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A Review- Fog Computing and Its Role in the Internet of Things

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ABSTRACT
Fog computing extends the Cloud Computing paradigm to the edge of the network, thus enabling a new breed of applications and services. Dening characteristics of the Fog are: a) Low latency and location awareness; b) Wide-spread geographical distribution; c) Mobility; d) Very large number of nodes, e) Predominant role of wireless access, f) Strong presence of streaming and real time applications, g) Het-erogeneity. In this paper we argue that the above characteristics make the Fog the appropriate platform for a number of critical Internet of Things (IoT) services and applications, namely, Connected Vehicle, Smart Grid , Smart Cities, and, in general, Wireless Sensors and Actuators Net-works (WSANs).
Keywords: Fog Computing, Cloud Computing, IoT, WSAN, Software Dened Networks, Real Time Systems, Analytics.

I. INTRODUCTION

The pay-as-you-go Cloud Computing model is an ecient alternative to owning and managing private data centers (DCs) for customers facing Web applications and batch processing. Several factors contribute to the economy of scale of mega DCs: higher predictability of massive aggre-gation, which allows higher utilization without degrading performance; convenient location that takes advantage of inexpensive power; and lower OPEX achieved through the deployment of homogeneous compute, storage, and networking components.

Cloud computing frees the enterprise and the end user from the speciation of many details. This bliss becomes a problem for latency-sensitive applications, which require nodes in the vicinity to meet their delay requirements. An emerging wave of Internet deployments, most notably the Internet of Things (IoTs), requires mobility support and geo-distribution in addition to location awareness and low latency. We argue that a new platform is needed to meet these requirements; a platform we call Fog Computing [1], or, briey, Fog, simply because the fog is a cloud close to the ground. We also claim that rather than cannibalizing Cloud Computing, Fog Computing enables a new breed of applications and services, and that there is a fruitful inter-play between the Cloud and the Fog, particularly when it comes to data management and analytics.

This paper is organized as follows. In the second section we introduce the Fog Computing paradigm, delineate its characteristics, and those of the platform that supports Fog services. The following section takes a close look at a few key applications and services of interest that substantiate our argument in favor of the Fog as the natural component of the platform required for the support for the Internet of Things. In the fourth section we examine analytics and big data in the context of applications of interest. The recognition that some of these applications demand real-time analytics as well as long-term global data mining illustrates the interplay and complementary roles of Fog and Cloud. We conclude with comments about the state of the Fog Computing and discussion of future work.

II. THE FOG COMPUTING PLATFORM

Fog computing, also known as fogging, is a model in which data, processing and applications are concentrated in devices at the network edge rather than existing almost entirely in the cloud. That concentration means that data can be processed locally in smart devices rather than being sent to the cloud for processing. Fog computing is one approach to dealing with the demands of the ever-increasing number of Internet-connected devices sometimes referred to as the Internet of Things (IoT).

In the IoT scenario, a thing is any natural or man-made object that can be assigned an IP address and provided with the ability to transfer data over a network. Some such things can create a lot of data. Cisco provides the example of a jet engine, which they say can create 10 terabytes (TB) of data about its performance and condition in a half-hour.

Transmitting all that data to the cloud and transmitting response data back puts a great deal of demand on bandwidth, requires a considerable amount of time and can suffer from latency. In a fog computing environment, much of the processing would take place in a router, rather than having to be transmitted

III. CHARACTERIZATION OF FOG COMPUTING

Fog Computing is a highly virtualized platform that provides compute, storage, and networking services between end devices and traditional Cloud Computing Data Centers, typically, but not exclusively located at the edge of network. Figure 1 presents the idealized information and computing architecture supporting the future IoT applications, and illustrates the role of Fog Computing.

Compute, storage, and networking resources are the building blocks of both the Cloud and the Fog. Edge of the Network, however, implies a number of characteristics that make the Fog a non-trivial extension of the Cloud. Let us list them with pointers to motivating examples.

Edge location, location awareness, and low latency. The origins of the Fog can be traced to early proposals to support endpoints with rich services at the edge of the network, including applications with low latency requirements (e.g. gaming, video streaming, augmented reality).

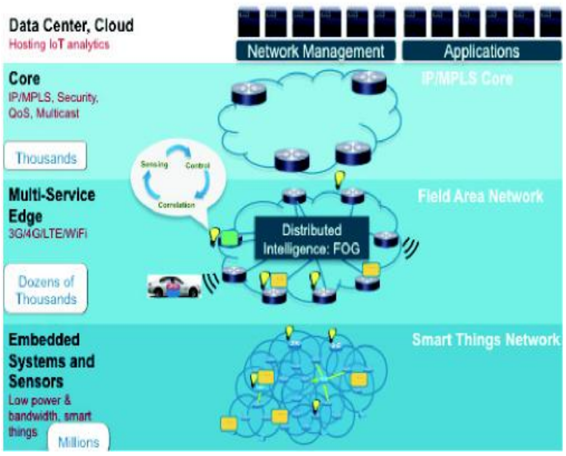

Figure 1: The Internet of Things and Fog Computing

- Geographical distribution. In sharp contrast to the more centralized Cloud, the services and applications targeted by the Fog demand widely distributed deployments. The Fog, for instance, will play an active role in delivering high quality streaming to moving vehicles, through proxies and access points positioned along highways and tracks.
- Large-scale sensor networks to monitor the environment, and the Smart Grid are other examples of inherently distributed systems, requiring distributed computing and storage resources.
- Very large number of nodes, as a consequence of the wide geo-distribution, as evidenced in sensor networks in general, and the Smart Grid in particular.
- Support for mobility. It is essential for many Fog applications to communicate directly with mobile devices, and therefore support mobility techniques, such as the LISP protocol 1, that decouple host identity from location identity, and require a distributed directory system.
- Real-time interactions. Important Fog applications involve real-time interactions rather than batch processing.
- Predominance of wireless access.
- Heterogeneity. Fog nodes come in dierent form factors, and will be deployed in a wide variety of environments Interoperability and federation. Seamless support of certain services (streaming is a good example) requires the cooperation of dierent providers. Hence, Fog components must be able to interoperate, and services must be federated across domains.
- Support for on-line analytic and interplay with the Cloud. The Fog is positioned to play a sign cant role in the ingestion and processing of the data close to the source. We elaborate in section 4 on the interplay between Fog and Cloud regarding Big Data.

A. Fog Players: Providers and Users

It is not easy to determine at this early stage how the different Fog Computing players will align. Based on the nature of the major services and applications, however, we anticipate that:

- Subscriber models will play a major role in the Fog (Infotainment in Connected Vehicle, Smart Grid, Smart Cities, Health Care, etc.)
- The Fog will give rise to new forms of competition and cooperation between providers angling to provide global services. New incumbents will enter the arena as users and providers, including utilities, car manufacturers, public administrations and transportation agencies.

B. Fog Computing and the Internet of Things

In this section we demonstrate the role the Fog plays in three scenarios of interest: Connected Vehicle, Smart Grid, and Wireless Sensor and Actuator Networks.

The Connected Vehicle deployment displays a rich scenario of connectivity and interactions: cars to cars, cars to access points (Wi-

Fi, 3G, LTE, roadside units [RSUs], smart trace lights), and access points to access points. The Fog has a number of attributes that make it the ideal platform to deliver a rich menu of SCV services in infotainment, safety, trace support, and analytics: geo-distribution (throughout cities and along roads), mobility and location awareness, low latency, heterogeneity, and support for real-time inter-actions. A smart trace light system illustrates the latter. The smart trace light node interacts locally with a number of sensors, which detect the presence of pedestrians and bikers, and measures the distance and speed of approaching vehicles. It also interacts with neighboring lights to coordinate the green trace wave. Based on this information the smart light sends warning signals to approaching vehicles, and even modes its own cycle to prevent accidents. Re-coordinating with neighboring STLs through the or chest ration layer of the Fog follows any medication of the cycle. The data collected by the STLs is processed to do real-time analytics (changing, for instance, the timing of the cycles in response to the trace conditions). The data from clusters of smart trace lights is sent to the Cloud for global, long-term analytics.

C. Smart Grid

Smart Grid is another rich Fog use case. We defer section 4 a discussion of the interplay of Fog and Cloud in the context of Smart Grid.

D. Wireless Sensors and Actuators Networks

The original Wireless Sensor Nodes (WSNs), nicknamed motes [2], were designed to operate at extremely low power to extend battery life or even to make energy harvesting feasible. Most of these WSNs involve a large number of low

Bandwidth, low energy, low processing power, small memory motes, operating as sources of a sink (collector), in a unidirectional fashion. Sensing the environment, simple processing, and forwarding data to the static sink are the duties of this class of sensor networks, for which the open source TinyOS2 is the de-facto standard operating system. Motes have proven useful in a variety of scenarios to collect environmental data (humidity, temperature, amount of rainfall, light intensity, etc).

Energy constrained WSNs advanced in several directions: multiple sinks, mobile sinks, multiple mobile sinks, and mobile sensors were proposed in successive incarnations to meet the requirements of new applications. Yet, they fall short in applications that go beyond sensing and tracking, but re-quire actuators to exert physical actions (open, close, move, focus, target, even carry and deploy sensors). Actuators, which can control either a system or the measurement process itself, bring new dimensions to sensor networks.

The information on is not unidirectional (from the sensors to the sink), but bi-directional (sensors to sink, and controller node to actuators). In a subtler, but sign cant way, it becomes a closed-loop system, in which the issues of stability and potential oscillatory behavior cannot be ignored. Latency and jitter become a dominant concern in systems that require rapid response.

S.S. Kashi and M. Shari [4] survey the contributions in the coordination of Wireless Sensor and Actuator Networks (WSANs). They point out that in one architectural choice, the WSAN consists of two networks: a wireless sensor net-work and a mobile ad hoc network (MANET). T. Banka et al [6] stress that emergent applications demand a higher bandwidth, collaborative sensing environment. Their experience is rooted in the CASA (Collaborative Adaptive Sensing of the Atmosphere) project. CASA [5], a multi-year, multi-partner initiative led by UMASS, deployed a network of small weather radars, integrated with a distributed processing and storage infrastructure in a closed-loop system to monitor the lower troposphere for atmospheric hazards like tornados, hailstorms, etc. Zink et al [3] provide technical details of the deployment.

The characteristics of the Fog (proximity and location awareness, geo-distribution, hierarchical organization) make it the suitable platform to support both energy-constrained WSNs and WSANs

E. Open Challenges and Future Directions

The proposed Cloud centric vision comprises of a flexible and open architecture that is user centric and enables different players to interact in the IoT framework. It allows interaction in a manner suitable for their own requirements, rather than the IoT being thrust upon them. In this way, the framework includes provisions to meet different requirements for data ownership, security, privacy, and sharing of information.

Figure 2: Roadmap of key technological developments in the context of IoT application domains envisioned

Some open challenges are discussed based on the IoT elements presented earlier. The challenges include IoT specific challenges such as privacy, participatory sensing, data analytics, GIS based visualization and Cloud computing apart from the standard WSN challenges including architecture, energy efficiency, security, protocols, and Quality of Service. The end goal is to have Plug n‘ Play smart objects which can be deployed in any environment with an interoperable backbone allowing them to blend with other smart objects around them. Standardization of frequency bands and protocols plays a pivotal role in accomplishing this goal.

A roadmap of key developments in IoT research in the context of pervasive applications is shown in Figure:2, which includes the technology drivers and key application outcomes expected in the next decade [7]. The section ends with a few international initiatives in the domain which could play a vital role in the success of this rapidly emerging technology.

IV. ANALYTICS, AND THE INTERPLAY BE-TWEEN THE FOG AND THE CLOUD

While Fog nodes provide localization, therefore enabling low latency and context awareness, the Cloud provides global centralization. Many applications require both Fog localization, and Cloud globalization, particularly for analytics and Big Data. We touched upon this point earlier in reference to smart track light. Here we consider Smart Grid, which data hierarchies help illustrate further this interplay.

Fog collectors at the edge ingest the data generated by grid sensors and devices. Some of this data relates to protection and control loops that require real-time processing (from milliseconds to sub seconds). This rst tier of the Fog, designed for machine-to-machine (M2M) interaction, collects, process the data, and issues control commands to the actuators. It also lters the data to be consumed locally, and sends the rest to the higher tiers. The second and third tier deal with visualization and reporting (human-to¬machine [HMI] interactions), as well as systems and processes (M2M). The time scales of these interactions, all part of the Fog, range from seconds to minutes (real-time analytics), and even days (transactional analytics). As a result of this the Fog must support several types of storage, from ephemeral at the lowest tier to semi-permanent at the highest tier. We also note that the higher the tier, the wider the geographical coverage, and the longer the time scale. The ultimate, global coverage is provided by the Cloud, which is used as repository for data that that has a permanence of months and years, and which is the bases for business intelligence analytics. This is the typical HMI environment of reports and dashboards the display key performance in dictators.

V. CONCLUSIONS

We have outlined the vision and dened key characteristics of Fog Computing, a platform to deliver a rich portfolio of new services and applications at the edge of the network. The motivating examples peppered throughout the discus-sion range from conceptual visions to existing point solution prototypes. We envision the Fog to be a unifying platform, rich enough to deliver this new breed of emerging services and enable the development of new applications.

We welcome collaborations on the substantial body of work ahead: 1) Architecture of this massive infrastructure of compute, storage, and networking devices; 2) Orchestration and resource management of the Fog nodes; 3) Innovative services and applications to be supported by the Fog.

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