NECESSITY OF THE INTERNET OF THINGS AND FOG COMPUTING INTEGRATION

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Abstract:
The Internet of Things (IoT), as a network of interconnected devices, has exploded over the past few years generating more data than ever before. At the same time, high-dimensional, high-velocity and high-variety data put an enormous burden on the Internet infrastructure. Sending a large amount of data generated by IoT to the Cloud implies problems with bandwidth, a considerable amount of time, and latency issues. Hence, utilization of Cloud computing is not adequate in applications that require very low and predictable latency, fast mobile applications, applications in a wide geographic area or large-scale distributed control systems.In these cases, Fog computing, by creating an additional computing layer between devices and Cloud, enables the computation execution at the place where data is generated. Without the need for the Cloud, Fog computing holds the potential to overcome barriers that Cloud computing utilization in particular cases implies. However, Fog computing will not completely replace the Cloud computing. Instead, Fog and Cloud computing together will lead to numerous benefits in the IoT applications. This paper analyzes ideas and influence of theFog computing appliance in various IoT scenarios, as well as benefits, potentials, and challenges of Fog computing implementations.

Keywords:
Internet of Things, Fog computing, Cloud computing, integration

1. INTRODUCTION

The idea of connecting everyday physical objects to the Internet, making them able to identify themselves to other devices and be controllable and available from anywhere, anyhow, and anytime in an intelligent manner, refers to the Internet of Things (IoT). In other words, IoT describes an ecosystem in which applications and services are driven by sensed, collected and exchanged information between smart devices, as well as with the environment, with or without human intervention. The most important IoT application domains are: health, education, agriculture, transportation, manufacturing, electric grids, and so on [1] (Fig. 1.).

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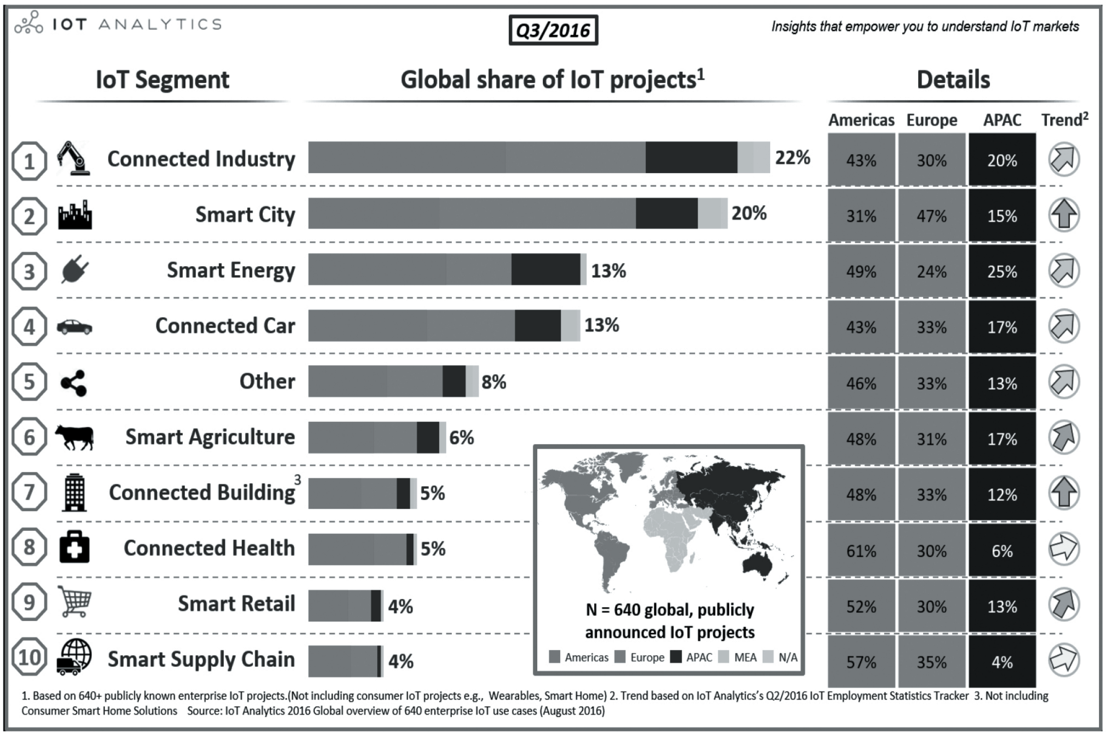

Fig. 1. The top 10 IoT application areas – based on real IoT projects [2]

The incorporation of IoT into people's lives is accompanied by an increasing number of smart IoT devices. Numerous estimates state that 20-50 billion connected devices will be in operation by 2020 while the Cisco anticipates that the total volume of data generated by IoT will reach 600 ZB per year by 2020 [3].Large quantities of information generated by IoT devices represent a serious challenge.Voluminous data alone doesn't do much, but IoT collected data and algorithms together, are exceptionally valuable [4]. Hence, an explosion of data demands its analysis in order to achieve the IoT potentials such as: real-time smart decision-making, optimized use of resources, lower costs, higher profits, increased safety, anomaly detection, incident prediction, etc. [5]. Despite the advantage of easier access to results from anywhere, posting large quantities of data to the Cloud for analysis and storage is not practical for several reasons: data processing time, latency and bandwidth issues. So as to overcome these challenges, Fog computing appears to be an adequate solution. Performing analytics at the edge of the Cloud and making edge devices as processing nodes enable faster, easier and real-time decisions while results are being uploaded to the Cloud for further processing or storage. Business Intelligence forecasts that the number of IoT devices that use Fog computing will rise from 570 million devices in 2015 to5.8 billion in 2020 [6].

Hence, this paper represents an analysis of the importance of Fog computing integration with the IoT, and it is organized as follows. The data characteristics and challenges for dealing with escalating volumes of data generated by IoT devices are discussed in Section II. Section III represents the main principles, benefits, and challenges of Fog computing and its integration with the IoT. Section IV contains concluding remarks.

2. IOT-GENERATED DATA ISSUES

The constant IoT growth and its omnipresence in people's lives will consequently imply the large-volume, complex, growing data sets, making data management capabilities as an IoT key requirement in the future.

The main characteristics of IoT-generated data can be described with five V's:

- *Volume*: As time goes on, new machines, sensors, and devices become part of an IoT ecosystem, come online and put information into data systems, resulting in the immense volume of data generated by the IoT. In order to deal with terabytes and petabytes of data, it is mandatory to radically rethink how to transmit, store, manage and exploit the IoT-produced data [7, 8].

- *Variety*: With the IoT growth not only is data growing, it is also diversifying encompassing different types of data, including both structured and unstructured data [4, 8]. Collecting, storing and using simultaneously structured and unstructured data is nowadays enabled using new and innovative big data technologies [9].
- *Velocity*: Velocity, defined as the speed at which vast amounts of data are being generated, collected and analyzed, increases with the IoT growth. Analysis of data generated by IoT, its transmission speed and access to the data, is all-important in making time and accurate decisions [9].
- *Value*: Immense amount of data is useless unless it can be turned into value [9]. Creating a value which can be transformed into new understandings, making real-time decisions, predicting events, cutting cost and so on, represents a mandatory activity in handling with big data issues.
- *Veracity*: Veracity, the quality or trustworthiness of the data, is essential to achieve effective results with data analytics, and making accurate decisions [4, 9].

These five V's describes the data that have to be analyzed, captured, searched, shared, stored, and visualized in order to obtain new insights about the behavior of systems and people in an IoT ecosystem, make on-time and accurate decisions and predictions. Hence, it is crucial to discover how to manage all the IoT-generated information, where, and why?

3. FOG COMPUTING AND IOT

Dealing with data described with five V's is not simple. The flood of growing amounts of a great variety of data and high speed of data generation and processing can quickly overwhelm today's storage systems and analytics applications. Difficulties with data generated by IoT lie in technical and security issues [10].

Cloud computing systems will not be capable of managing the total burden of IoT-generated data because posting all these data, from thousands or hundreds of thousands of edge devices to the Cloud and transmitting response data back requires a larger bandwidth, a considerable amount of time and can suffer from latency issues. Adding a middle layer between devices and Cloud, splitting big data to sub data, and its processing in smart devices where data originates instead of routing everything over Cloud channels refers to Fog computing (Fig. 2).

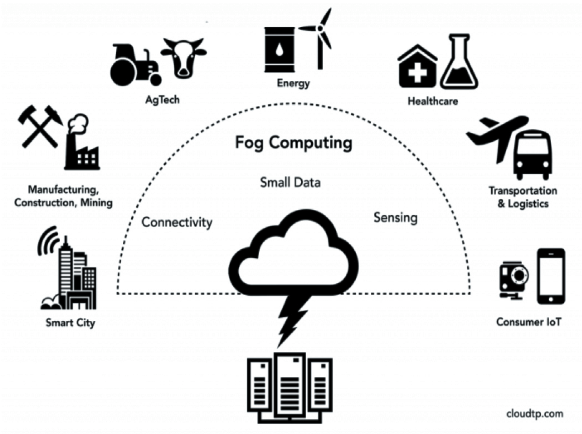

Fig. 2. Fog computing

Fog computing principles and benefits of its integration with IoT

Fog computing is not a replacement for Cloud computing, it extends the Cloud computing paradigm at the edge of the network, closer to things that produce IoT data. Getting closer to the source of data, simplify extracting key information when handling with big data, such as IoT-produced data. In other words, sensors stream data to IoT networks while applications running on Fog devices process the data and transmit the critical information (the results, not the raw data) to available Cloud, Fog, or network resources identified as the best place for processing incoming tasks, depending on how quickly a decision is needed [11] (Fig.3, Table I). While Fog devices receive sensor data streams from IoT devices in real time, one should run IoT-enabled applications for real-time control and analytics (millisecond response time) and provide transient storage and send only results to the Cloud. Cloud, on the other hand, receives and aggregates information from many Fog devices, performs analysis and can send new application rules to the Fog devices based on the achieved insight [12]. Edge and Cloud resources communicate using M2M (machine-to-machine) standards and the CoAP (Constrained Application Protocol) while SDN (Software-defined networking) helps with the efficient management of heterogeneous Fog networks [11]. Hence, the Fog computing vision retains the benefits of Cloud (e.g. agility, flexibility and distributed computing), while allowing communication of the data over the IoT devices much easier than Cloud [13].

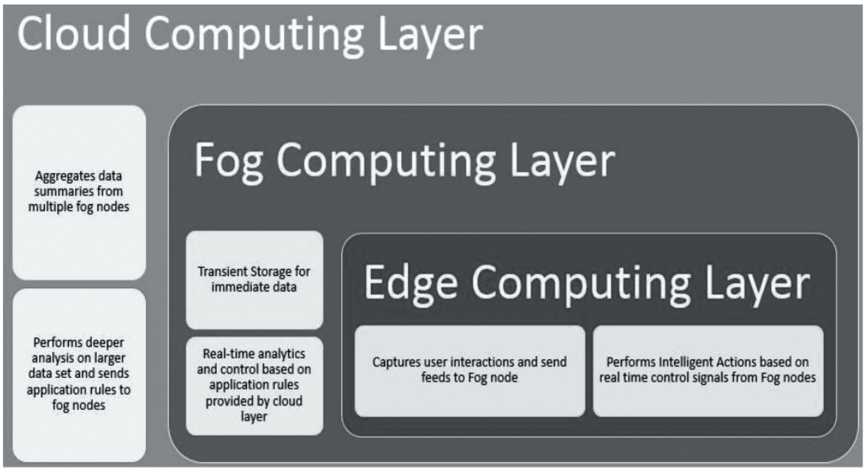

Fig. 3. The role of computing layers in an IoT ecosystem [14]

	Fog nodes closest to IoT devices	Fog aggregation nodes	Cloud
Response time	Milliseconds to subsecond	Seconds to minutes	Minutes, days, weeks
Application examples	Machine to Machine communication Haptics* (*controlling technology using the sense of touch), including telemedicine and training	Visualization Simple analytics	Big data analytics Graphical dashboards
How long IoT data is stored	Transient	Short durations: perhaps hours, days, weeks	Month or years
Geographic coverage	Very local (e.g. one city block)	Wider	Global

Table 1. Fog nodes extend the Cloud to the network edge [12]

Fog computing enables making extremely time-sensitive decisions closer to things/devices that produce data and act on it, reduces network bandwidth consumption and contributes to data privacy and security analyzing sensitive data locally instead of sending it to the Cloud for analysis [14]. In addition, Fog computing supports user mobility, resource, and interface heterogeneity as well as distributed data analytics [11].

In summary, the necessity of Fog computing integration with the IoT is justified with its following features which have potential to increase the overall performance of IoT applications [15, 16]:

- Location: Fog infrastructure is located between smart objects (edge devices) and the Cloud, enabling improved latency and bandwidth issues.
- Distribution: Fog infrastructure can be implemented in the sense of many micro centers (with limited storage, processing and communication capabilities) closer to the edge devices and thus reduces network load. Hence, there is no single point of failure.
- Scalability: The Cloud as the centralized approach is not sufficient to handle an increasing number of edge devices. On the other hand, the Fog infrastructure with improved capabilities to deal with increased load allows IoT systems to be more scalable.
- The density of devices: Fog computing paradigm enables resilient and replicated services even if communication with the operation center is not effective.
- Mobility support: Fog infrastructure resources act as a “mobile” cloud as it is situated close to the edge devices.
- Real-time: Fog computing vision offers better performance for real-time requirements.
- Standardization: Fog resources can interoperate with various cloud providers.

- On the fly analysis: Fog infrastructure resources are able to perform data aggregation in order to send partially processed data.
- Privacy: Fog computing by separating public and private data improves privacy and security issues.

Fog computing utilization in IoT applications

Fog computing is built up to address applications and services that do not fit the paradigm of the Cloud, such as [13, 17, 18]:

- Applications that require very low and predictable latency like health-monitoring and various emergency-response applications;
- Geographically distributed applications - applications in which thousands or millions of things across a large geographic area are generating data (e.g. sensor networks for monitoring environment);
- Fast mobile applications such as smart connected vehicle or connected rail; and
- Large-scale distributed control systems (e.g. smart grid, smart traffic light systems).

Hence, various applications could benefit from Fog computing [11]. In healthcare applications, where real-time processing and event response are critical, Fog computing can be very useful. Fog computing-based smart healthcare system enables low latency data processing and low bandwidth utilization at the edge of the network, heterogeneity and interoperability, mobility support, location and privacy awareness, real-time and online analytic even in case of poor connection with Cloud, real-time rapid interaction in case of emergency and less energy consumption than Cloud solutions [11, 16, 19]. The benefits of Fog computing use in Smart grids lie in improving energy generation, delivery, energy consumption and billing [11, 13, 20]. Fog computing also plays a major role in other latency sensitive applications, such as: augmented-reality applications, cognitive systems, and gaming [11] as well as in transportation, agriculture, smart cities and buildings.

Challenges for Fog computing implementation in IoT

Despite obvious benefits Fog computing offers, there are numerous challenges for its implementation: balancing load distribution between edge and Cloud resources, API and service management and sharing, and SDN communications. Deciding which analytics tasks have to be performed with Cloud or edge-based resource, in order to minimize latency and maximize throughput, is essential. Having in mind that processing nodes are generally mobile devices that fre¬quently join and leave networks, in Fog computing vision it is crucial to have the ability to add and remove resources dynam¬ically. In addition, privacy and security, issues connected with the failure of individual sen¬sors, networks, service platforms, and applications, as well as power consumption represent key challenges in the realization of Fog computing paradigm [11].

4. CONCLUSION

A constantly increasing number of IoT devices creates unprecedented volumes of data. A centralized approach such as Cloud is not sufficient to manage large quantities of high-velocity and high-variety of IoT-generated data. Even though Fog and Cloud use the same resources and share many of the same mechanisms and attributes, Fog computing, opposite to the Cloud, supports decentralized and intelligent processing closer to where data is produced, reducing greatly the quantity of data being transmitted to and from Cloud. In this way Fog infrastructure by enabling distribution of computing, communication, control, storage and decision making, successfully deals with latency, bandwidth, privacy and cost challenges. These advantages of the Fog computing paradigm justify its implementation in numerous IoT applications, especially in time-sensitive, large-scale and geographically distributed applications.

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