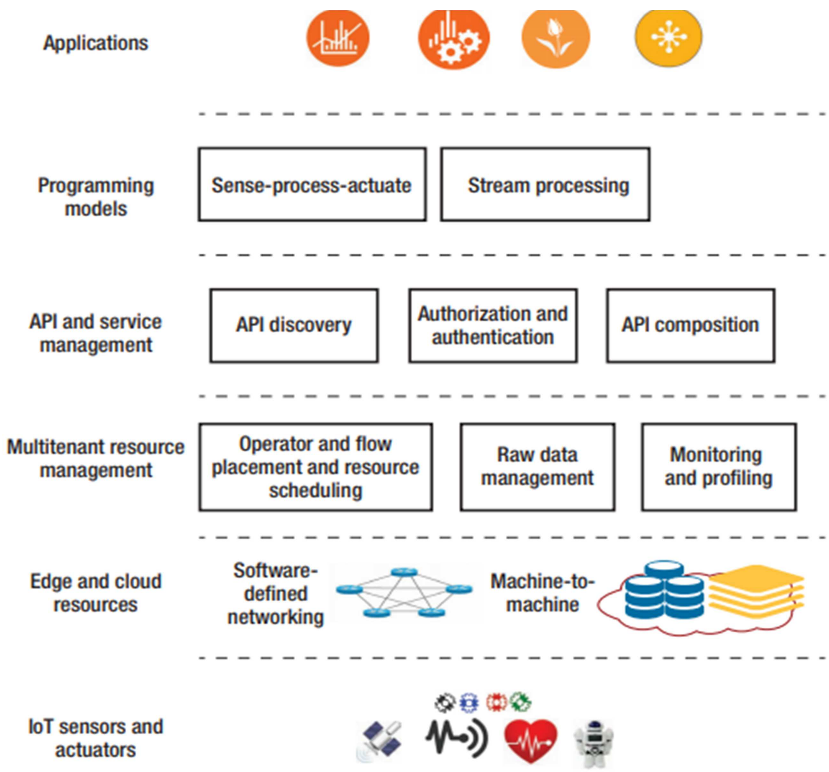

Figure 5. *Fog computing components [20].*

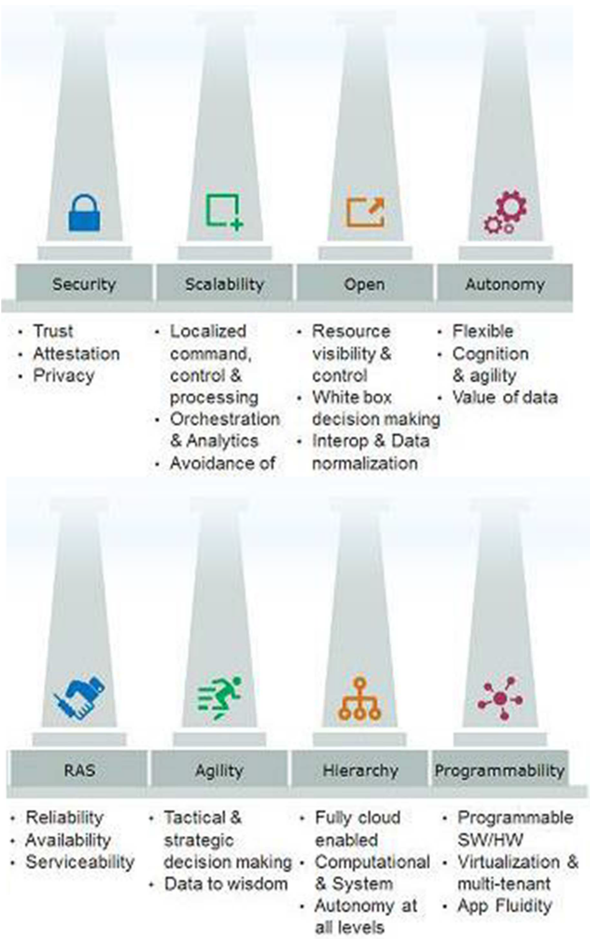

Figure 6. *OpenFog Reference Architecture pillars [19].*

3.3. Fog Computing Reference Architecture

The purpose of a Reference Architecture is unify the vision of solutions and help accelerate innovation by providing foundation for industry standards. Many works tried to propose a RAs for fog computing [30–32]. February 2017, the OpenFog consortium (Cisco, Intel, ARM, Dell, Microsoft and the university of Princeton) released the OpenFog Reference Architecture for Fog Computing [19]. This reference is based on eight pillars: security, scalability, open, autonomy, RAS, agility, hierarchy and programmability. They represent the essential attributes that a system needs to include in order to have a complaint system according to the OpenFog definition.

Based on the previous pillars of the reference architecture RA, OpenFog propose an abstract architecture that includes perspectives (performance, security, manageability, data analytics and control, IT Business and Cross Fog Applications).

The OpenFog is designed by the consortium using the ISO/IEC/IEEE 42010:2011 international standard for describing architecture to stakeholders.

i. OpenFog Architecture Description: an abstract representation of an instance of a fog node (figure 7).
ii. Viewpoint: an approach of looking at a system. Includes (but not limited): Functional and Deployment viewpoints.
iii. View: A view is a representation of one or more structural aspects of the architecture. The structural aspects are the Software view, System view, and Node view.
iv. Perspective: A perspective is a crosscutting concern of the architecture.

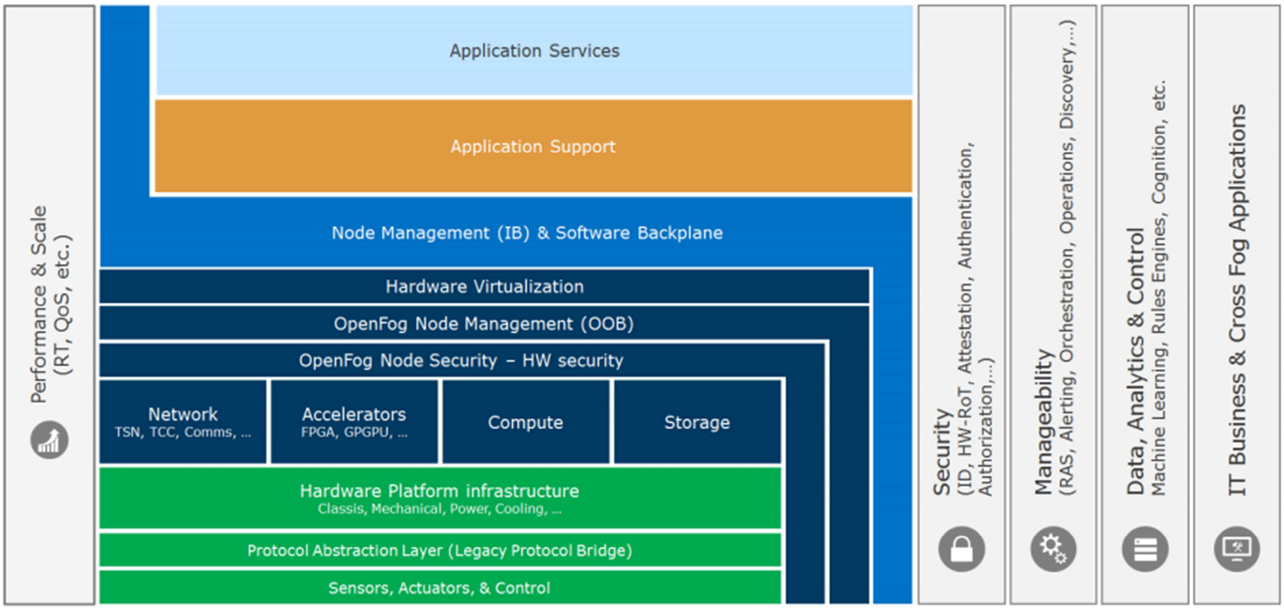

Figure 7. *OpenFog Reference Architecture description [19].*

For now, Open Fog remains the most complete yet powerful reference architecture for fog computing based applications using Internet of Things.

4. Conclusion

A new era of Internet has emerged, brings multitude functionalities and applications. Therefore, many concepts and technologies needs to be well defined. In this paper, we focused on the link between Internet of Things and one of its enablers: the Fog computing. We give an overview of this paradigm and its most relevant elements. We also compare it to an existing model, which is the cloud computing. The reference architecture RA for fog computing was also given.

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