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Smart City Architecture and Applications based on IoT: A Theoretical Overview

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Abstract— The Urban development is turning into more and more reliant on the sensible use of intelligent services. In the process of offering better services to all citizens and enhancing the performance of organizational strategies, the idea of a smart city has been praised as a promising solution for the coming challenge of global urbanization. This paper represents a literature review of smart cities. First, it introduces the origin and essential issues facing the smart city concept and then performs the fundamentals of a smart city by analyzing its definition and application domains. Second, a data-centric view of smart city architectures. But, because of the broad scope of smart cities, their definition has no longer been standardized, therefore proposed architectures are various. This work additionally proposes and discusses an architecture from the perspective of the data that supports all the functionality of smart cities. Urban IoTs, in fact, is designed to assist the smart city vision, which aims at utilizing the most advanced ICTs to support added-value services for the management of the city and the citizens. This paper, therefore, affords the applications of a smart city primarily based on IoT enabling technologies, protocols, and so on.

Index Terms— Smart City, Architecture, Literature overview, Internet of Things (IoT), Big Data, IoT applications

1 Introduction

THESE days the world has witnessed a rapid urbanization process, which has become a global phenomenon. The urbanization of the world's population has become a key problem that needs to be addressed. In the 1950s, only 30% of the world's population lived in cities; by 2014, the urbanization level had reached 54%. The United Nations predicts that the figure might be 66% by 2050 [1]. However, the way of accelerating urban development around the world additionally brings many new troubles, which includes traffic jams, pollution, and pressure on natural resources. These problems are completely different set of challenges for cities in the 21st century [2]. To solve these problems, the concept of 'Smart City' is created through which a city can meet those challenges by making suitable adjustments. The term 'Smart City' arose for the first time in the early 1990s [3]. The smart city has been actively studied, and researchers have come up with distinct definitions, frameworks, and implementations of the smart city [4-8]. Smart city, which is the concept of IBM, specifically focuses on making use of the information technology to all areas, embedding sensors and equipment to hospitals, power grids, railways, bridges, tunnels, roads, buildings, water systems, dams, oil and fuel pipelines and different objects in each corner of the world, and forming the 'Internet of Things' through the internet. When Internet of Things is combined via supercomputers and cloud computing, people can control life more diligently and dynamically, and in the end, attain 'Internet + Internet of Things = Smart Planet' [9]. The internet has to turn out to be a main a part of citizens day by day lives. An urban IoT delivers some advantages within the management and optimization of traditionally public services. Among them, the most common are transport and parking, lighting, surveillance and maintenance of public areas, renovation of cultural history, rubbish collection, and school. Smart cities have attracted impressive attention since 2008, with the release of IBM's Smarter Planet project [10]. Information and Communication Technology (ICT) performs an essential role in smart city construction. Top-level architecture research plays a significant role in guiding technology development in every domain of a smart city and enhancing research into useful resource configuration. The earliest architecture research was carried out by IBM [6]. It gave a comprehensive introduction to the technology functions mainly focused on infrastructure and services, without providing much significance to city data. A variety of revolutionary information technologies, including cloud computing, big data, data vitalization, the internet of things and mobile computing, have been broadly deployed within the smart city concept [11]. In these, data-centric enabling technology plays a vital role in smart city implementation.

This paper describes the background and related work on smart cities and their various definitions in Section II. Section III briefly presents the literature overview of the architecture. Section IV describes the architecture proposition. In Section V the applications based on IoT are presented and finally, Section VI concludes the paper.

2 Smart City Definitions

The concept of the smart city has attracted world interest, including governments, companies, universities, and institutes. Different stakeholders have tried to understand and explain the smart city from their different point of view. A firm definition of a smart city is still emerging. It is tough to formalize the definition, because the smartness of a city may be as simple as a single function provided to a particular group of citizens, or as complex as a whole administration method [12]. Numerous surveys of smart city definitions have been made [11, 13, 14]. However, maximum of these surveys explain unique definitions and classification of smart city definitions from the different point of views. In this segment, the definitions of a smart city will be analyzed from the following four perspectives:

1. Technical infrastructure
2. Application domain
3. System integration
4. Data processing

2.1 Technical Insfrastructure

From a technology prospect, Harrison et al. defined a smart city as an interconnected, instrumented and intelligent city [6]. Al-Hader et al. defined the smart city as representing the transmission and reception of information using communication protocols on the network components [15].

2.2 Application Domain

Giffinger and Gudrun defined a smart city from the domain application perspective, and they pick out six smart characteristics of smart cities: economy, people, governance, mobility, environment, and living [3]. Lazaroiu and Roscia described a smart city as a solution that acknowledges electricity, water, and fuel intake, as well as heating and cooling structures, public protection, waste management and mobility [16].

2.3 System Integration

Dirks and Keeling described a smart city as the organic integration of structures and their relation to making the system smarter [17]. Javidroozi et al. considered that for a city to be smart, the integration of city systems is essential, in order to provide flexibility and access to real-time information for the creation and delivery of efficient services [18].

2.4 Data Processing

Al-Hader et al. highlighted that sending and receiving information is the foundation of monitoring and controlling the practical working structure of smart city [15]. Harrison et al. represented a smart city from a data processing perspective [6].

3 Architecture

Because of the ambivalent definition of smart cities, their architecture varies. A large number of smart city architectures discovered in the literature specializing in distinct aspects, which includes technology, human-system interaction, and logic. Smart city architecture offers suggestions on how to use the technology to conceive and enforce a smart city mission.

3.1 Literature Review of Architecture

Researchers have proposed many distinct smart city architectures. This section introduces a list of popular smart city architectures and analyzes their technical traits.

Liu and Peng summarized the smart city architecture of China's pilot smart cities. Their architecture consists of four layers: sensing, transmission, processing, and application.

Komninos summarized the architecture for smart cities from the angle of technology, in which a smart city is split into three distinct layers [19]. First, the information storage layer stores all forms of digital content material. The second layer is the application layer which gives relevant services to users through organizing digital content material. The third layer is the user interface, which exposes this layer via selection of internet applications using using maps, 3D pictures, textual content, charts, and other interface tools.

Al-Hader et al. proposed a five-stage pyramid architecture for smart cities from a human-system interaction perspective [15]. The lowest layer is the smart infrastructure layer consisting of electronics, water, natural gasoline, fire-protection, electronic communications, and network. The second layer is a data storage layer that incorporates diverse databases and complete data resources. The third layer is a smart building management system. The fourth layer is the smart interface layer consists of a common operational platform, incorporated internet services and so forth. The top layer of the pyramid is the integration and mixture of the systems layer.

Anthopoulos and Fitsilis proposed a physical architecture that contains five layers [20]. The infrastructure layer consists of all network and location-based carrier systems. The information layer is an information storage layer. The carrier layer gives location-based services to customers. The business layer provides the rules and policies allowing the smart city to understand how to operate. This architecture stimulated through the digital city, follows a Service Orientated Architecture (SOA), and mainly supports cellular applications and services.

Luca et al. proposed a smart city architecture in which they divided smart cities into two parts: Knowledge Processors (KPs) and Semantic Information Brokers (SIBs). The information is collected in the SIBs which operate as a server for KPs. As soon as KPs are linked to SIBs, operations are induced by means of the Smart Area Access Protocol (SSAP) [21].

4 Discussion and Proposition

In the above literature survey, there are divergent visions of smart city architectures. Through these unique expressions, a few common characteristics can be discovered.

4.1 Data Oriented Smart City

Almost all the architectures consider data sensing and data transmission as the fundamental start point for a smart city. Data storage, data mining and data processing are regarded as core factors for the realization of smartness. That is to say, the future of smart city concepts will concentrate on data. The challenge for the smart city is to understand the interactions between the city and its people [22]. From the perspective of computers and systems, the city is defined by its sensed data. Therefore, to understand the city, it is necessary to understand the interactions of the city, the data and the citizens. Data vitalization might be a good set of solutions in a data-centric smart city.

4.2 The Multidisciplinary Smart City

The data-centric smart city is a multidisciplinary idea. The distinct architecture layers of a smart city range from the underlying physical infrastructure to specific domains. Not only different ICTs, big data, IoT, data vitalization, SOA, and so on, play an essential role in smart cities but also other sciences and technologies, which include transportation, environment, energy, and sociology are mainly involved. A smart city is a systematic idea, in which ICTs offer the common technology platform that helps and take benefit of different disciplines sciences and technology. Multidisciplinary functions of a smart city need to be considered along with knowledge, experience, and technology of different disciplines.

5 Smart City Architecture Proposition

After considering the two characteristics of smart city architectures above, the proposition for smart city architecture, as shown in figure 1. Considering that data and data management play a core function in smart cities, the logical hierarchical architecture includes four well-known layers and planes: the data acquisition layer, the data vitalization layer, the common data and service layer, and the domain application layer, the standard and evaluation plane, and the security and authentication plane which are acting as a supporting layer.

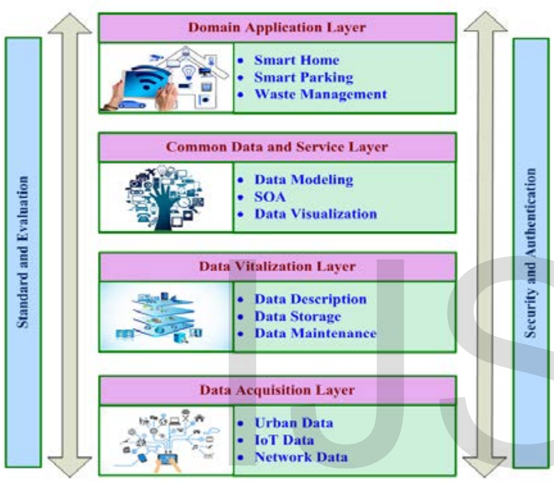

Figure 1. Proposed Smart City Architecture

5.1 Data Acquisition Layer

The first layer consists of the data acquisition and data transmission infrastructure and systems. The data acquisition layer incorporates all sensor systems and data sources in the smart city and collects and stores their external data. It can seize any information which includes pictures, video, sound, and others and stores it logically [23]. The advanced equipment, sensors, Global Positioning System (GPS), and Radio Frequency Identity Devices (RFID) readers and tags, are deployed in particular domains to accumulate data. It is essential for the community to expand tremendously reliable and low-cost sensor devices to monitor exclusive sorts of data source, consisting of noise, water, air, and temperature. This layer permits the connection to different data networks comprised of IoT, ad hoc networks and Geographic Information Systems (GISs). This layer additionally gives data transmission with largescale networks [24].

5.2 Data Vitalization Layer

The second layer is the data vitalization layer. This layer possesses large-scale data storage functionality to support the data accumulated from the data acquisition layer with high reliability and scalability [25]. As soon as data is accumulated, its usage turns into the primary problem for a smart city. The key technique is data vitalization, which emphasizes data cleaning, evolution, association, and maintenance. The method of cleaning consists of unwanted data elimination, missing data recovery, and inconsistent data checking [26]. Data association technologies help in finding the interconnection among data and generating association policies. Data maintenance guarantees data robustness after access and processing. When most of these processes have been applied, the data has been said to be vitalized.

5.3 Common Data and Service Layer

The common data and service layer uses vitalized data for common services like SOA, data visualization, data modeling, etc. SOA methodologies are generally implemented on this layer to package all required functionality into services [27]. Cloud computing technologies provide the large-scale storage and computing capacities required by applications [28]. Data query and retrieval technology offer top layer applications with contextualized and accurate data. All the data required can be demonstrated to top layer applications through the use of data visualization technologies as services [29].

5.4 Domain Application Layer

This layer gives smart city users with unique domain applications. Domain services have been extensively mentioned in the smart city context, e.g., smart transportation, smart parking, and many others: Smart-X systems. Many projects focus on these systems. However, effectively deploying Smart-X system alone is not sufficient to make a whole city smart. Unique domain applications are designed on this layer, to serve a smart city's end users, and understand the smartness of the complete city. Consumer experience is essential for domain applications, or even determines the fulfillment or failure of smartness [30]. Superior technologies cannot accomplish by means of this layer. It additionally concerned plenty of design challenges from administration, security and standards perspectives.

6 Applications of Smart City Based On IoT

Smart city will be the future trend of urban development. Usually, the development of a smart city can be divided into three stages, consisting of the development of public infrastructure, construction of the general public platform for smart city, the development of application systems. The application of the IoT paradigm plays a crucial role in many national governments to adopt ICT solutions within the management of public affairs, therefore, figuring out the so-called smart city concept [4]. Figure.2 shows some common applications. In this section, the applications of IoT based on the smart city will be discussed.

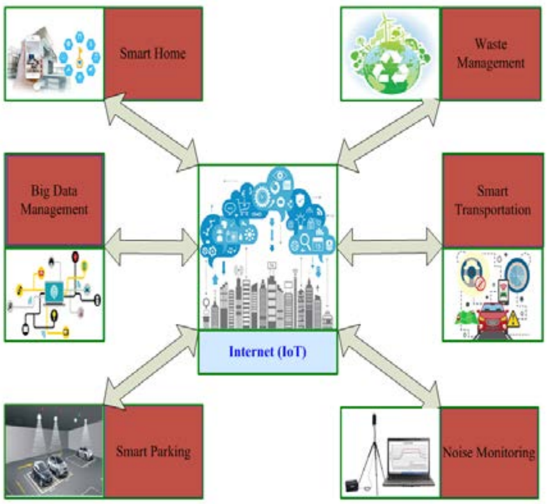

Figure 2. Smart City Applications based on IoT

6.1 Smart Home

Sensor devices, consisting of RFID, infrared sensors, GPS, laser scanners and so forth, can be blended with the internet to form the internet of things. Then taking all of the items in life as a terminal to be connected to the network, accomplishing the centralized and remote control of electrical and mechanical equipment through the interaction of numerous networks and terminals. This may be convenient for user identification and management [31]. As an example, the realization of a smart home can be suitable to attain the intelligent control of lighting and electric appliances. By receiving the smart notification of home alarm messages. At the same time, whether interior or exterior, one can enjoy the achievements of a smart city.

6.2 Smart Transportation

Every city can take appropriate advantage of the sensor network according to their wishes and traffic scenario. The IoT and other technical methods to change the conventional transport system and set up the smart traffic control system, which includes adaptive traffic signal control system, urban traffic control system and so forth. At this point, the smart traffic control system can obtain the combination of urban planning, construction, management, and operations, and provide support for other subsystems of the smart urban system.

6.3 Waste Management

Waste management is a number one problem in many modern cities, because of both the cost of the provider and the trouble of the storage of rubbish in landfills. Deeper penetration of ICT solutions in this area, however, can also bring about tremendous financial savings and economic and ecological benefits. For example, the usage of intelligent waste packing containers, which detect the level of load and permit for an optimization of the collector trucks path. This can reduce the price of waste collection and enhance the quality of recycling [32]. To comprehend this type of smart waste management service, the IoT shall join the end devices, i.e., intelligent waste packing containers, to a manipulate center where an optimization software approaches the data and determines the most desirable management of the collector truck fleet.

6.4 Noise Monitoring

Noise can be visible as a shape of pollutants as plenty as Carbon Oxide (CO) is for air. In that sense, the city authorities have issued particular legal guidelines to minimize the quantity of noise within the city center at specific hours. An urban IoT can provide a noise tracking service to measure the amount of noise produced at any given hour [33]. Besides constructing a space-time map of the noise pollution within the area, can be used to implement public security via sound detection algorithms that could recognize, for example, the noise of a gunshot.

6.5 Big Data Management

Logically, a massive amount of data will be generated from all smart city systems. To deal with diverse sorts of data, with varying speed an efficient big data management system is needed. This system must be dependable and scalable without a downtime. The continuous generation, collection, processing, and storage of large heterogeneous data from many smart city sensors have its significant permanent challenges. However, big data collected throughout the city is useful and necessary for accomplishing the objective of a smart city. As an example, GPS sensors installed on vehicles may additionally provide valuable information about transport flow.

6.6 Smart parking

The smart parking is primarily based on road sensors and smart displays that direct motorists alongside the satisfactory path for parking inside the city [34]. The advantages deriving from this service are many: faster time to find a parking slot means fewer CO emission from the automobile, lesser traffic congestion, and happier citizens. It is possible to comprehend an electronic verification system of parking which allows in slots reserved for residents, through the use of short-range communication technologies, which includes RFID or Near Field Communication (NFC). The smart parking service can be directly incorporated into the urban IoT infrastructure.

7 Conclusion

This paper provides a gateway to better understanding the idea of the smart city through the evaluation of its definition and application domains. It shows that any smart city definition should consider four key perspectives: technical infrastructure, the application domain, system integration and data processing. The smart city architectures are deemed to have datacentric and multidisciplinary characteristics by reviewing the literature. In this article, the proposed smart city architecture composed of four layers: data acquisition, data vitalization, common data and services, and domain application. This paper additionally introduced the emerging future form of the internet known as 'Internet of Things' that will connect everything and everyone and furthermore described its future applications. However, the development of the smart city which is primarily based on the IoT will change humans everyday life dramatically.

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