Fog Computing

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The Internet has witnessed two radical changes in the past decade: rapidly growing cloud computing and pervasive mobile devices. Motivated by these two trends, a plethora of research has been conducted to support mobile cloud computing, which bridges the cloud and mobile devices by leveraging both the powerful computing capability of the cloud and the mobility support of mobile devices. Much of the work has been focused on how to effectively offload computation-intensive tasks from resource-constrained devices to the cloud and get the results back promptly.

However, because of frequently unpredictable network latency, especially in a mobile environment, often cloud computing can't meet the stringent requirements of latency-, security- and privacy-sensitive, or geographically constrained applications. On the other hand, the growing amount of data generated by end devices and systems often can become impractical or resource-prohibitive to transport over networks to remote clouds.

To this end, a new diagram, *fog computing*, has emerged. Fog computing will distribute advanced computing, storage, networking, and management services closer to end users along the continuum, from the cloud to things and devices, thus forming a distributed and virtualized platform. Thus, it is also referred to as edge computing.

Looking into the Fog

Fog computing offers many key advantages desired by today's applications, such as real-time processing, rapid and affordable scaling, and local content and resource pooling. As such, fog computing has quickly garnered much attention from both industry and academia. It naturally bridges the Internet of Things (IoT) with the existing Internet computing infrastructure. Current and upcoming applications that demand fog computing include connected vehicles, autopilot vehicles, smart grids, wireless sensor and actuator networks, smart homes, smart cities, connected manufacturing, connected oil and gas systems, and mobile healthcare systems, to name a few. Although motivated by cloud computing, fog computing has many

different characteristics – the more unique of which include the following:

- possessing edge location, location awareness, and latency-sensitivity;
- being geographically distributed;
- comprising large-scale sensor networks and a large number of nodes;
- offering real-time interactions;
- having heterogeneity;
- offering interoperability and federation; and
- having online analytics and interplay with the cloud.

Today, fog computing is still in its early stages and presents a set of new challenges, such as security and privacy; programming abstracts and models; fog architecture; IoT support; computing, network, and storage constraints; resource provisioning and management; and distributed fog computing centers.

In This Issue

This special issue investigates many of the issues we outlined. In the first article, "On Using Micro-Clouds to Deliver the Fog," Yehia Elkhatib and colleagues explore the potential fog infrastructure with Raspberry Pi to validate the feasibility of "micro-clouds" that are composed of resource-constrained devices on the network edge. Experiments are conducted with several applications to test the serving latency, hosting capability, I/O overhead, and startup latency.

Concerning IoT support, in "Fog Orchestration for Internet of Things Services," Zhenyu Wen and colleagues discuss the challenges for fog application orchestration, such as scale and complexity, security criticality, dynamicity, and fault diagnosis and tolerance. Research directions are further discussed on component selection and placement, dynamic orchestration with runtime

quality of service (QoS), incremental computation in orchestration, and systematic data-driven optimization.

Next, in "Improving Quality of Experience in Future Wireless Access Networks through Fog Computing," Nicola Iotti and colleagues analyze data collected from public Wi-Fi hotspots to show the potential of deploying proactive caches on fog nodes to enhance user experience and reduce latency and bandwidth usage.

Security and privacy is an important issue for fog computing. In their article "Fog Computing for the Internet of Things: Security and Privacy Issues," Arwa Alrawais and colleagues discuss security and privacy issues such as authentication, trust, rogue nodes, privacy, access control, intrusion detection, and data protection in IoT environments. A mechanism is proposed to use fog computing to improve the

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distribution of certificate revocation information among IoT devices for security enhancement.

Regarding programming models, in "Challenges and Software Architecture for Fog Computing," Zijiang Hao and colleagues propose an open software architecture for fog computing that allows flexible design choices and user-specified policies. They implement a prototype system and present some preliminary experimental results to show its usage.

In the final article, "A New Era for Cities with Fog Computing," use cases are reported. Marcelo Yannuzzi and colleagues discuss technical challenges, design principles, main results, and lessons learned from a project that involved the Barcelona City Council, industrial partners, and

academia in the Smart City project. They also discuss the so-called *Quadruple Silo* problem that includes hardware, data, service management, and administrative silos.

We hope that readers find these articles interesting and informative. We sincerely thank all of the authors for their submissions and the reviewers for their timely and high-quality reviews. ⌧

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