2018 IEEE International Conference on Smart Cloud

Smart Virtualization for IoT

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***Abstract*—Nowadays, the cloud hosts the majority of IoT virtualizations. This approach depends on an active Internet connection. The question that emerges is how we can move those virtualizations to the edge of IoT networks without losing the power and flexibility from the cloud but fulfilling the requirements of constrained and pervasive environments. This research presents an architecture that integrates dew computing to provision virtual resources at the edge level. This architecture proposes smart virtual resources deployed towards edge devices to provide data views and IoT services to users. This approach goes beyond traditional IoT virtualizations and builds distributed virtual systems that include the benefits of the cloud, fog, and dew computing to provide services directly at the edge level.**

Keywords—internet of things, dew computing, cloud computing, fog computing, edge computing, smart virtualization, software-defined component, blockchain.

I. Introduction

According to Canellos D. [1], the challenges and innovations in IoT do not emerge from IoT networks separately. They will emerge from the integration of IoT with cloud computing. Until now, the integration between IoT and the cloud only represents the provisioning of data, in which data flows from sensors to services in the cloud (e.g.: [2]). These systems use the virtually unlimited computational and storage capabilities from the cloud [3].

The rapid scalability of IoT networks makes it difficult to implement cloud services that interact with the IoT infrastructure because of the high latency and bandwidth consumption, and the heterogeneity of devices. Also, the centralized architecture of the cloud might not be able to handle the velocity of data generated by sensors in real time [4]. Thus, it becomes necessary to implement an architecture that allows the execution of richer services and virtualizations close to the IoT infrastructure without losing the computing capabilities from the cloud but avoiding high latency and bandwidth consumption, and deficient performance.

This research proposes an architecture that includes dew computing [5] to provide smart virtualizations of IoT resources at the edge level. These virtual resources become smart as they can communicate with the cloud, fog, and dew level when needed. Also, smart virtual resources can provide services directly to users, integrating resources from the cloud, fog or dew, such as data processing, data storage, configuration scripts and blockchain. By doing this, we enhance the capabilities of the edge level. Smart virtual resources can directly handle requests from third parties efficiently, and the cloud or fog layer is strictly accessed when needed. The proposed architecture enables the provisioning of virtual resources and services without depending on an Internet connection.

The remainder of the paper is structured as follows. Section 2 presents an introduction of cloud services for IoT virtualization. Section 3 presents an introduction of virtualization at the edge of IoT networks. In section 4, we explain the architecture for smart virtualization in IoT. Finally, section 5 presents conclusions and future work.

II. Cloud Services for IoT Virtualization

Even though cloud computing [6] and IoT [7] are two paradigms that emerged separately to face different requirements, both are considered complementary technologies to build a flexible deployment environment for IoT systems.

While IoT works in the real environment and lacks computational capabilities, cloud computing provides access to virtualized and scalable services over the Internet [18]. The cloud benefits IoT in the following aspects [8][9], efficient use of resources, the orchestration of resources, on-demand self-service, broad network access, resource pooling, rapid deployment and elasticity, and planned services.

Although the cloud represents a robust and reliable architecture for IoT computation offloading and virtualization (e.g. [10]), its consolidated power might not be efficient to handle the velocity of data flow produced by sensors [4]. Additionally, the significant latency restricts the direct access to IoT components and might affect the decision-making over data [8]. Thus, it might be more efficient to provide IoT services at the edge of sensors [11].

III. Virtualization at the Edge of IoT Networks

A. Fog Computing for IoT Virtualization

Fog Computing moves the features of the cloud toward the edge of networks [8]. A fog layer benefits IoT in the following aspects [8][12]: location awareness rather than location ignorance typical of cloud computing, geographical distribution of a vast number of nodes rather than centralized clusters, wireless mobility rather than static nodes, real-time things engagement rather than streaming/batch processes, resource heterogeneity rather than one static model.

978-1-5386-8000-1/18/$31.00 ©2018 IEEE
DOI 10.1109/SmartCloud.2018.00028

Some researches have integrated a fog layer to the IoT architecture. For instance, Aazam and Huh [13] introduce a fog "Smart Gateway," which processes data in real time and enhance the communication and service provisioning in the cloud. However, this kind of fog implementation works as a bridge to move processed data to the cloud. They do not consume resources from the cloud to provide services at the edge of IoT networks.

B. Dew Computing for IoT Virtualization

Dew computing was initially proposed to handle the availability of websites without requiring an active Internet connection [5]. The main idea of dew computing is to transform a local node into a dew server that handles the same data and services hosted in the cloud but for one local user [14].

The distribution of data and services for local users that the dew computing foundation provides can be applied to IoT networks. For this research, instead of having a copy of a website, an IoT dew server would have a copy of the configuration of virtual systems and data that can be replicated towards edge devices at any time.

IV. Proposed Architecture

Nowadays, the computing capabilities of edge devices make it possible to virtualize systems at the edge of IoT networks and even store configuration scripts and some data.

We propose an architecture in which dew servers manage the data and the provisioning of virtual systems towards edge devices. In this architecture, the three layers (sensor, fog and cloud) collaborate to provide efficient IoT services at the edge level. This architecture achieves two goals. First, avoiding the provisioning of virtual resources through the cloud as a front-end but the dew servers. Second, providing data processing services and data views directly from edge devices hosting virtual systems.

Unlike traditional dew computing implementations, dew servers proposed by this research do not serve a local user but a group of edge devices. Additionally, dew servers do not provide web services but services to configure and deploy virtual systems towards a specific group of edge devices. Finally, the proposed dew servers can interact with services in the fog and cloud to satisfy the requests received.

Figure 1 shows the overall architecture proposed by this research. This architecture implements a 1:N relationship [14] between a dew server and edge devices. Edge devices are represented as turtles as their limited computing might be compared to the slow behaviour of turtles, however, inside the shell, they can execute some well-designed services and still have satisfactory performance. To fulfill the two goals explained before, each dew server implements three components: edge client service, configuration scripts, and database.

The edge client service enables interaction with virtual resources. It enables individual data for each virtual resource separately. The configuration scripts manage the configuration of the virtual resources deployed towards the edge devices. For instance, a script that specifies the sensors or actuators that work with each edge device. The database stores replicas of specific data required to exclusively fulfil the requirements of the virtual resources hosted on a group of edge devices. The entire database might be hosted in the fog or the cloud.

Dew servers do not provide any IoT data service to third parties or final users. They act as a backup of the configuration of virtual resources deployed on edge devices.

Edge devices are the ones that provide IoT services and data views to different users through the smart virtual system deployed on them. This approach allows moving virtual resources from one edge device to another, which eliminates the physical limitations at the edge level

Depending on the computing capabilities of edge devices, they might become edge dew servers. Edge dew servers have two components, the configuration of views and a key/value storage. If it is not possible, all that data will be provided by dew servers as well.

If an edge component fails, the virtual resources hosted on it can be deployed again on another edge device by reading the data and executing scripts from the dew server. In the same manner, if a dew server fails, it can be replicated by reading data and executing scripts from the cloud or fog.

As we have a replica of the virtual system on dew servers, the propagation of virtual resources without internet access becomes a reality. This approach improves the performance of IoT networks. If there is no communication with dew servers, then virtual resources access the fog. Finally, if there is no communication with the fog, virtual resources access the cloud.

A. Smart Virtual Resources

A definition of virtual resources for IoT management has been presented in our previous study [15]. That study focuses on virtualizing physical components, not systems.

This research defines a virtual resource as a software-defined component [16] that becomes smart as they can communicate with the cloud, fog, dew and sensor layers dynamically, and store data locally to improve performance and reduce latency. Smart virtual resources can collaborate between each other to offer a virtual system.

Our definition of a smart virtual resource has four components. First, a REST API to enable access to functionalities and data synchronization [17]. Second, a key/value local storage to keep recent data in memory, be the first searching point when users request data and work with a fog storage to offload data. Third, a communication component that manages the communication between the cloud, fog, dew, sensors, and between virtual resources. It might include different communication protocols such as HTML, MQTT [18], or CoAP [19] to expose constrained components [20][21]. Finally, a network component that handles the matching of the protocol topologies, for instance, bluetooth low energy (BLE) and Wi-Fi.

A smart virtual resource can have some replicas that can be called to work at any time. These replicas are asleep until they are needed. For instance, when a virtual resource that manages data views and queries is saturated, its replicas are awakened, and requests are redirected to them. This approach would give some elasticity at the edge level.

Smart virtual resources improve portability of services and communication between the layers of the proposed architecture.

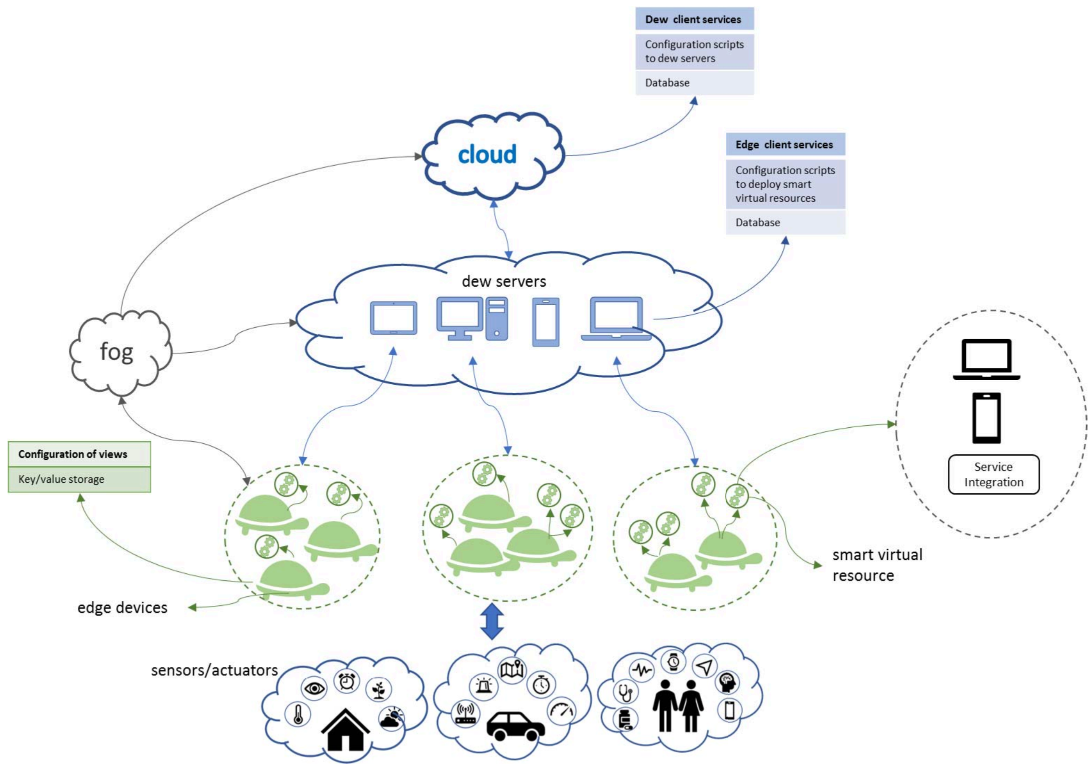

Fig. 1. Architecture to deploy smart virtual resources towards edge devices through dew servers.

B. *Security at the edge level*

As no central gateway or router faces third-party requests, edge devices are likely to be easily corrupted. We must implement access control policies to guarantee secure access and reliable data and operations at the edge level. We cannot go back to centralized solutions (e.g.: [13][22]) as this research proposes a distributed architecture that fits the characteristics and requirements of IoT networks [23].

An option that might fit the characteristics of IoT networks could be blockchain protocols [24]. The integration of blockchain features (immutability, consensus, smart contracts, and distributed database) [25] to the IoT architecture would contribute to achieving reliability and security at the edge level.

Blockchain protocols at the fog layer have been studied in our previous work, [26][27] [28]. These studies highlight the database and provenance features of permission-based blockchain protocols to handle the configuration of devices. The results obtained from experiments show satisfactory performance of the permission-based blockchain protocol Multichain deployed in a fog network. To use blockchain services at the edge of IoT networks, we can integrate blockchain client API's to the smart ecosystem as virtual resources whose configurations are stored by dew servers. This approach would make the IoT infrastructure more dynamic regarding service management as smart virtual resources can work as plug/unplug artifacts.

Also, in our previous studies, we have used blockchain as a mechanism to distribute software-defined components towards the edge network to support multitenancy and some AI features [29][30]. Thus, we have made the constrained network more autonomous. The flexibility of resources from the cloud and the decentralized architecture of blockchain protocols might be a valid combination to provide reliable provisioning of virtual systems in IoT and secure access to data.

V. Conclusions

This research presented an architecture that implements dew servers to provision virtual resources towards specific groups of edge devices. This architecture integrates smart virtual resources at the edge level to provide IoT services and data views directly from edge devices. Also, a permission-based blockchain protocol is integrated to achieve security and reliability on edge networks.

The architecture presented in this work has been designed based on the characteristics of each suggested technology and the results of previous evaluations of those technologies.

Dew computing can be implemented in different areas such as new models of data analysis [31].

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