Mesh-based Cloud Data Storage & Management Framework for Internet of Things

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Abstract—The Internet of Things (IoT) is the network of physical objects, devices, vehicles, buildings and other items that enables these objects to collect and exchange data. One of the application domains of IoT is smart building where a number of things are efficiently interconnected in order to combine and integrate the physical world to the information space and to provide the services in an efficient way. In the smart building management systems, the data of building conditional monitoring are increasing rapidly. Facing with these massive, distributed, heterogeneous and complex state data, conventional data storage and management will encounter great difficulties. Conventional infrastructure uses centralized approach, expensive large-scale server, disk array storage hardware and relational database management system; which leads to poor system scalability, higher costs, and essentially, is difficult to adapt to the requirement of higher reliability on real-time state data of the smart building applications. Accurate, fast, open, shared information system is the basis for the IoT applications. In this paper, we proposed a mesh-based data storage and management framework which provides reliable data storage and management of the vast amount of information in the IoT applications. We have evaluated and validated our approach by applying our cloud data storage and management framework in our cyber-physical test-bed, a facility which is intended to test innovative technologies for urban sustainability.

Keywords: Mesh, Cloud, Data Storage, Smart-building, Internet of Things

1. Introduction

Smart building systems are becoming popular and significant due to the improvement they provide to the quality of life. Urban IoT is aimed to support the concept of smart cities, whose objective is to exploit advanced control and communication technologies to support high quality services [1]. In the scope of the IoT [2], smart building management system requires architecture that is able to deal with large amount of information from its building components, extract valuable building information in a timely fashion, interpret data in real-time or near-real-time to allow for further improvements in reliability. In order to be part of the IoT, all the information and resources of smart building must be accessible from everywhere. These requirements for smart building can be met by utilizing the cloud computing model. Cloud computing efficiently uses distributed resources and thus it has the benefits of high reliability, flexible, scalable and large-scale computing capability [3] [4]. In order to achieve a reliable smart building infrastructure, cloud computing solutions and services must be incorporated.

Addressing the core requirements of smart building architecture and utilizing the modern advanced technologies, in this paper, we proposed a mesh-based cloud data storage and management framework for IoT which offers better architecture than conventional centralized scheme to accommodate a large scale data, analyze timely information and make rapid decisions. Our idea is to have all the computational power as well as control and monitor capabilities in the cloud.

The remaining of this paper is organized as follows. We first discuss the related works in Section 2. We then briefly present our proposed mesh-based cloud data storage and management framework for internet of things in Section 3. Finally, we finally conclude our paper in Section 4.

2. Background

Internet of Things is becoming so persistent that everything is going to be connected to the Internet and its data will be used for various progressive purposes, creating not only information from it, but also, knowledge and even wisdom. In smart building, all the appliances and devices are geographically distributed throughout the building environment and, as mentioned in the introduction, each building component should be able to access and exchange data via certain communication protocol. Data store and management system allows the data to be stored in a systematic manner and enable them to be retrieved, processed and analyzed either immediately or later. Generally, data are stored on centralized magmatic hard disk drives.

In recent years, cloud computing and cloud database become popular and people are interested to get benefits of cloud technologies in the smart applications [5]. A cloud database can be in the form of either a virtual machine instance which can be purchased for a limited time or a database as a service in which the service provider installs and maintains the database, and application owners pay according to their usage.
Cloud data storage can either be centralized or distributed. In a centralized cloud data storage system, as shown in Fig. 1, the data are stored at a central stand-alone data storage center which is physically in one location and users typically use an Internet connection to access it. Cloud data storage provider, e.g., Dropbox [6], uses centralized topology in which all clients have to connect to the same data center [7]. On the other hand, in a distributed cloud data storage system as in Fig. 2, the data are stored in multiple data centers which are spread over a geographical area and users can access to a different data center closest to it. Google Drive [8] follows distributed topology and uses multiple cloud storage data centers [9] [10].

In addition, cloud data storage can also be classified as either public or private. A public cloud is one in which the services and infrastructure are provided off-site over the Internet by a third-party provider. In contrast, a private cloud is one in which the services and infrastructure are maintained on a private network. Both can offer advantages over traditional data center in the areas of performance and scalability. However, the advantage of private cloud over public cloud is that the private cloud provides greater levels of control and security. Another great benefit of private cloud is the ability to customize the compute, storage and networking components to best suit with specific information technology requirements.

To the best of our knowledge, existing data center in smart building applications adopts traditional centralized data storage system. Some of the challenges in centralized data storage system for smart building applications are as follows:

- A centralized database tends to create bottlenecks if a large number of users access it simultaneously and their needs are substantial since all the data physically reside in one place.
- Centralized data server is not good enough for various types of data formats.
- Difficult to maintain huge amount of data.
- Data availability is not efficient in terms of scalability, recoverability and accessing time.

Our idea is to develop a wireless mesh-based cloud data storage and management platform which is an integration of two modern technologies; wireless mesh network and cloud service. Our proposed data center platform allows end users to make use of the data storage center efficiently and effectively in terms of accessibility, data storage, analysis and data processing and better performance.

3. Proposed System

3.1 System Architecture

Our distributed cloud data storage and management system is mainly composed with two-tier network and it supports hierarchical scheduling or multi-level decision making. High level architecture of our proposed data storage platform can be seen in Fig. 3.

The first-tier is wireless mesh backbone network in which wireless mesh access points (APs) are used to distributedly store the real-time data in the distributed cloud system. The mesh APs can be installed regionally either in each zone or room to store time-critical or continuous changing type of data. The second-tier is central data storage center which stores the long-term or historical information of the entire building system. The main objective of our approach is to allow the end users to make use of the data storage center efficiently and effectively in terms of accessibility, data storage, analysis and data processing for better performance.
3.2 Mesh-based Cloud Data Storage Platform

A mesh network is a network topology in which each node, called mesh AP, relays data for the network. Each mesh AP is configured with internal storage capacity and build up private distributed data storage network to efficiently store the building data. All nodes cooperate in distribution of data in the network. Gateways on the edge collect raw data, store it and perform a first-level of translation and/or analysis. Mesh-based cloud data storage can accommodate large scale data interactions that take place on smart building environments.

Fig. 4: Data distribution between different zones.

Fig. 4 shows data distribution between the different regional mesh clients. Through the proposed platform, different systems are allowed to upload the data to the mesh-based cloud data center through the associated gateways. In Fig. 4, wireless sensor network, one of the IoT components, uploads the sensor data to cloud data center. First-level data processing is performed with the help of cloud computing and then those data are stored in its regional mesh AP.

Proposed platform allows to exchange information between different systems in different zones. The data are available to the other mesh client who wants to obtain the real-time information of the other region in the building. As in Fig. 4, the user (mesh client) in one zone can easily obtain the real-time sensor information of other zone through wireless mesh backbone. In this testing, we used four-radio dual-band wireless mesh AP (MeshRanger MN4300) which is compatible in both indoor and outdoor environment and the real deployment of the mesh APs in our test-bed can be seen in Fig. 5.

Fig. 5: Mesh-AP installation in different zones.

Cloud platforms are intrinsic to creating a software architecture to drive effective use of smart IoT applications. Cloud data storage has better architecture than centralized systems to process huge, persistent streams of data generated across the utility value chain. In smart building, on-going data streams from multiple sources need to be continuously monitored, verified, and processed given changing conditions, with near-zero latency. With the help of our proposed mesh cloud storage platform, multiple tiers of storage can be linked together to keep data in the most efficient way, transparently to the user.

3.3 Distributed Cloud Computing

Our proposed data storage platform allows users to benefit from the power of the cloud. Proposed system can perform first-level data processing such as aggregation, analysing real-time data securely, easily, assuring data integrity and can scale seamlessly and efficiently as the system requires. We provide an IoT cloud platform to ease and speed up the development and deployment of solutions based on real time stream data. The platform provides a wide range of cloud services, including connectivity, to vertical applications (smart appliances, smart metering devices, smart vehicles, etc.) working with remote devices (sensors, tablets, etc). It allows the interoperability of multiple systems and devices, offering a semantic platform to make real world information available to smart IoT applications as shown in Fig. 4.

Cloud data storage platform provides functionalities to gather, integrate, store and analyze data from the building and enables the building users to understand what is happening in real time in order to proceed with solutions immediately. By integrating with an efficient decision making service, the proposed platform can provide more value and power to all end-user.

3.4 Hierarchical Data Composition

One of the features of our proposed platform is to support efficient hierarchical scheduling and/or decision making by providing the data to the users hierarchically. Our data
storage platform provides distributed database service to users. In our platform, we generally classify the data into two types: Type-1 and Type-2.

We define the global and historical data as Type-1 and which are stored in central data storage system. Type-2 data are real-time recurrent or time-critical data and which are distributively stored in mesh APs. Information sharing is available between mesh APs through wireless mesh backbone network. Data can be processed by accessing regional mesh APs in efficient time manner and make decision timely and feedback locally rather than go through the central decision server for every decision making process.

3.5 Database as a Service (DaaS)

Data as a Service (DaaS) model will enable the building management system to continuously monitor the condition of the building and support energy management decisions quickly and accurately. Building management authorities will also be able to use this aggregate, real time data to perform analysis, building maintenance and to improve any performance issues.

3.6 Advantages of the Proposed System

Dynamic Cloud Topology: Cloud topology changes dynamically depending on the request of users.

Improved Throughput: It avoids network congestion at central data center since some of data can be obtained from regional APs and the users do not need to go through the central stand-alone data center for every decision making process which may lead to heavy traffic congestion and bottlenecks.

Data Transparency: It provides data transparency which makes users the transparent use of data storage, analysis and exchange data among building components or different zones.

Lower Data Communication Cost: Data communication costs are lower with our distributed data storage platform since some decisions can be performed locally by providing access to distributed mesh APs in each zone.

On-the-go Scaling: Another advantage of our proposed platform is on-the-go scaling. With the help of the cloud data storage system, the users do not need to worry about running out of storage space or increasing the current storage space availability since cloud provides almost unlimited storage capacity. This is very important feature to store huge amount of data for the large-scale IoT system.

Easy-access-to-information: It provides easy access to geographically distributed information. The users can access the information from anywhere via wireless mesh backbone. This feature makes users more reliable and convenient since the users do not need to care about the geographic location issues.

Massive System: Our proposed platform is a unified data collector for various data types of different sub-systems and helps the other sub-systems to work under one management engine for better performance.

4. Conclusion

We have presented a mesh-based data storage and management framework for internet of things in a smart building environment. Our work addresses two important issues, data scalability and data efficiency. We have implemented our algorithm in our cyber-physical test-bed and validate its effectiveness. From the testing, we could see our proposed platform provides efficient and effective data storage service in terms of data accessibility, transparency and scalability. In the future, we are going to deploy our data storage and management system in the large-scale and real environment.

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