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Dew Computing: the Complementary Piece of Cloud Computing

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***Abstract*—Dew computing, as a new paradigm and new research area, is on the horizon. In this paper, we will explore the essence of dew computing, discuss its potentials and challenges. Dew computing brings on-premises computer applications to a level that they are constantly get support from cloud services; dew computing is the future direction of on-premises computer applications. Based on the features and requirements of dew computing, we propose a new kind of computers: dew computers. Although we envision some characteristics of dew computers, the exact features of dew computers need to be further explored and determined. Dew computing is tightly related to cloud computing, and it is the complementary piece of cloud computing.**

1. Introduction

The topic of this paper is about a new research area: dew computing [1] [2]. In this age, we have encountered too many buzzwords. When the new term "dew computing" is presented, people may think it is another buzzword without much sense. Well, whether or not it is a buzzword, the questions we want to ask are: Is this term necessary? Does it bring in anything new?

In this paper, we will discuss the meaning of dew computing and its brief history (Section 2), the application potentials of dew computing (Section 3), the technical challenges brought in by dew computing (Section 4), and the relationship between dew computing and cloud computing (Section 5). Through all these discussions, the readers may get a conclusion about whether dew computing is a buzzword and whether it is worth to keep.

2. What is Dew Computing?

A few authors have discussed dew computing from different angles [1] [2] [3] [4] [5] [6] [7] [8] [9]. Some of these papers have given a definition or a description of dew computing. We will examine these definitions/descriptions and compare them to reveal the consensus features.

Wang [1] [2] proposed dew computing's definition as the following: "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."

Skala et.al. [8] described dew computing in the following sentences: "Dew Computing (DC) goes beyond the concept of a network/storage/service, to a sub-platform - it is based on a micro-service concept in vertically distributed computing hierarchy." "DC pushes the frontiers to computing applications, data, and low level services away from centralized virtual nodes to the end users."

Ristov et. al. [9] discussed the features of dew computing in the following paragraph: "The idea behind the dew computing is using the resources as much as possible before the processing is transferred to the cloud server. It uses the dew computing architecture providing micro services in collaboration with macro services, or dew services in collaboration with cloud services."

We noticed that Wang's definition emphasizes two key features: independence and collaboration; Skala's description emphasizes the position of dew computing components related to other components, and it is roughly equivalent to the independence feature; Ristov et. al.'s description contains both independence and collaboration features, and the expression is almost identical to [2].

The bottom line is that all these three definitions/descriptions do not contradict with each other. Thus, we use Wang's definition in the rest of this paper.

This definition concerns on-premises computers. On-premises computer is a concept that is often used in cloud computing; on-premises computers are equivalent to non-cloud computers. On-premises computers include personal computers (desktops or laptops), tablets, mobile phones, servers, and clusters.

This definition emphasizes two key features: independence and collaboration. *Independence* means the on-premises computer is able to provide functionality without cloud services and an Internet connection. In other words, it means this application is not a completely-online application or cloud service. *Collaboration* means the dew computing application has to automatically exchange information with cloud services during its operation. Such collaboration in-

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cludes synchronization, correlation, or other kinds of interoperation.

To get a clear understanding regarding to the dew computing concept, here we show a few examples. Some of the examples are dew computing applications; some of them are not.

The first example is Dropbox [10]. Files/folders in Dropbox are always available to users regardless if Dropbox servers are available. This satisfies the independence feature. Files/folders are automatically synchronized with Dropbox servers; this satisfies the collaboration feature. Thus, Dropbox is a dew computing application.

The second example is Google Drive [11]. Although Google Drive is very similar to Dropbox, it is not a dew computing application. The reason is that Google Drive does not satisfy the independence feature: a file cannot be opened if Google Drive servers are not available.

The third example is TurboTax [12], Canadian income tax software. This software has a desktop version which can be installed locally, and it is also available online. Apparently the desktop version satisfies the independence feature, but it does not satisfy the collaboration feature because it does not exchange information with the online service. This software is not a dew computing application.

From these examples, we obtained the following observations:

First, dew computing applications are a special group of applications where they satisfy the independence and collaboration features. Not all online applications and dual-available (available locally and online) applications are dew computing applications.

Second, although dew computing is a new term and new concept, applications satisfying dew computing requirements have come to existence for many years. A detailed survey of currently existing dew computing applications can be found in [1].

The word *dew* was associated with computing in an open access paper [3] available online in January 2015; what was proposed in this paper was Web-based and it is equivalent to a dew computing category (WiD category which was explained in [1]). Later, a broader definition of dew computing was proposed [2]. Besides the three definitions and descriptions [1] [8] [9] we introduced earlier in this section, other major works in the dew computing area include some papers related to cloud-dew architecture [4] [5] [7], a scalable distributed computing hierarchy including cloud computing, fog computing, and dew computing [8], and the relationships among cloud computing, fog computing, and dew computing [6].

Now we have discussed the concept of dew computing. The next question we want to ask is: what could dew computing bring to us? In Section 3, we will see what dew computing is able to bring to users. In Section 4, we will see what dew computing is able to bring to technology development.

3. The Application Potentials of Dew Computing

The values of the dew computing concept can be reflected in different ways. In this section, we will show that dew computing, as a new paradigm, may inspire new applications.

Can we propose some new applications that satisfy the definition of dew computing? First, let us consider the dew computing example shown in Section 2: Dropbox. We notice that there are some other dew computing applications that are very similar to Dropbox, such as OneDrive [13], Google Drive Offline [14], and so on. All these applications provide file storage services; they all satisfy the independence and collaboration features. We may use a category to describe all these applications, and call this category Storage in Dew (STiD) [1].

To generalize this idea, we may create other categories in the form of *X in Dew*, where X is a kind of resource or service; the basic meaning of X in Dew is that X somehow has its existence in an on-premises computer and X exchanges information with cloud services. The goal of this paper is not to explore all the possible categories. Detailed discussion about different categories can be found in [1]. Here we only discuss a few categories to show the inspiring power of dew computing.

We start with a category called Web in Dew (WiD). The literal meaning of WiD is that the World Wide Web is put into an on-premises computer. Because this task is impossible, we may want a fraction of the Web be put into an on-premises computer. To realize WiD, we need to install a Web server on the computer, to create Websites on the on-premises computer, to extend domain name mapping to the on-premises computer, and to solve some other technical challenges. We should also remember that WiD is not only to put duplicated Websites on an on-premises computer, but also to make these duplicated Websites collaborate with cloud Websites. All the details of WiD are reflected by the papers about cloud-dew architecture [3] [5] [7]. Figure 1 shows the core idea of cloud-dew architecture, which implements WiD.

WiD makes Web-surfing without an internet connection possible. When there is no internet connection, the user can still access the Websites built-in the on-premises computer. We use an example to show this idea.

Suppose a user attends a party where there is no Internet connection. The user cannot open http://www.facebook.com in his/her browser to show his/her own pictures and find other information. If http://www.facebook.com has adopted the dew computing idea and created a WiD application, the Website would have been duplicated onto the on-premises computer. The duplication is not exactly copying: the duplicated Website does not need to deal with a global heavy load so that it could be much simpler than the Website; the duplicated Website will be implemented using publicly-known technology so that company's secret can be kept; the duplicated Website's database won't be too big because it only has the data related to the user. We may use

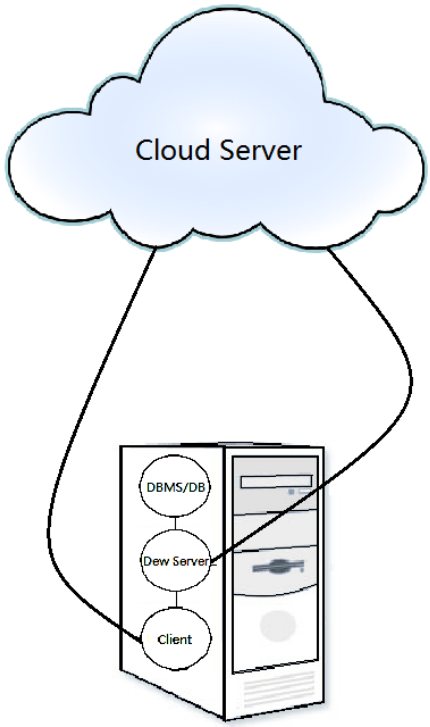

Figure 1. Cloud-dew architecture: A new kind of server, dew server, is introduced. A dew server is a web server that resides on users local computer. The dew server and its related databases have two functions: first, it provides the client with the same services as the cloud server provides; second, it synchronizes dew server databases with cloud server databases.

http://mmm.facebook.com to refer the duplicated Website in the on-premises computer where *mmm* is an indicator that this is a Website in an on-premises computer. When an Internet connection is available, the user can use both the Website http://www.facebook.com and the duplicated Website http://mmm.facebook.com; when an Internet connection is not available, the Website http://www.facebook.com is not available but the user still can use http://mmm.facebook.com to access his/her own pictures and other information or perform necessary updates. These updates will be synchronized with the Website when an internet connection is available again. An on-premises computer may host many duplicated Websites so that some extent of Web-surfing is available when there is no Internet connection.

WiD could be used for various purposes. Internet connections are not always available. Even when Internet connections became available anywhere, there still would be costs and risks related to the Internet connections. Here we skip the applications related to cost reduction, military use, political use, and so on, and only concentrate on one area of WiD application: the Internet of Things (IoT).

Internet of Things (IoT) [15] [16] is a fast-growing research area and application area. From the "things" point of view, there are various technologies such as RFID, NFC and wireless sensor networks (i.e. IEEE 802.15.4, ZigBee, 6LoWPAN, Wireless M-Bus) that can be used to connect them in a network and eventually to the Web. Some of these technologies have already been used in applications. But for us, we are more concerned about the information generated from these "things" and the processing of such information.

Web of Things (WoT) [17] provides an application layer of IoT that will simplify the creation of IoT information processing applications. Although the "things" will generate large amounts of streamed data and these things can communicate and inter-operate with each other automatically, an important requirement is that most of the data should be saved and processed locally. Thus local human interfaces and control centers are needed.

For example, although hundreds or thousands of sensors and devices inside a house are physically connected to IoT, most of the data should be saved and processed inside the house. Only some necessary and permitted data should be sent out from house to the outside world. A human interface or a control center is needed for the users to specify and change the settings and rules. WiD is perfect for such applications: an on-premises computer with a WiD application will be the control center; the users can monitor and control all the devices and sensors inside the house from the Websites residing on the on-premises computer; the on-premises computer will exchange information with cloud servers when necessary and when such communication is permitted by the user. Figure 2 shows a typical scenario where the dew computing architecture is used to organize an IoT system.

Such mechanism can be used in a house, a car, a farm, a warship, and so on. Generally speaking, WiD and its structure, cloud-dew architecture, provide a hierarchical server structure that resembles the hierarchical structure of the world. With the development of IoT and WoT, WiD and cloud-dew architecture will play a role in places where hierarchical server structure is needed.

We also should mention that the roles of dew computing in IoT are different from the roles of fog computing in IoT. Fog computing is a paradigm that extends cloud computing and services to the edge of the network. Similar to cloud, fog provides data, compute, storage, and application services to end-users. The distinguishing fog characteristics are its proximity to end-users, its dense geographical distribution, and its support for mobility [16].

Fog computing may contribute to IoT by making good use of the edge devices of networks. Dew computing may contribute to IoT by making good use of on-premises computers.

After the discussions regarding to WiD, we would like to discuss another category of dew computing: Infrastructure as Dew (IaD).

Infrastructure as Dew (IaD) [1] is a category that is on the opposite direction to Infrastructure as a Service (IaaS) in cloud computing. In IaaS, a (virtual) machine is in a cloud service; in IaD, a (real) machine is an on-premises computer.

If the IaD concept is just an alias of the on-premises computer, we do not need to bring in such a new term. The new feature that IaD brings in is that an on-premises computer is dynamically supported by cloud services. In other words, the data of an on-premises computer should

be dynamically monitored and recorded by cloud services; in case the data on the on-premises computer is lost, we should be able to recover the lost data from cloud services.

IaD can be implemented in different forms. We just discuss one of them: the complete separation of data and device.

An on-premises computer can have all its settings/data saved in cloud services. Such settings/data not only include system settings/data, but also include each applications settings/data. If IaD is fully implemented, data and devices can be completely separated. If a laptop or a cell phone is lost or damaged, the user only needs to get a new device and all the settings/data can be completely recovered to the new device. Currently, some cell phone companies provide backup/restore functions, but not all application settings/data can be restored. With the progress of IaD, such complete restore will become possible.

Above we discussed two dew computing categories, WiD and IaD, and their possible applications. We can find the following two observations:

First, dew computing applications, such as offline Web surfing and complete cell phone recovery, are very attractive applications. They have a special flavor: a truly distributed flavor.

Second, dew computing and its categories are very useful in proposing new applications. Dew computing paradigm brings in a systematic thinking framework of finding new applications according to the independence and collaboration features. With the development of dew computing, there would be many new categories and applications being proposed. The potentials of dew computing is only limited by imagination.

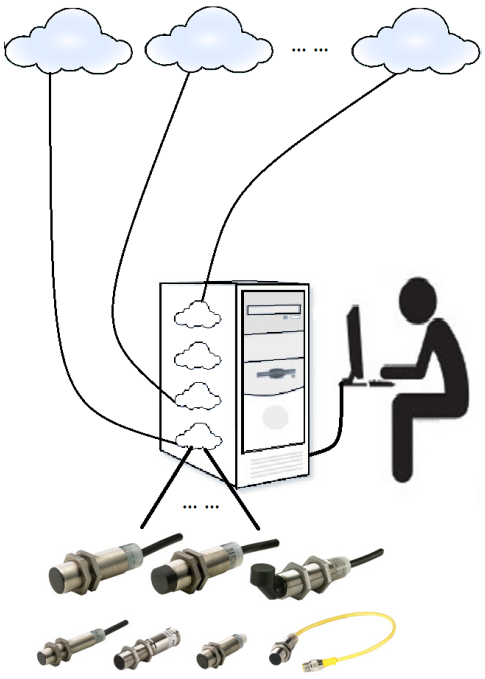

Figure 2. Dew Computing in IoT. The local website created according to dew computing WiD category is used to control devices and sensors. Most data will be kept local. All data communication with the cloud is controlled by the user through the local website in the same manner as operating the cloud control center. Data will be sent to the cloud only when it is necessary and allowed by the user.

4. The Technical Challenges of Dew Computing

Dew computing, as a new paradigm, brings in many technical challenges. These technical challenges cover wide range of areas in computer science, including hardware, operating systems, networks, databases, browsers/servers, and so on. Here we discuss these areas individually.

4.1. Hardware

Dew computing does impose challenges in hardware technologies and computer design. Here we just discuss one issue.

One of the requirements in dew computing is that on-premises computers need to constantly exchange information with cloud services to satisfy the collaboration feature. Such information exchanging should be always taking place, even when users are not operating the computer. Keeping an on-premises computer running 24/7 wastes too much energy. A standby state which is similar to cell phone standby is needed in all kinds of on-premises computers, if they are used in dew computing. The rapid development of Solid-State Drive (SSD) and related technologies may be used to respond to such challenges.

Another hardware issue is related to multi-core processors. In the standby state, it might be necessary to downgrade a multi-core processor to run in a single-core mode.

4.2. Operating Systems

As we discussed earlier, some dew computing applications were developed before the dew computing concept was proposed. With the development of dew computing, more dew computing applications may appear. All these dew computing applications are on top of operating systems. At some stage, it would be a good idea to integrate dew computing mechanism into operating systems.

The efficiency of on-premises computers and related cloud services might be improved if the collaboration feature of dew computing is implemented and managed by the core of an operating system. Dew management could be a core function or extended function of an operating system. A dew server and other dew computing components could be part of an operating system in the similar way as that an IIS (Internet Information Services) server is part of a Windows system.

4.3. Networks

Currently, each dew computing application uses its own proprietary way to implement the collaboration feature; each

application's implementation contains all the functions from user interface to communications. If a few dew computing applications are running in an on-premises computer, this approach may still work. In the future, when many dew computing applications are running in one on-premises computer, it is quite possible that these applications conflict with each other regarding to communication ports and other resources. Even if no conflict among the applications happened, it is not an efficient way because redundant code exists in all the applications.

It is necessary to have a new communication protocol for information transfer between dew computing applications and cloud services. Such a protocol is part of the fundamental infrastructure of dew computing.

4.4. Databases

As [1] points out, all dew computing categories have one common feature: some forms of data exist in an on-premises computer and are automatically synchronized with cloud services. Data and databases are key elements in dew computing. Although databases technology is mature, some challenges exist when databases are used in dew computing applications.

In dew computing environment, many server-side technologies are migrated from servers to on-premises computers. Servers are in a tightly-controlled environment, but on-premises computers are in a much more complicated environment. What was not a security issue in a server could become a security issue in a dew computing application. For example, in a server, it is quite safe for a code file to contain a database's user credentials because the server's access is highly controlled; while in a dew computing application, it is not safe anymore for a code file to contain such credentials because of many reasons: malicious software on the same on-premises computer, users mistakes, and so on.

Database security issues should be dealt with from different angles if these databases are planned to be used in dew computing applications.

4.5. Browsers and Servers

Browsers are designed to retrieve and display Hypertext from the Internet; Web servers are designed to supply Hypertext to the Internet. In dew computing WiD category, browsers are used to retrieve and display Hypertext from on-premises computers; Web servers are used to supply Hypertext to the same on-premises computer.

Web servers work well in WiD environment, but browsers can only accomplish WiD tasks with the help of some special techniques [3] [7]. This is because we want users to have a similar URL experience in WiD as in the Internet so that we proposed a mechanism called Local Domain Name System (LDNS) [3].

The current solution to implement LDNS is temporary and less than ideal. A seamless solution is to redesign browsers with WiD requirements in mind.

While we hope browsers be redesigned to cover LDNS functions, another side of the challenges is to redesign lightweighted browsers and servers for WiD purposes. In a WiD environment, both the server and the browser are inside the same computer; it is possible to redesign the server and the browser so that they are much simpler and use much less system resources.

4.6. Dew Computers

From Section 4.1 to Section 4.5, we can see that dew computing brings in technical challenges to on-premises computers on all aspects of system organization. Traditional computer system organization has to be changed to brace the challenges from dew computing. A new kind of computers is on the horizon. This new kind of computers can be called dew-ready computers or simply *dew computers*. The exact features of dew computers are still not clear, but the following characteristics are what we can imagine in a dew computer:

- It has a standby mode to exchange information with cloud services on 24/7 basis using low energy cost technologies.
- Its operating system supports dew computing.
- It has a unified network framework/protocol to perform collaboration operations.
- Its databases are specially managed to deal with security issues.
- Its browsers supports WiD applications.

5. The Roles of Dew Computing

From Section 3 and Section 4, we can see that dew computing can inspire new applications and promote technology development; dew computing brings in new content to computer science and new applications to users. Dew computing does have its values. We are able to say that dew computing is a new promising research area instead of a useless buzzword.

After examining the values of dew computing and its potentials, we may want to step back to find out the position of dew computing in the big picture and, especially, the relationship between cloud computing and dew computing.

In considering the relationship between dew computing and computer applications, dew computing promotes that all on-premises computer applications get support from cloud services, if possible. Without dew computing, on-premises computer applications will remain as isolated pieces. Thus dew computing is the future direction of on-premises computer applications.

In considering the relationship between cloud computing and dew computing, we can generalize the following points:

First, dew computing is tightly related to cloud computing. The definition of dew computing shows that dew computing is based on cloud computing. Without cloud computing, there would be no dew computing.

Second, dew computing is not part of cloud computing. The scope of dew computing is beyond the scope of cloud computing. Dew computing covers on-premises computers, which are not covered by cloud computing. Although cloud computing will become more and more popular, users will always use on-premises computers.

Third, dew computing is helpful in realizing the potentials of cloud computing. Dew computing promotes that, if possible, every application should use cloud services somehow. With dew computing, cloud computing can reach its greatest popularity.

To summarize the above points, dew computing is the complementary piece of cloud computing.

6. Conclusions

In this paper, we discussed various aspects of dew computing. Dew computing is an on-premises computer software-hardware organization paradigm in the cloud computing environment. Dew computing emphasizes two key features: independence and collaboration. Dew computing and its categories are very useful in inspiring new attractive applications. Dew computing, as a new paradigm, brings in many technical challenges. These technical challenges cover wide ranged of areas in computer science, including hardware, operating systems, networks, databases, browsers/servers, and so on. Dew computing brings on-premises computer applications to a level that they are constantly get support from cloud services; dew computing is the future direction of on-premises computer applications.

Based on the features and requirements of dew computing, we proposed a new kind of computers: dew computers. Although we envisioned some characteristics of dew computers, the exact features of dew computers need to be further explored and determined.

Dew computing is tightly related to cloud computing; dew computing is not part of cloud computing; dew computing is helpful in realizing the potentials of cloud computing. To summarize, dew computing is the complementary piece of cloud computing.

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