Overview of Cloudlet, Fog Computing, Edge Computing, and Dew Computing

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***Abstract*—Cloudlet, Fog Computing, Edge Computing, and Dew Computing are post-cloud computing models. Researchers and public need to grasp the essential meaning of each one and their differences. In this talk summary, we will describe the origins, definitions, basic principles, and applications of these computing models.**

***Index Terms*—Dew computing; Fog computing; Edge computing; Cloudlet; Cloud computing; Network topology; Internet of Things; Mobile applications; Blockchain.**

I. Introduction

Cloudlet, Fog Computing, Edge Computing, and Dew Computing are computing models proposed to provide some features that Cloud Computing cannot provide. They share one common feature: they all perform computing tasks at devices that are closer to users. We may call them post-cloud computing models. Researchers and public need to know their characteristics, to know their similarities and differences. We would like to provide an overview to these computing models.

These post-cloud computing models cover huge amount of research work. We do not intent to provide a full survey to the whole landscape of these computing models in this talk. We only concentrate on the following aspects of each model:

1) the origin: when did it start and how it was started;
2) the definition: what does it mean;
3) the principles and applications: how does it work and how was it used.

We would like to explain our positions regarding to the origins and definitions of these models.

For origins, in our understanding, every computing model goes through the following steps for its origination:

1) Before the concept was proposed, some concrete technical approaches that are very similar to the new concept or exactly the same with the new concept were proposed as research ideas and/or applied in products or services;
2) The new concept was proposed after technical accumulation;
3) After the concept was proposed, technical approaches based on the new concept were widely and quickly spread; existing approaches were interpreted with the new concept; new approaches were proposed according to the new concept.

No computing model can be proposed without technical accumulation described in Step 1. A long-term accumulation process is necessary for the establishment of a computing model.

The origination of a new concept is a significant event because the new concept leads researchers to explore solutions to wide range of problems using a paradigm or a framework that comes with the new concept. Thus, we would like to introduce the origin of each computing model.

For definitions, each computing model may have more than one definition. Different researchers may have different opinions toward these definitions. For each computing model, we try to find a definition that, we believe, accurately describe this model.

As a general statement, this talk summary was prepared for tutorial and discussion purposes. It reflects our limited knowledge and subjective opinions; we do not guarantee its accuracy and completeness, although most of our descriptions have supporting references.

II. Cloudlet

A. Origin

Although the word *cloudlet* existed long time ago with different meanings, it was started being used in the meaning of a computing arrangement in 2009 [1][2].

B. Definition

The following is a definition of a cloudlet [2]:

A cloudlet is a trusted, resource-rich computer or cluster of computers that is well-connected to the Internet and is available for use by nearby mobile devices.

C. Principles and Applications

The Cloudlet model promotes to put small-scale cloud data centers at the edge of the Internet. A cloudlet is the middle tier of a 3-tier hierarchy: mobile device - cloudlet - cloud. A cloudlet is close to a mobile device but not on the mobile device.

III. Fog Computing

A. Origin

Fog Computing was proposed by Cisco. It was first proposed by Flavio Bonomi, Vice President of Cisco Systems, in a keynote presentation at a conference in Sept. 2011 [3][4].

B. Defintion

The following is a definition of Fog Computing [5]:

Fog Computing is a scenario where a huge number of heterogeneous (wireless and sometimes autonomous) ubiquitous and decentralised devices communicate and potentially cooperate among them and with the network to perform storage and processing tasks without the intervention of third-parties. These tasks can be for supporting basic network functions or new services and applications that run in a sandboxed environment. Users leasing part of their devices to host these services get incentives for doing so.

C. Principles and Applications

Fog Computing extends Cloud Computing and services to devices such as routers, routing switches, multiplexers, and so on. It mainly involves automation devices because Fog Computing was proposed with Internet of Things (IoT) as its background.

IV. Edge Computing

A. Origin

The term *edge cluster* was used in a paper in August 2015 [6]. *Edge Computing* was proposed for the first time in October 2015 [7]. Some work has been done before this time. As discussed in Section I, we consider those work as the accumulation work before its birth.

A paper used the term "computing on the edge" in 2004 [8], but it is an "early flavor of edge computing" and the new vision of Edge Computing was "far beyond this initial approach" [7]. The fact that the accumulation work did not use this term also indicates that this paper was not the origin of Edge Computing.

Many research papers about Edge Computing appeared after 2015. It is reasonable to say that Edge Computing was originated in 2015.

B. Definition

The following is a definition of Edge Computing [9]:

Edge Computing refers to the enabling technologies allowing computation to be performed at the edge of the network, on downstream data on behalf of cloud services and upstream data on behalf of IoT services. Here we define edge as any computing and network resources along the path between data sources and cloud data centers.

C. Principles and Applications

Edge Computing pushes applications, data, and services away from central servers (core) to the edge of a network; it is based on the core-edge topology [9][10].

Cloud offloading, video analytics, smart home / smart city are some examples where Edge Computing can be actively applied to [11][12].

V. Dew Computing

A. Origin

Dew Computing was proposed in 2015 [13][14][15]. The first paper became online in January 2015.

B. Definition

The definition of Dew Computing can be found in [16]:

Dew Computing is an on-premises computer software-hardware organization paradigm in the Cloud Computing environment where the on-premises computer provides functionality that is independent of cloud services and is also collaborative with cloud services. The goal of Dew Computing is to fully realize the potentials of on-premises computers and cloud services.

C. Principles and Applications

Dew Computing is a new computing model appeared after the wide acceptance of Cloud Computing. While Cloud Computing uses centralized servers to provide various services, Dew Computing uses on-premises computers to provide decentralized, cloud-friendly, and collaborative micro services to end-users.

Dew Computing is complementary to Cloud Computing. The key features of Dew Computing are that on-premises computers provide functionality independent of cloud services and they also collaborate with cloud services.

VI. Comparison and Discussion

A. Similarities

All these computing models share a common feature: they all perform computing tasks at devices that are closer to users. It is hard to determine the exact differences among these models by checking their definitions. The reasons are:

1) Normally a computing model was proposed to solve a specific problem with a narrow definition. With the progress of research, researchers tend to expand the definition to cover a wider range of area. Thus the definitions of these computing models become quite similar. Such definition expansion reflects researchers' eagerness and excitement in exploring new technologies.
2) Even if differences among these models are found in definitions, some researchers may have different opinions to these definitions.

To understand the underlying reasons of these similar computing model definitions, we had better take a bird's view position to observe the general trend in the history of computer science. Dr. Mahadev Satyanarayanan [10] summarized the past history in the following quote:

"Since the 1960s, computing has alternated between centralization and decentralization. The centralized approaches of batch processing and timesharing prevailed in the 1960s and 1970s. The 1980s and 1990s saw decentralization through the rise of personal computing. By the mid-2000s, the centralized approach of cloud computing began its ascent to the preeminent position that it holds today. Edge Computing represents the latest phase of this ongoing dialectic."

After the widely acceptance and huge success of Cloud Computing, some researchers discovered the limitations of Cloud Computing and proposed remedial solutions from different perspectives. Not only Edge Computing, other models such as Cloudlet, Fog Computing, and Dew Computing were also proposed as the result of this trend.

B. Differences

Although these computing models reflect the same trend in response to Cloud Computing's limitations, these models were quite different because:

1) they originated from different background;
2) they were proposed to solve different problems;
3) they are related to different disciplines or industries;
4) they deal with different types of devices and environment;
5) they have different methodologies. Here we would like to point out some differences among these models.

Cloudlet features micro data centers; it is related to mobile services. Micro data centers could be set up by mobile service providers, application providers, or even users.

Fog Computing is tightly related to Internet of Things. Fog Computing emphasizes proximity to end-users and client objectives, dense geographical distribution and local resource pooling, latency reduction and backbone bandwidth savings.

Edge Computing's rational is that computing should happen at the proximity of data sources [9]. Edge Computing is also tightly related to IoT.

Dew Computing is more closely related to software design; its strong point is to inspire novice applications. Dew Computing was proposed to solve the data availability problem when an Internet connection is not available. Dew Computing's features, categories, and architecture are helpful for new applications be developed. Dew Computing normally does not involve edge devices such as routers and switches.

Sometimes, the difference is quite clear. For example, if Cloudlet model is introduced in mobile applications, a 3-tier hierarchy: mobile device - cloudlet - cloud would be established. A cloudlet is close to a mobile device but not on the mobile device. If Dew Computing is introduced, the dew component would be on the mobile devices.

Different models may work together. For example: A hierarchy was proposed [15] for Cloud Computing, Fog Computing, and Dew Computing to work together.

Different models may obtain similar results. For example, an Edge Computing idea about cloud/edge applications [17] has similar ideas with the cloud-dew architecture proposed in Dew Computing [13].

Each model may have its special strength. For example, the Dewblock system [18], that small-data-size blockchain clients with full node features, can hardly be classified into Cloudlet, Fog Computing, or Edge Comptuing applications; it is only possible under the computing model of Dew Computing.

C. Choice Suggestions

If someone is interested in these post-cloud computing models, which one should he/she choose? What should be considered in making a choice? Here we give some suggestions.

If you are interested in improving mobile services, from services providers' viewpoint or from application developer's viewpoint, Cloudlet model is the suitable model for you to work on.

If you are related to IoT research or IoT industry, Fog Computing is the area you should pay attention to. With the development of IoT, huge amount of sensors will be deployed everywhere. The best place for computing powers to process data from these sensors should not be far away cloud servers or low-capacity sensors. Devices such as routers and switches are a better choice.

If you are interested in infrastructure design, such as smart home / smart city, or are interested in cloud offloading for improved efficiency, Edge Computing could be a suitable choice.

If you are interested in the design of novice distributed applications, Dew Computing could bring you with inspirations and architectural assistance. Dew Computing normally does not involve edge devices, such as routers and switches; Dew Computing is not restricted by network topology.

VII. Conclusion

Cloudlet, Fog Computing, Edge Computing, and Dew Computing spire in the post-cloud world. They were proposed to solve different problems. They involve different devices. They have different methodologies. They have only one belief in common: Cloud Computing should not be the only form of computing. The essential differences among them are not in their definitions that claim their coverages because definitions can be easily updated, expanded, and interpreted in different ways. The essential values of these computing models exist in their built-in principles, architectures, styles, and philosophy. Similar to programming languages, although each programming language has full computing power of a Turing Machine, each language has its own style, strength, and characteristics. These computing models will provide different frameworks, paradigms, guidelines, and architectures to researchers and developers in the post-cloud era.

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