Fog Computing

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Fog computing provides an effective solution to various problems by extending the cloud's functionality to typically more limited computing units closer to user devices. Fog computing can provide a higher level of user experience due to its geographic and network topology location and distribution. IoT services also need to be managed seamlessly to ensure adequate QoS (due to the mobility of devices or the temporary periods without an internet connection). Such domains are combined under the auspices of Dew computing, as in critical cases, extending an IoT service to the end user's device is a feasible task. Such scenarios can hardly be investigated at a large scale due to the lack of dedicated simulation environments.

Dew computing fog computing Internet of Things Rainbow service

1. Introduction

The number of smart devices connected to the internet has grown exponentially in the last decade, driven by rapid technological advances and ever-increasing user demand. According to Cisco's annual internet report (visited on 15 May 2022): https://www.cisco.com/c/en/us/solutions/collateral/executive-perspectives/annual-internet-report/white-paper-c11-741490.html), by 2023, the number of mobile devices will reach 13.1 billion globally, of which, 1.4 billion devices will have 5G capabilities. The large amounts of data generated by these devices significantly burden traditional cloud computing-based networks; therefore, various distributed and decentralized network paradigms have gained ground. Fog computing complements previous cloud technology by bringing services closer to the users.

Compared to the traditional cloud model, the fog model is more supportive of mobile data processing, as it is more efficient in maintaining minimal latency and predictable response times. Services that process short life-cycle data streams are typically deployed to computing units located at the edge of the network. In the fog model [1], the units are limited in terms of resources, but any device may act as a fog node, which is able to communicate over the network and has storage and computing capacity. This distributed model also provides the possibility to use virtualized units.

Distributed models are intensively researched due to the emergence of the Internet of Things (IoT) and 5G technology. Cloud computing and its complementary models have major roles in the development of IoT applications, especially in storing data and processing related tasks with low latency requirements or deadline constraints.

Although the fog model resolves the problems induced by the volume and diversity of IoT data, mobile data processing is not a trivial task. Data center coverage is limited; due to the long distances covered by the movements of mobile devices, the data to be processed potentially need several network hops to reach their destinations. Furthermore, increased latencies and unpredictable response times degrade the quality of service (QoS). One possible way to reduce the negative impact, as much as possible, is to dynamically migrate the IoT services to a more optimal (preferably closer) location. Movement-induced service migration is a challenging problem that needs to be addressed from many different angles. For example, the distance between the device and the node (both physical and network distance), the size of the service to be migrated, the available bandwidth, or the current load on the destination node.

Cloud-influenced domains, such as fog, edge, and mobile edge computing [2], are often utilized to outsource cloud computing features and services to the perimeters of mobile networks. Such complex networks strongly rely on (typically the internet) connections; therefore, another novel paradigm was introduced, namely Dew computing, to deal with the lack of internet access. Dew computing compounds the basic capabilities of end devices and the cloud model. In this area, IoT data can be discovered, processed, and stored locally in the case of offline modes. When a network connection is established, the end devices may initiate synchronization with the fog and cloud services. With the Dew concept, various challenges arise, such as resource and network utilization, limited storage, and energy consumption [3].

The concept of Dew computing can be applied to various domains [4], such as air transportation systems, including flying objects (meteorological drones, airplanes and so on), healthcare systems aimed at real-time monitoring of patients and interactions with doctors, smart manufacturing focusing on Industry 4.0, and traffic control relying on distributed surveillance systems.

2. Dew Computing

The relatively recent expansion of the use of processing units in a vast majority of technical products, including home and office control and appliances, industrial equipment, traffic control (earth, sea, and sky), vehicles, lighting, personal data collecting/processing wearables (e.g. health and sports-oriented) and so on, including mobile computing, storage, sensing, and communication integrated personal devices (so-called “smartphones”) and home computers have led to the necessity to expand the paradigmatic structure of cloud and fog computing with a low-level paradigmatic layer, the Dew computing layer [5][6][7], enabling seamless inclusion of the mentioned (very heterogeneous) types of processing units into the Dew-Fog-Cloud vertical hierarchy until Rainbow global service ecosystem) [8][9].

The major distinction between the equipment in the cloud/fog/edge areas of the hierarchy and the Dew computing area is that the equipment in the cloud/fog/edge areas are primarily dedicated to general tasks involving computations and communications, and are integral parts of the internet. The Internet of Things (IoT) is a natural extension of the internet and presupposes that “Things” will communicate through (and be a part of) the internet. However, regarding all of the equipment that was mentioned, they have one important thing in common: they have to be self-standing, self-sufficient systems, i.e., they must perform their functions completely independent of any connections with other equipment or systems. Hereby, it is defined that the self-sufficient system as an independent system of components that can perform its intended functions without any external communication/processing needs (for example a car, a washing machine, a traffic lights system and so on). All of that equipment is outside of the edge of the internet, including mobile devices and personal computers. However, it can be very beneficial if such equipment could be ’coordinated’, and cooperate with cloud and/or fog services whenever an internet connection is established. However, it must be noted that non-internet connectivity is also a major aspect at present and there will be an increasing amount of future equipment (LAN and ad hoc radio/wire/optical connections).

Therefore, at the layer of Dew computing, it is possible to solve the large diversity of communication and information/services. Herein, how to model such tasks in a state-of-the-art simulator called DISSECT-CF-Fog was exemplified. In the next subsection, an overview of Dew modeling possibilities in the simulation field will be provided .

3. Simulation Approaches

Investigating and maintaining IoT-Fog-Cloud systems in the real-world could be extremely expensive due to the financial expenses of IoT devices and cloud services. Furthermore, examining various scheduling and offloading algorithms may be time- and energy-consuming. Simulation approaches have become acceptable solutions for such purposes among researchers because they mimic existing systems in realistic manners. They ensure cost-efficient and scalable environments to test and validate new procedures and algorithms, in which results can be used for further modification of the real system.

One of the most well-known simulators dedicated to modeling the cooperation of IoT and fog computing is called iFogSim [10], which extends the functionality of CloudSim toward fog computing. With the latest version, device mobility can be simulated, which attracts the need for application service migration as well, because the positions of the end devices change frequently. This can cause increased response times and the required QoS cannot be guaranteed without migrating services to a more suitable provider. Furthermore, fog node clustering and microservice orchestration of application services are also part of the upgraded system. The literature may refer to this extension as iFogSim2.

MobFogSim [11] is derived from the original version of iFogSim, supporting user (i.e., device) migration to minimize access delay by triggering the handover of user devices between computing nodes. Mobility may require migration solutions for VMs and containers to mitigate increasing latency and improve QoS. IoTSim-Edge [12], similar to iFogSim, is built upon CloudSim, and it extends its capabilities with IoT-related behavior, including IoT data generation, battery drainage simulation, local and remote IoT data processing, as well as device mobility. EdgeCloudSim [13] relies on CloudSim as well; therefore, it inherited the functionalities of the core simulator. However, it has a new CPU utilization model, device mobility, and edge orchestrator.

To the best of the knowledge, DewSim [14] is currently the only simulator that models a Dew computing environment directly. It mainly focuses on simulating mobile device clusters, of which, members are considered the primary computing resource providers. Trace-based battery simulation is also available in the simulator in order to model battery drainage realistically. With different job allocation strategies, jobs are only distributed among battery-dependent devices; moreover, non-battery-dependent devices and detailed physical infrastructure management are not considered at all. P. Sanabria et al. [15] introduced an extended version of DewSim, which supports simulating hybrid Dew/edge environments, including non-battery-dependent devices; however, the management of the computing infrastructure is still missing.

DISSECT-CF-Fog [16] deals with a detailed IaaS model, including physical and virtual machines, storage, and data center network properties, among others. In general, its components are split into two main parts, physical and virtual layers. The physical parameters describe the physical capabilities of the fog and cloud nodes. The fog extension also provides a comprehensive IoT layer representation, where IoT physical layer components (sensors and actuators) can be represented, and smart devices with different properties can be modeled. In the virtual layer, IoT applications running on the computing node are responsible for processing data. This layer also considers the energy consumption of the entities, IoT device mobility, and pricing schemes of real providers.

The simulators are presented in **Table 1**, where it is denoted that the domains (IoT, edge/Dew computing and fog/cloud computing) and the functionalities available in the tools. According to the preliminary analysis and previous studies [16][17] (which showed that DISSECT-CF-Fog is more scalable, reliable, and faster than iFogSim), herein, DISSECT-CF-Fog is chosen to extend towards IoT-Dew-Fog systems by modeling Dew computing.

Table 1. Summary of the related simulation approaches (√ means the simulator contains that functionality).

Simulators	Internet of Things			Edge/Dew Computing	Fog/Cloud Computing	
-	IoT Devices	Battery/Energy Consumption	Mobility	-	IaaS	Migration
iFogSim	√	√	√	X	√	√
MobFogSim	√	√	√	X	√	√
IoTSim-Edge	√	√	√	√	√	X
EdgeCloudSim	√	√	√	√	√	X
DewSim	√	√	X	√	X	X
DISSECT-CF-Fog	√	√	√	√	√	√

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