Smart City Architecture: A Technology Guide for Implementation and Design Challenges

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Abstract: Urban development is becoming increasingly reliant on effective use of intelligent services. In the process of providing better services to all citizens and improving the efficiency of administration processes, the concept of a smart city has been lauded as a promising solution for the coming challenge of global urbanization. However, due to the broad scope of smart cities their definition has not been standardized, thus proposed architectures are diverse. This work proposes a new architecture from the perspective of the data that underpins all the functionality of smart cities. The proposed architecture is discussed, outlining design challenges and offering insight into the development of smart cities.
Key words: smart cities; architecture; layered framework; technology overview

I. INTRODUCTION

A city is a relatively large, permanent settlement which generally has complex systems for sanitation, utilities, land usage, housing, transportation, etc. [1][2]. Recently the world has witnessed a rapid urbanization process, which has become a worldwide phenomenon. In the past 10 years, the urbanization rate of China has increased from 36% to 51.27% [3]. It is expected that the urbanization rate will continue to grow at an unprecedented rate, particularly in developing countries for many years to come [4].

The process of urbanization has greatly promoted the modern economy and increased the human ability to transform nature and bring great increases to the standard of living. However, the process of accelerating urban development around the globe also brings many new problems, such as traffic jams, pollution, and pressure on natural resources; these problems are a unique set of challenges for cities in the 21st century [5]. To better solve these problems, the concept of "Smart City" was coined to refer to the process by which a city is able to make appropriate changes to meet those challenges.

The evolution of smart cities can be dated back to the 1990s when the phrase was proposed to emphasize the urban development towards technology, innovation and globalization [6]. Smart cities have received considerable attention since 2009 when IBM cultivated the corporate initiative of Smarter Planet, which subsequently obtained wide support from governments, enterprises, universities, and other related communities around the world [7]. Its fundamental strategy is to apply advanced information communication technologies (ICTs) to solve the problems during urbanization and improve the city's overall attractiveness. Smart cities have been widely lauded as a new paradigm for dealing with the challenges of urban development and many countries have launched smart city related projects: the US, European Union, Japan, Korea, and Singapore, are all pi-

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oneers in this field.

The US is one of the leading countries that have long been recognized for its important primary impact in ICT related innovations. Similar to IBM's Smarter Planet, in May 2009 the European Union put forward its smart city program, the Digital Agenda, and stated that the development of cities should be smart, sustainable, and comprehensive [8]. In July 2009, the Japanese government also launched i-Japan strategy 2015 striving to provide Japanese citizens with a vibrant digital society [9]. In March 2006, The Republic of Korea introduced the u-Korea development strategy [10], which aims to make Korea step into intelligent society. In June 2006, Singapore officially announced its ambitious Intelligent Nation 2015 plan and launched a series of activities to promote smart city which will enhance quality of life [11].

Despite the vigorous promotion, innovation, and development of smart cities, by a multitude of countries, the term itself is still an emerging fuzzy concept [12]. Several basic questions have not been clearly answered [13]. For example, what are the main characteristics of a smart city? In what way will people label a city as smart? One possible reason is that, due to the broad aspects of a city's operation, different stakeholders have their own understanding of a smart city from divergent perspectives, such as infrastructure capability [14][15], data handling [16], applications [17], and administration [13]. As a result the definition of a smart city has continually evolved, and accordingly a great effort is required to develop a core set of principles to guide the future direction of urban sustainability.

To meet this challenge, and realize the well documented benefits of smart cities, several research objectives have been defined in the literature. Among them smart city's architecture is one of these key objectives since it provides the fundamental understanding for smart city projects. However, just as the definition of smart cities remains unstandardized, so too does its architecture. Many different smart city architectures have been proposed from differing viewpoints [15][16][18][19][20].

In this work, we study smart cities from the viewpoint of their data processing. Data intensive computing is fundamental for all smart city applications [21], the huge volumes of data often come from a large number of sensors deployed in the city [22]. The rapidly developed next-generation technologies have become essential to addressing the social, political, and environmental challenges facing cities in the near future [23]. Therefore, it is sensible to define the architecture of smart cities from a data perspective. With this in mind, we present our multi-layered smart city architecture to better describe the essential technologies employed in building a smart city. We present a comprehensive overview of related technologies and illustrate some design challenges.

We describe background and related work on smart cities and their architecture in Section 2. In Section 3 we present our proposed hierarchical structure of our proposed smart city architecture. In section 4 we discuss some principles for the reality of implementing smart cities. We conclude in Section 5 and discuss future work.

II. Background

2.1 Smart city definitions

The implementation of a truly smart city requires the provision of a clear definition of what a smart city really is. Better understanding of the term will be helpful in assessing its content and scope. However, although smart cities are currently a hot research topic, a consensus on their definition has yet to be reached.

The concept and definition smart cities have evolved gradually since first proposed in the nineties, and a core set of principles related to them have been developed to guide the future direction of urban sustainability. The smartness of a city can be as simple as a single function provided to a certain group of citizens or as complicated as an entire administration process which represents the restructuring efforts of government procedure. As such it is difficult to formalize the definition.

From a technology perspective, Harrison et al. define a smart city as connecting the physical, IT, social, and business infrastructures to leverage the collective intelligence of the city [15]. Al-Hader et al. argue that the concept of smartness is represented by transmitting and receiving data using communication protocols to and from the network elements, and that the sending and receiving of data is the base of monitoring and controlling the functional operational framework needed for smart management of network assets [16].

Other definitions attempt to describe smart cities using the fields they involve. For example, Washburn et al. agree that smart cities should use smart computing technologies to make critical infrastructure components and services of a city more intelligent, interconnected, and efficient [24]; these services include city administration, education, healthcare, public safety, real estate, transportation, and utilities. Giffinger and Gudrun had a different viewpoint and they identify six smart characteristics of smart cities: economy, people, governance, mobility, environment, and living [17]. Similarly, Balakrishna explains that a smart city can be defined from the perspective of environment, economy, people, governance, living, and mobility [25].

2.2 Smart city architectures

Due to the ambiguous definition of smart cities, their architecture is diverse without unified criteria. As a result a large number of smart city architectures can be found in the literature focusing on different aspects, such as, technology, human-system interaction, and logic. Here we present a list of popular architectures to help better understand the fundamental components of a smart city.

Komninos summarized the architecture for smart cities from the perspective of technology, in which a smart city is divided into three different layers [18]. First, the information storage layer stores all kinds of digital content. The second layer is the application layer which provides relevant services for users by organizing digital content. The third layer is the user interface, which exposes this functionality through a variety of web applications by using maps, 3D images, text, charts, and other interface tools. There is another administration layer which is responsible for providing proper access right for users to digital contents.

Al-Hader et al. proposed a five level pyramid architecture for smart cities from a human-system interaction perspective [16]. The bottom layer is the smart infrastructure layer including electronics, water, natural gas, fire-protection, electronic communications, and network. The second layer is the smart database resource layer which contains spatial databases, database servers and complete data resources. The third layer is the smart building management systems layer that includes automotive control networks. The fourth layer is the smart interface layer containing a common operational platform, integrated web services and so on. The top layer of the architectures is a smart city layer which combines and integrates the underlying four layers.

From a logical and physical view, Anthopoulos and Fitsilis proposed a five-layer generic smart city architecture [19]. The stakeholder layer describes the potential users, including citizens, user groups and servants. The service layer contains releasing information to the public as well as providing information to the citizens and businesses through application software. The business layer provides the definition of the rules and policies to allow the smart city to understand how to operate. The infrastructure layer includes the basic network and other access points. The information layer is designed to produce and store data properly.

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) [22]. The information is stored in the SIBs which serve as servers for KPs. Once KPs are connected to SIBs, operations are triggered by the Smart Space Access Protocol (SSAP). Through SSAP operations, KPs can manage sessions and transactions between producers and consumers.

In addition, Harrison et al. believe that a smart city model should predict the behaviour of individuals, communities, and even the entire city [15]. Although people can focus on technical progress alone, it is difficult to determine what these technologies bring to a city's finances and living. The proposed framework intends to take the data from the infrastructure and resident groups and establish an effective model to predict their future behaviour.

Moreover, Lugaric et al. proposed test architecture for the smart city architecture [26] from the prospective of platform for emergent phenomena. This architecture contains three parts: the physical network the communications infrastructure and the flow of information. Conceptually, the system brings the results of data exchange and processing through the simulating communications infrastructure to the physical system in an integrated way. The results are forwarded to the data centre so that a network component can react quickly to rapid equilibrium data throughout the system. This is an iterative process to ensure the entire system's dynamic equilibrium.

Chourabi et al. proposed a framework from the perspective of systems to provide a comprehensive understanding of the smart city [20]. They divide influencing factors into two groups. Outer factors include the governance, people and communities, the natural environment, infrastructure, and economy. Inner factors are technology, organization, and related policies.

Al-Hader and Rodzi divide smart cities into two big parts from the view of monitoring and development [27]. The first layer is the monitoring layer providing surveying and data communication updates. Some devices are needed for surveying and data communication, such as ground penetrating radar, cable locators, programmable logic controllers, and communication modems. The second layer is the development layer which contains geospatial applications and the network data model. Geospatial applications include the network analysis model, facility sitting model, and the maintenance and operational model. Network data models for electricity, communication, water, gas, sewers, and storm provisions are included.

III. Data Oriented Smart Cit Architecture

Though much effort has been devoted to smart city, its proposed definition and architecture are greatly divergent and without a unified fabric. We define a smart city as: *A city which has certain smart ability to deal with a city's problems and provides citizens with a better living environment through intelligent accumulation and analysis of different kinds of data from the city's routine operation based on advanced information technologies*.

Traditional data organization processes cannot satisfy the requirements of a smart city. Gathering data is becoming easier whereas finding an effective way to store, manage, and analyse the data has become a more important challenge [28]. Furthermore, Chourabi et al. argue the importance of technology among all factors in affecting the success of a smart city [20]. It is now believed that data and a new generation information technology have started to play a much more important role in implementing a smart city. Therefore, to help better understand what a smart city is, we propose our general adaptive multi-layered smart city architecture, as shown in Figure 1.

3.1 Data acquisition

Smart cities involve a complicated and comprehensive data intensive computing and application system. Data plays a key role in implementing a successful smart city. The first problem is, therefore, how to obtain the diverse data on the scale of a city wide operation. In a smart city, our daily activities will produce a vast quantity of data. How we can sense these large amounts of data has become one of the major challenges. To meet this requirement, we believe that a highly effective and efficient city oriented data accumulation mechanism has become a necessity. We refer to this as the data acquisition layer in Fig. 1. The data acquisition layer composes all sensor systems and data sources in the smart city and collects and stores their external data. It can capture any kind of information including images, video, sound, and others and stores it logically [29].

The first challenge of this fundamental part of the architecture is to provide advanced equipment for data acquisition, which calls for highly efficient and effective techniques primarily responsible for sensing data in different fields. It is vital for the community to develop highly reliable and low cost sensor devices to monitor different types of data source, such as noise, water, air, and temperature. During the process of developing new devices, Radio Frequency Identification (RFID) technology is of great importance as it is one of the fundamental devices enabling the linked data creating the Internet of Things (IoT) [30][31].

Alongside the pervasive sensors deployed in a smart city, there is also a need to construct ubiquitous sensor networks, which are a technology available anywhere to be economically viable in finding sensors [32]. Only when the number of sensors linked together becomes large enough, can the smartness of a city's operation be realized [33].

The data from sensors needs to be pre-processed to make it useful and meaningful. For this purpose, system on a chip (SoC) is a potentially useful tool; it tries to integrate all the components of an electronic system into a single chip as embedded software [34]. In this way SoC brings pre-processing ability for data acquisition at the sensor nodes themselves. With the deployment of sensors in a city, the amount of data accumulated will become huge. Therefore convergence devices are necessary to act as aggregation points to provide the access layer with communication between the virtual networks and control and limit the access from access layer to the core layer,

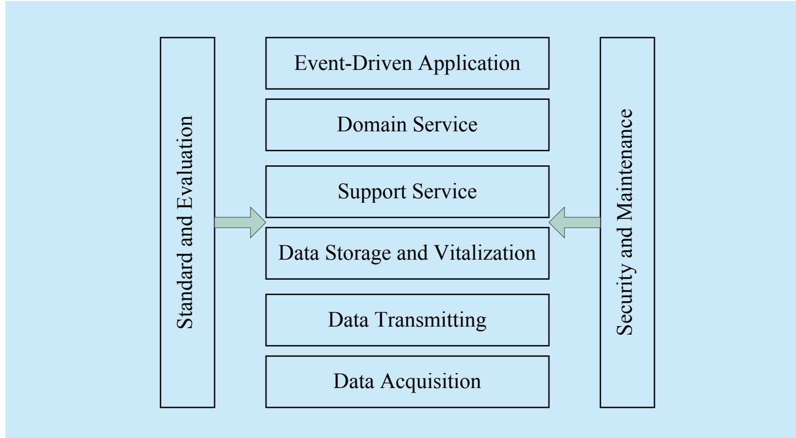

Fig.1 *Overview of our Smart City Architecture*

thereby ensuring the security and stability of the core network [35]. Creditable acquisition technology provides data validation functions to ensure that data collected from the man-machine interface or communication interface meets the requirements of the system settings such as data format and length [36].

Deployment of a large number of advanced sensors itself does not guarantee a reliable data acquisition layer for a smart city. Different types of sensing systems are needed since city oriented data acquisition need to takes advantage of a multitude of devices to dynamically model and monitor a city's operation.

Smart city sensing needs a perceptual model, which is a process of linking action to the appropriate objects in the environment [37], since it is vital to carry out data fusion from different sensors and allow applications to establish various levels of interpretation to deal with the uncertainty and vagueness [38]. That means the city oriented data acquisition need to not only deploy ubiquitous devices but also build city level infrastructure to complete important and fundamental tasks. The city infrastructure sensing system deploys all kinds of sensing terminals like sensors and probes. It aims at perceiving urban construction, municipal infrastructure and making urban information collection system perfect.

Typical examples of these kinds of system include earth observation, environment and catastrophe monitoring, transportation surveillance and so on. Earth observation and navigation technology is an applied science that uses a variety of techniques and procedures to determine present position, heading, and/or direction and distance to a destination [39]. By using Internet Geographic Information Services (GIServices) and wireless mobile Geographic Information Systems (GIS), a city can enhance the spatial awareness of decision makers and facilitate more efficient and comprehensive decision making processes as spatial awareness is one of the fundamental decisions making capabilities for human beings [40].

Environment and catastrophe perception system acquire information dynamically using sensor networks then analyzing and processing the data comprehensively to monitor environmental challenges. Transportation surveillance is a special Ad Hoc network in which vehicles can perceive surroundings using sensors and communicate with other vehicles or infrastructure [41].

3.2 Data transmission

End-to-end communication services for applications within smart city layered architecture are vital. Importance should be attached to advanced communication hardware, network technologies, and transmission control.

Optical network offers higher bandwidth and speed than traditional copper cable networks. It is the foundation of future smart city networks, though some problems remain unsolved such as architecture scalability, complexity, etc. However, they need to be highlighted and will have deep impact on smart city network infrastructures.

With the development of wireless devices such as smart mobile phones, their high flexibility, versatility and other advantages, wireless wideband networks have become necessary for any efforts towards smart cities. The requirement for pervasive access of Internet based applications has greatly boosted the massive usage of wireless applications [42]. As such wireless networks are an important part of smart city construction.

Ultra wide band technology, or UWB, is another direction in constructing smart city's data transmission infrastructure. Due to its capability of higher speed transmission over a short distance, it has numerous advantages such as higher temporal resolution, lower power spectral density of emission signal, low system complexity, low-power consumption, and precise positioning. In fact, for Internet access, "triple play" is an important aspect in most Chinese cities as it can make telephone network (PSTN), cable television network, and IP network multiplexed at the backbone and carried by a convergent next-generation network (NGN) [43].

The data transmission network is the platform for data resource integration of smart city construction and often consists of a large number of low-cost sensor nodes that have strictly limited sensing, computation, and communication capabilities [44].

Apart from physical network, there is also another network from social perspective which deserves to be highlighted. Social network provide a wealth of information and can help predict the movement of a population. People are a main component of smart cities in terms of beneficiaries. As a result, discovering the properties of the social network in a smart city means a lot for the development of social network [45]. In order to provide citizens a new perspective to get knowledge from massive data and support the construction of data-intensive applications in smart city, the data transmission must adjust to facilitate the new web access mode.

Along with development of infrastructure and network, it is also needed for controlling mechanism to guarantee the safety of data transmission. The first problem is how to maintain quality of service (QoS), which is to allow different priority levels for different users, data, or program requests, to guarantee the performance of data streams. It is an important consideration for supporting a variety of applications that utilize the network resources [46].

3.3 Data vitalization and storage

Once data is collected, its utilization becomes the main concern for a smart city. The key process is data vitalization, which emphasizes data cleaning, evolution, association, and maintenance.

Since data are from different types of sensors, quality problems may arise, e.g., duplication, errors, and inconsistency. Contradictions within data sources need to be avoided wherever possible. The process of washing the dirty data is generally called data cleaning [47]; the process of cleaning includes redundant data removal, missing data recovery, and inconsistent data checking [48].

Data evolution can be divided into two parts. First, data evolution theory [49] assumes that data entities have computing ability and both intrinsic and extended semantics. Second, the Internet of Data (IoD) aims to learn from the IoT. Similar to the IoT [50], the IoD must rely on the Internet as a communication infrastructure. Virtual tags [51] in the IoD are similar to RFID tags in the IoT [52].

City level data mining is non-trivial process to reveal hidden, previously unknown and potentially valuable information from the database [53]. The correlated dynamic data modelling is used to develop statistical models and inference of multidimensional measurements with correlated response variables within a single framework. Data association mining aims to reveal association rules among data which has a range of applications in cities [54]. It also can help avoid information overload in Web search engines [55].

Data maintenance and management attempt to make the data warehouse self-maintainable by minor modifications when there is an addition to or deletion from a view by providing an algorithm for this incremental maintenance purpose. Maintaining data replication levels is a fundamental process of wide-area storage systems; replicas must be created to avoid data loss because storage nodes will fail. We also need to store this data in distributed data centres for efficient access.

Efficient processing and access of massive data stores is imperative. Data storage of a smart city must also have the ability to support large-scale complex data with high reliability and scalability. Users must also have multiple access methods to the data with low energy consumption. Research into mass data storage includes cloud storage services architecture [56], large scale heterogeneous storage systems, large-scale hybrid storage structure for a variety of typical application-aware file system, technical on organizing and managing data dynamically, metadata management and fault tolerance techniques, large-scale dynamic data transportation techniques, adaptive storage optimization strategies [57][58][59].

3.4 Support service

Once data is safely stored and vitalized, making use of that data is the next task. Data intensive computing facilities should be available as platforms for the applications that must sit above.

Service-oriented architecture (SOA) is a software design methodology based on structured collections of discrete software modules, known as services, which collectively provide the complete functionality of a large software application [60]. SOA generally provides a way for consumers of services, such as web-based applications, to be aware of available SOA-based services. SOA defines how to integrate widely disparate applications for a Web-based environment and use multiple implementations. Service orientation requires loose coupling of services with operating systems and other technologies that support applications. In smart cities, a variety of services must be supplied to the government, enterprises and citizens. All these services are supported by SOA.

Cloud computing refers to both the applications delivered as services over the Internet and the hardware and systems software in the data centres that provide those services [61]. It has become as a very popular paradigm for hosting and delivering services over the Internet [62]. The vast quantities of data produced and stored by smart cities require large-scale computing, storage and software resources to process it. Cloud platforms which offer great scalability for data analysis will be a core part of the computing power for smart cities.

Intelligent information retrieval is the application to get useful information from large amount of data [63]. The information may be web pages, images, information and other types of files. Throughout the course of its development, the information retrieval technology has developed to the user centred stage from the stage of text retrieval and link analysis, namely, how to understand the read needs of users [64]. Because the urban data is huge, there is an urgent need for an intelligent search engine which can retrieve the useful data efficiently.

After obtaining interesting information, how to present it to the end users is the next challenge. It is necessary to organize the information in a human friendly way. Visualization and simulation technology will help to build the 2D/3D model of a city and provide numerical simulation platform for the application in smart city. These technologies not only provide a novel means for city management, virtual enterprise, the public services, but also provide interactive platform for all smart city users.

Computer simulations are a useful part of mathematical modelling of many natural systems to gain insight into the operation of those systems and to observe their behaviour [65].

Virtual reality is a term that applies to computer-simulated environments that can simulate physical presence in places in the real world, as well as in imaginary worlds [66]. Augmented reality refers to the notion of layering relevant information into our vision of the world [67]. These can both help a city manager visually manage a city scientifically and reasonably. Personalized intelligent portals serve an essential role to the development of the personalized learning, and offer convenient tools for users [68]. A portal focuses on personalization of the provided services: self-regulation, self-monitoring, social support, virtual home visits and reminders [69]. These portals allow users to gain the data they need quickly and accurately.

3.5 Domain service and event driven smart applications

These two layers are important because they have direct interaction with citizens. Their performance will affect the citizens' experience of intelligent services. Domain services have been widely discussed within the smart city context, e.g., smart transportation, smart health, etc: smart-X systems. There are many projects that focus on these systems. However, successfully deploying smart-X system alone s is not enough to make an entire city smart. We say that the system is not truly smart if a single system can meet a citizen's requirement. It is the integration of many of these systems that is smart: the integrated abilities of multiple different systems we call event driven smart applications.

Event awareness is important to the success of a smart city implementation because for citizen people will not be aware smart-X systems but just want to get services based on their unclear or implicit needs. This situation calls for an innovative approach to satisfy the needs by learning the real requirements and provide services while maintaining interoperability among different smart-X systems transparently to the customer. In fact, this layer is so important that it cannot be achieved by only employing advanced technologies. The targets also involved a lot of design challenges from administration, security and standards perspectives.

3.6 Comparison with architectures in the literature

After identify the important technologies in the proposed six layers of smart city, it is believed data oriented architecture will give scholars in this community an insight into smart city and its applications. Defined archi-

Table I *Comparison of Architectures in the Literature*

	Data Acquistion	Data Transmission	Data Vitilization & Storage	Support Service	Domain Service	Event-Driven Applications
Komninos[18]			x	x	x	
Al-Hader et al. [16]	x		x	x	x	
Anthopoulos and Fitsilis [19]	x	x	x	x	x	
Luca et al. [22]			x	x	x	
Harrison et al. [15]	x	x				x
Lugaric et al. [26]	x	x	x	x	x	
Al-Hader and Rodzi [27]	x	x				

tectures and comparison are drawn in Table I.

As shown in Table I, most of the proposed architectures attached importance from data acquisition, transmission, storage and handling, support service and domain service, however, few of them identify the importance of integrated intelligence, namely the transparency of smartness for end users. Mostly approaches discuss the importance of smart transportation, smart gas, smart health and other smart-X applications. From our architecture, it is believed that the data vitalization, or integration of data from heterogonous source, will play a vital role in smart city implementation.

Furthermore, few of the proposed architectures talk about administration, security and standard. Smart city is not just a long list of smart applications enabled by advanced technologies. It is believed these features are the critical successful factors in smart city implementation.

IV. Critical Success Factors

Success of implementing a smart city cannot rely on employing advanced techniques alone. Several other essential critical factors also deserve to be highlighted. Particular importance will be attached to administration process changes: changing from legacy to smart processes, and then updating to new smart processes. Furthermore, security is critical in all aspects of the smart city so security contracts are required and standardization of the smart city is important for implementation.

4.1 Administration

A smart city is stimulated by city government with assistance from industry, research institutes, and other organizations. Smart cities bring a new viewpoint for administration which requires changes of process to be admitted and three main requirements must be met to make a smart city successful.

1) Top management support. To achieve an event aware smart city, it is fundamental to change the administration processes to enable different information systems to work together smoothly. Top management support (TMS) is then becoming an essential factor to its success [70]. In fact, only with fully educated staff members' support from top management, can the strategic management for a smart city be made.

2) Investment. Smart city implementation and maintenance is an expensive task. Currently there is much discussion of employing hybrid investment options, such as BOT (Build-Operate-Transfer), BOO (Build-Own-Operate) to enable smart city development and operation. In a smart city, an important issue to be considered is how to use the data itself to make profit. Data is now a strategic resource and it will be helpful to offer securely controlled and monitored access the data to boost data intensive service and applications.

3) Citizen's Real Experience in Smartness. A smart city is not just the deployment of a set of information systems. The main objective of a smart city is to provide every person a smarter experience with regard to an event. The intelligent service will become the core

part of smart city's evaluation [71]. As such when we deploy a smart city service, how we make it collaboratively interoperate with other intelligent services is the next challenge for smart city implementation.

4.2 Security

Data is essential to underpin a successful smart city implementation, thus the security of smart cities is of vital importance. Since the data in a smart city includes individual, enterprise, and state economic data, providing the right level of security for sensitive information for citizen, governments, and enterprises when they use *smart* services is a major requirement. The security system of smart city should be applied pervasively to all layers from data acquisition to applications, with the relevant different types of security requirements and techniques.

1) Sensor security. The security of data acquisition provides protection for sensor content. This involves rich interplay between many disciplines, such as, signal processing, hardware design, supply-chain logistics, privacy rights, and cryptography [52]. Security mechanism, such as trusted platform module (TPM) [72] for RFID privacy, identity-based encryption [73], key management [74], quantum cryptography [75] need be properly applied to ensure the reliable and secure, authentication, integrity and confidentiality of data and metadata.

2) Transmission security. When the data are transmitted during the network, it is necessary to protect the security of the network by preventing network attack, illegal intrusion, and maintaining a secure network topology. Various techniques including network intrusion detection [76], network management, and authentication technology [77] are needed to identify unauthorized use, misuse, and abuse of computer systems by both inside and external adversaries.

3) Data vitalization security. The data vitalization layer should prevent vitalized data from being revealed, damaged, or tampered with by those without authorization. Techniques can be used to determine the source of data, add metadata that provide information on specific characteristics, and insert hidden information into the content, e.g. virtual tag [78], which will be used to track the data history.

4) Application security. The security of the support layer is mainly about protecting cloud computing and platform services. Various services can be used to guarantee the security of corporate data in the cloud [79]. Securely introducing an effective third party auditor (TPA) [80] is required for cloud data storage security, and a cloud service access control model based on negotiation technologies [81] can help protect cloud services.

4.3 Standards

A smart city comprises a huge number of information systems deployed across the city. Different systems have different stakeholders, domains and usage contexts. As such to have a single standard system for smart city is essential to maintain interoperability among different information systems to ensure event awareness. We define three levels of smart city standard.

1) Standard framework: The first challenge for smart city standards is to build a set of general standards to make smart city a consistent system. Since there will be a large number of information systems deployed in the smart city, there exists lots of standards from different communities. As such a standard framework is a preliminary and compulsory to make each system in smart city work together according to the overall standard. It is the framework that points out the direction for the development of the smart city because it provides the information sharing and social services standard guideline in which terminology, architecture, interoperability, and evaluation metrics should be attached much importance.

2) Basic standards: Basic standards are a set of standards dealing with fundamental technologies employed in smart city's implemen-

tation. From the data handling's perspective, it should cover the range from information acquisition, transmission storage, vitalization to processing and utilization. It mainly includes the standard of sensing technology, wired and wireless transmission, data storage, data processing and software resource.

3) Application standards: Applications are essential to a successful smart city as they are the interfaces through which the citizens directly interact with the city. To make them interoperable and achieve event aware smartness, a set of standards from the viewpoints of information system development and deployment, middleware, platform technology, and domain services should be attained prior to smart city implementation.

4) Security standards: The standards for smart city security should be considered from two perspectives. First, standards should cover all technique related to security to make it resistant to external attacks and information leaking. Secondly, standards should also take into account the management aspects to avoid improper information usage.

V. Conclusions

We have presented the smart city architecture from s data perspective. Its six layers of Events, Domain Services, Support, Storage and Vitalization, Data Transportation, and Data Acquisition cover all aspects of a smart city. The set of critical success factors we outline enable the smart architects to focus on the right areas of security and administration in a smart city's infrastructure. Our smart city architecture offers the community further insight and a reference to current critical thinking in affecting a successful smart city.

Acknowledgement

This work was partially supported by the National Natural Science Foundation of China (No. 61272350), the National High Technology Research and Development Program of China (No. 2011AA010502), and the Fundamental Research Funds for the Central Universities. We are grateful to Shenzhen Key Laboratory of Data Vitalization (Smart City) for supporting this research.

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