Fog-Enabled Smart Campus: Architecture and Challenges

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Abstract. In recent years, much attention has been paid on the design and realization of smart campus, which is a miniature smart city paradigm consisting of its unique infrastructures, facilities, and services. Realizing the full vision of smart campus needs an instrumented, interconnected, and intelligent cyber physical system leveraging ICTs and physical infrastructures in the campus. Moreover, the study of a smart campus could pave a way for studying smart cities. In a smart campus, heterogeneous big data is continuously generated by the different functional sensing devices. This poses great challenges on the computation, transmission, storage, and energy consumption of traditional sensor-to-cloud continuum, which typically incurs huge amount of network transmission, high energy consumption, and long (sometimes intolerable) processing delay. Based on these observations, we propose a fog-enabled smart campus to enhance the real-time service provisioning. An architecture of smart campus is put forward, in which multiple fog nodes are deployed to guarantee the real-time performance of services and applications by performing tasks at the network edge. Furthermore, a lot of open research issues regarding to this architecture are discussed in hope to inspire to expand more research activities in this field.

Keywords: Smart campus · Fog computing · Architecture · Internet of Things

1 Introduction

1.1 A Subsection Sample

Sensor-cloud (SC), i.e. the sensor-to-cloud continuum, has received increasing attention recently, which integrates WSN and Cloud Computing and aims to enable the processing of sensed data with a variety of types in the remote cloud centers [1, 2]. The development of Internet of Things (IoT) and the Information and Communication Technology (ICT) help accelerate the development of Sensor-cloud. IoT defines a new connection paradigm, where people and things can connect and communicate at anytime, in anyplace, and with anything as well as anyone, ideally using any network and any services [3]. The development of IoT gives rise to great changes in the Information

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and Communication Technology (ICT), which can provide services to greatly promote the living standards of urban residents. As an application of SC, the concept of smart cites was proposed by different researchers in the past few years, which utilizes ICT as well as physical infrastructures (e.g., IoT devices and sensors) to fulfill the vision of an instrumented, interconnected, and intelligent city [4, 5].

Smart cities include many areas, such as smart homes, smart vehicles, smart campuses, smart factories, and smart offices. Of all these areas, the idea of smart campuses is the most similar to that of smart cities because in essence a smart campus is a relatively smaller ecosystem of a smart city in terms of population and engaged activities. Many researchers who study smart cities starts with smart campuses, since the smart campus research can directly apply to other territorial initiatives, such as smart cities and smart factories. On the other hand, smart campuses also have their own characteristics. For instance, the actors are mainly students, teachers and office staffs, and the engaged activities are mainly teaching activities. To the best of our knowledge, there is still no a widely accepted definition of smart campuses, but as far as we are concerned, the smart campus can be described as follows: As a small-scale, but self-contained model of a smart city, a smart campus aims to provide intelligent, humanized, convenient services for students, teachers and staffs with daily activities in a campus community via ICT and physical infrastructures.

Note that the activities facilitated by services delivered by a smart campus are not restricted to academic aspects, other nonacademic activities, such as smart parking, smart grid management, and smart alarm systems, are also involved. All these intelligent services cannot be realized without the use of IoT devices/sensors which collect and transmit data for further processing and analysis.

The amount of data generated from time to time by these sensing devices is significantly large (e.g., the surveillance cameras), which poses issues such as the costs on latency, storage, and energy consumption for communication. SC cannot guarantee the efficiency when coping with these big data, especially for some latency-sensitive services/applications (e.g., real-time incidents warnings) [6]. Based on these observations, we in this paper propose a fog computing based architecture of a smart campus with regards to service provisioning and application management.

Fog computing paradigm, also known as edge computing, is considered as one of the key enablers of IoT and big data applications [7, 8]. It brings computation and storage resources to the edge of a network, enabling the execution of highly demanding applications while meeting strict delay requirements. It usually acts as an intermediate layer between cloud data centers and IoT devices/sensors; it brings cloud-based services closer to IoT devices [9]. Thus, data can be processed in real-time and the efficiency of service provisioning can be guaranteed.

2 Related Works

Since an amount of the similarity exists between a smart city and a smart campus, we in this section review some existing works about smart campuses as well as smart cities. A smart campus offers an integrated, comfortable, intelligent environment for working, study and living via ICTs, IoT, mobile internet, and cloud computing. A smart campus involves many subareas such as smart parking, smart building, smart teaching, smart learning, and smart energy grid [10–12]. We in this section mainly focus on the architecture design and techniques to implement a smart campus as well as a smart city. A number of papers paid attention to the concept of a smart city and a smart campus and proposed the corresponding architectures as well as the domain applications [13–16]. Since huge quantity of data is generated continuously in a smart city and green city, how to manage these big data is crucial to the fulfillment of a smart city. Wei et al. have applied ant colony optimization for the task scheduling optimization problem in the mobile cloud computing scenarios [13].

Perera et al. have surveyed the application of fog computing in smart cities, and reviewed existing approaches proposed to tackle challenges in fog computing domain [3]. In addition, they identified major functionalities that fog computing platform can support, with the purpose of shedding light on further directions on fog computing based smart cities. Newaz et al. have proposed a web-based energy cloud platform framework for analyzing energy consumption behavior of campus environment, and predicting energy demand in the future [17].

To improve the educational environment and the comprehensive management level of universities, Bi et al. have constructed a smart campus system based on Building Information Modeling and 3D Geographic Information System platform [18]. A 3D visualization campus information system called "smart campus" was constructed, which provides feasible solutions for constructing smart campus. Bates et al. have discussed big data in the smart city by a case study which uses the existing IoT infrastructure to create a campus-scale "living laboratory." This kind of living laboratory can promote energy savings [19]. Atif et al. have constructed a ubiquitous learning model in the context of a pervasive smart campus [20]. They defined a model of a smart campus, and advocated learning practices in the light of new paradigms such as context-awareness, ubiquitous learning, and pervasive environment. A progress report about China's smart city is given in [21]. Liu et al. have constructed an architecture of China's smart city with four layers, i.e., sensing layer, transmission layer, processing layer and application layer, respectively.

For latency-sensitive tasks and applications, a cloud computing based smart campus does not provide a satisfactory solution due to the latency related tasks/applications uploading. To the best of our knowledge, very few work that brings fog computing into the smart campus research. In this paper we propose a fog computing-based architecture of a smart campus, where some time-critical tasks/applications can be deployed and utilized efficiently in a smart campus.

3 Architecture

In a smart campus, various types of data are collected by sensors employed widely all the time. The large volumes of data are then processed and analyzed, with the purpose of benefiting teachers and students in both daily teaching and leisure activities. For some latency-sensitive services in smart campuses, the response time of data processing in campus cloud data center may not be fast enough due to the limited bandwidth and many concurrent accesses to the cloud center. Therefore, fog computing, as an intermediate layer in between cloud data centers and IoT devices, is introduced to facilitate data collection, processing and analysis so that time-sensitive services can be performed in real-time.

3.1 Fog Computing in Smart Campus

To illustrate the application of fog computing in a smart campus, an example is presented in Fig. 1. While in reality, varieties of smart devices with computational capabilities deployed at the edge of network (e.g., gateways, routers) can serve as fog nodes, we recommend those special servers with appropriate computational capabilities as fog nodes in this paper. This is because services with different goals usually have different requirements for fog nodes in terms of computational and storage capabilities.

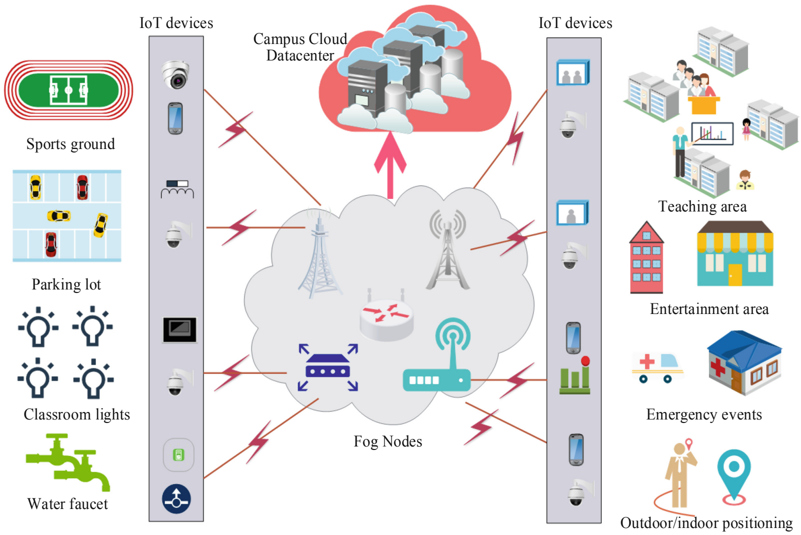

Fig. 1. An example of applying fog computing based smart campus.

In Fig. 1, we list enumerate eight typical application scenarios where fog computing is employed for decision making. For instance, from the view point of energy savings in a smart campus, lights in classrooms should be controlled automatically– they can be turned off automatically when classrooms are empty. This is an essential part of functionalities which a smart building is supposed to have. Another interesting observation is that sometimes classrooms are not empty, but occupied by only a few students studying. In such case, the power consumption is still not negligible. Interestingly, this case has been becoming the main cause of unnecessary electricity wastes compared to the former case for most universities in China. However, with fog computing introduced in smart campus, we can avoid this situation and greatly reduce unnecessary power consumption. For instance, the fog nodes gather the information collected by various sensors such as surveillance cameras in each classroom and analyze it with suitable algorithms to decide which classroom(s) the lights should be turned off. Then students in the classroom with lights being turned off can be guided to specific classrooms with lights on. Thus, the power consumption can be reduced to a great extent. In essence, this student reallocation problem is a special 0/1 multiple knapsack problem, and it is known that this combinatorial optimization problem is NP-hard.

Similarly, fog computing can also be used to control the air condition in each classroom based on temperature and the humidity of a classroom detected by sensors. By doing this, the carbon dioxide emission can be reduced and thus meaningful steps can be taken for environment protection, which at the same is also aligned with the major purpose of applying campus smart grid. In addition, in emergency events like car collision or persons injured in sports facilities, the fog nodes can start an emergency preplan and sometimes initiate direct communication with the campus rescue center for further assistance.

Due to space limitation, we do not dwell on other applications one by one here. However, in the section of case studies, we study three scenarios in more details to underline the necessity of applying fog computing to smart campus.

3.2 Architecture Design in Smart Campus

Figure 2 presents an architecture of fog computing based smart campus proposed in this paper, which consists of four layers – cyber physical layer, data management layer, data processing layer, and domain application layer. Note that we separate data processing and data management for the sake of information sharing and resource reuse.

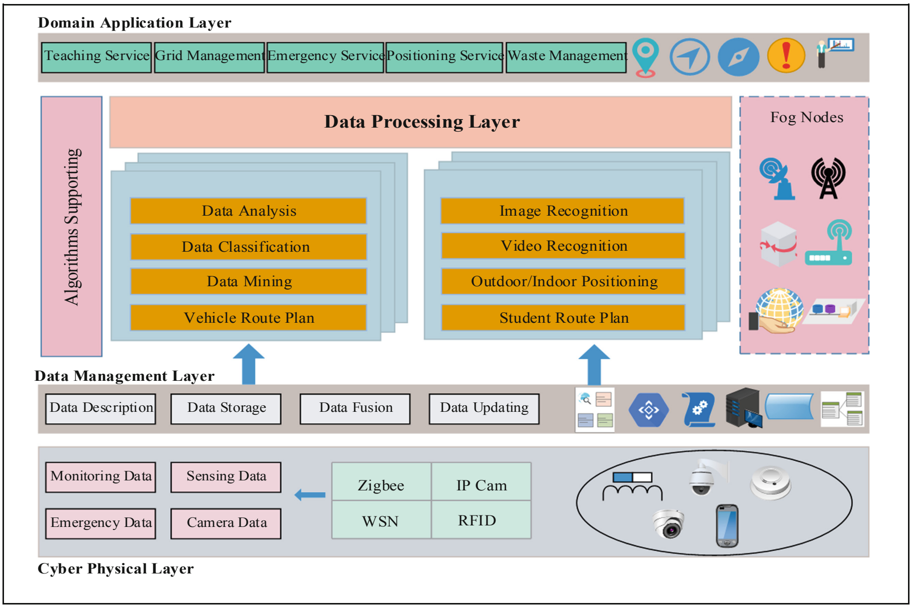

Fig. 2. The architecture of fog computing based smart campus proposition.

Cyber Physical Layer. In a smart campus, various types of information can be leveraged to improve the teaching and study environments and the living environments with the help of ICT and physical infrastructure. The cyber physical layer is composed by a densely distributed ecosystem which covers various sensors. Thus data from multiple sources can be sensed and collected, e.g., by surveillance cameras, GPS, RFID tags, etc. The core technology in the cyber physical layer is IoT, which enables direct interactions among various entities (e.g., sensors, routers, gateways).

Data Management Layer. Enormous amount of information is continuously collected by the cyber physical layer. To make data processing more efficient in the next stages, we add an intermediate layer called data management layer in between the cyber physical layer and the data processing layer. Data management layer is responsible for data preprocessing such as data description, data fusion. The same event can be captured by sensors of different types while data from different sensors usually have a variety of formats. Thus, redundancy of data may exist when storing them. To manage data efficiently, it is necessary to process the sensed data in advance, such as redundancy removing. In addition, data fusion is also an essential part in data management layer, which integrates data from multiple sources to provide much more consistent, accurate and meaningful information than that provided by any individual data source.

Data Processing Layer. Data processing layer is the core of the fog computing based architecture in a smart campus; it integrates the application of fog computing and remote campus cloud data centers. This layer is in charge of processing the sensed data of different types via fog computing. Many time-sensitive services and tasks can be processed in this layer. Typical tasks include vehicle route planning and student route planning which requires powerful computation capacities and at the same time demands a real-time response. It is sometimes very difficult for a single IoT device to perform these tasks. With fog computing based architecture, these tasks can be uploaded to the fog nodes at the edge of networks, thus achieving almost real-time performance and requirements. Moreover, the data and tasks can even be uploaded to cloud data centers for further processing in case fog nodes are overloaded.

Domain Application Layer. The domain application layer offers specific intelligent applications and services in a smart campus. For example, regarding the learning activities, students can be guided to suitable classrooms with vacant seats in a smart campus, thus saving the classroom/seats finding time. Smart parking service is another example to reduce the parking space finding time while cycling around the campus, especially for newcomers.

4 Challenges and Open Issues

While a fog computing based smart campus leverages several key techniques that are still in the early stages of development such as V2V and V2I in smart parking, smart gird and smart building, we can envision a promising prospect in the near future. Nonetheless, there still exist many challenges and open issues about this fog computing based architecture. In this section, we present and discuss some challenges and open issues, with the purpose of serving as an inspiring guidance for future research within this field.

4.1 Quick Decision Making for Fog Computing

Bringing fog computing into a smart campus is intended to guarantee the real-time performance of time-sensitive applications deployed in a smart campus. For instance, for smart parking in campus, the key to maintaining the real-time response is to perform most of computations locally. Specifically, a parking slots allocation scheme is computed by fog nodes based on some objective function. The campus cloud center would start to function when the performance of fog nodes degrades due to overheads or increasing need for coordination among fog nodes. As a result, designing suitable thresholds below which the uploading is activated, for various applications, is very important to ensure the real-time performance. In addition, how to make efficient strategies and deploy algorithms at the fog nodes for time-sensitive applications also affects the quality of service.

4.2 Deep Learning Based Middleware Design

Deep learning has been widely adopted for supporting many applications in the data processing layer of our smart campus architecture, such as image/video recognition, route planning, and data mining. Compared with traditional methods, deep learning-based algorithms perform much better but require much more computation capacity and energy consumption. An efficient way to incorporate deep learning into the smart campus architecture is to design a deep learning-based middleware and leverage it to support the applications. The challenge here is how to design a middleware that can support heterogeneous applications at the same time.

4.3 Efficient Security Enhancement and Privacy Protection

Smart applications are supported by information sharing and processing among diverse sensing and processing devices located at one or multiple trust zones in a timely manner. It is worth noting that many identity, location, and health related data will also involve in this process. Many security concerns may arise in this process. The major challenges include how to ensure that only authenticated users can acquire particular data, and how to fulfill users' privacy requirements, on the condition that the energy consumption and processing latency are still acceptable for the whole system.

4.4 Cooperation Between Fog Nodes and Campus Cloud Nodes

Cooperation between fog nodes and cloud nodes is also an import issue. There is a tradeoff between fog node computation offloading and transmission latency. On one hand, to overcome the resource constraints in fog computing, computation offloading mechanism is often adopted for the computation-intensive tasks, in which some computing modules of the application are offloaded to powerful nodes in a campus cloud center. On the other hand, since task offloading results in transmission latency, computation should be performed locally in fog nodes as much as possible. Therefore, the key to cooperation between fogs and clouds is that there should exist a tradeoff between fogs and clouds, where the fog nodes should decide which behaviors at what granularity level under what conditions should be offloaded to the cloud computing.

4.5 Data Fusion in Smart Campus

With the rapid development of ICTs and increasing application of various sensors deployed for smart campuses, sensed data with a variety of types and formats will show an explosive growth. How to integrate these data from multiple sources to generate more consistent, accurate, and meaningful information is very important in smart campuses. Data fusion techniques should be applied to supporting better service provisioning in smart campuses.

4.6 Campus Smart Grid

To respond to increasing demands for energy saving –including renewable energy and environments protection, smart grid in campuses aims to reduce the total overall energy while satisfy more campus' energy demands by innovating the current electrical power system via ICTs. However, a few issues still need to be addressed concerning the campus smart grid. For instance, there is still no clear consensus on smart grid design methodology in smart campuses. On another hand, how to develop efficient strategies and algorithms which is capable of analyzing and processing the sensed data from smart grid devices is crucial to achieve the expected goals of campus smart grid.

4.7 Testbed Construction

To realize a practical fog computing based smart campus architecture requires a significant investment on the deployment, operation and maintenance at both fog computing and cloud computing center. Accordingly, it is necessary and cost effective to design and develop a testbed before implementing the full-scale architecture. A testbed allows various data reduction, data fusion, task offloading, and service optimization algorithms to be deployed and tested, and various domain applications to be evaluated and characterized.

5 Conclusions

Smart campuses offer an integrated, comfortable, intelligent environment for working, study and living via incorporating Information Communication Technologies, Internet of Things, mobile internet, and cloud computing paradigms. However, traditional sensor-to-cloud continuum may incur long transmission delay, high energy consumption, and privacy leakage when the tasks/applications are uploaded to a campus cloud for execution. To break this stalemate, we propose a fog computing based smart campus architecture, in which a few fog nodes are deployed to process the data near the data source. Furthermore, a few challenges and open research issues are outlined in hope to inspire more future research activities within this field.

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