Smart City Architecture for Community Level Services Through the Internet of Things

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***Abstract*—Today, more than half of the world's population spend their lives in cities, and this number will jump to 70 percent by 2050. Increasing population density in urban environments demands adequate provision of services and infrastructure. This explosion in city population will present major challenges including air pollution, traffic congestion, health concerns, energy and waste management. Solution to these challenges might require the integration of various Information and Communication Technologies into the artifact of the city. This paper presents an architecture for smart cities, where city management, community service providers and citizens have access to real time data which has been gathered using various sensory mechanisms in order to analyze and make decisions for future planning.**

Keywords—Smart Cities; Internet of Things (IoT); network architecture; big data analysis; Wireless Sensor Network (WSN).

I. Introduction

Smart city is a new paradigm in the Information and Communication Technology (ICT) era which provides the infrastructure for citizens to access many services easily, and for governing bodies to intelligently manage and control the resources in a city. Smart cities use ICT to sense, analyze and integrate the information in running cities [1]. As the populations of cities are growing [2]and the boundaries of cities expanding, the concept of a smart city is gaining momentum on the agenda of local governments, as it can be seen as a crucial means to transform the traditional cities in order to improve economic growth, technological progress, and environmental progress and sustainability [3].

Two major developments have been happening in ICT that definitely have an impact on how cities are managed namely, (1) The Internet of Things (IoT); and (2) Mobile telecommunication. The Internet of Things (IoT) is a new notion in the realm of telecommunication which was introduced by Kevin Ashton in 1999 [4]. Semantically, IoT means interconnected things and objects which are individually addressable and interact with each other using standard communication protocols [5]. It is predicted that the IoT could penetrate ordinary life by 2025 [5].

In parallel to the developments in IoT, mobile communication has expanded around the world over the last few years, and today there are more than 5.6 billion mobile phones in use worldwide [6]. Each call, text and instant message contributes to the vast amount of data generated every day. Mobile devices, particularly smartphones and tablets, have various built-in sensors, with so many applications that can use and share data collected from these sensors.

Based on the expansion and development of technology, data has increased in scale in multiple fields. The data size produced every day is steadily increasing as a result of the expanding use of ICT and the increasing number of mobile devices such as mobile phones, tablets, personal computers and other devices resulting from the latest advances of IT. Hence, data have become an important feature in human daily life. Also with rapid growth of the IoT and cloud computing [7], there is a potential to develop real time applications to monitor the environments of users. The challenge however is how to collect and store large amounts of data from various sources of information and different types of technologies, and how to deliver it to the appropriate destination, while considering the requirements of each application. Mobile sensor networks and pervasive computing technology has emerged to help in developing a platform for analyzing large sets of data.

A smart city can potentially use ICT such as wireless sensor network, RFID and mobile communications as the sensing component to build infrastructure and services for city management, healthcare, public safety, and transportation [8]. A smart city can also use various analytical tools to analyze the huge amount of data which is created by people, objects, sensors, and other devices.

The objective of this paper is to present general reference architecture for the design of smart cities and its services. While there are currently many tools and frameworks that allow researchers and developers to collect and analyze data at the user level, a parallel framework for data collection and analysis at the community level is still absent. Such a framework can benefit from various models to build smart city applications for urban planning, sustainable communities, transportation, public health, public security, and commerce.

The rest of the paper is organized as follows: in Section II, we present various smart city enabling technologies. Our proposed architecture for a smart city framework is presented and discussed in Section III. In section IV we introduce some useful applications which we can run on a smart city platform. An example use case of the framework that focuses on smart community healthcare is presented in Section V and conclusions and future works are drawn in Section VI.

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II. SMART CITY ENABLING TECHNOLOGIES

A. *Sensing and identification*

Wireless technologies play a crucial role in the sensing and identification of objects. Today the ratio between radios and humans is nearing the 1 to 1 value [5]. Hence there is extreme potential to install the wireless adaptor on all objects around us and enable the IoT concept. Besides, more research is necessary to build and merge identification technology that acts on the world wide scale. This research needs to comprise of managing identifiers for real things and objects, support multiple identifiers for human and geo-locations, and also authenticate and authorize the entities regarding their positions.

Sensor networks will also play a vital role in IoT and work side by side with RFID to better track the status of things such as location, temperature, movement, etc. Sensor networks consist of very large number of nodes and would result in a problem when we use the IP protocol. However the current IPV6 protocol can address 10^{38} nodes, this is enough to address the entirety of objects in the world without any fear of IP availability, but the sensor networks spend a tremendous amount of their time on sleep mode to save energy; so there is a difficulty when IP protocol is used. In contrast to the authors' claim in [5] which try to adapt the entire network with IP protocol , this problem completely depends on the architecture. We don't necessarily need to use IP protocol to connect the objects to the network. As long as we have the ability to integrate entire objects and make a network, it would not matter which technology has been used. In particular, we can use cloud–centric architecture to eliminate worries about the object availability during communications.

Above all, sensor networks have large radio coverage and they can communicate with each other as peers in a peer-to-peer fashion. In contrast, RFID systems need the readers to communicate and they cannot create multi-hop network without any readers.

B. *IPV6 Mobile RFID*

RFID tags are one of the important parts of IoT. RFIDs are used by many things such as merchandise in the stores, maps, and posters, even passports have RFID tags to prevent forgery and determine fake documents. Since mobile phones are increasingly being equipped with Near Field Communication (NFC) technology they may be adapted to read RFID tags and extract some useful information such as multimedia from the tags.

One of the challenges and issues with reading RFID tags by mobile phone is the long transmission delay. In [9] the authors present a new way by integrating IPV6 with mobile RFID to decrease the transmission delays. By integrating mobile RFID with IPV6 a mobile device we can obtain data without any delay by eliminating the data transfer among many servers.

C. *Collaborative sensing*

Mobile data traffic is expected to grow faster than the fixed Internet in the coming years. The rapid growth of demand for high-speed Internet access service has encouraged worldwide standardization and deployment of broadband wireless access (BWA) and demand for higher capacities have increased exponentially [10]. Collaborative or participatory sensing is a new method to share sensory information by humans. Building on the growth in smart phones and mobile devices, people around the world can easily sense the environment and share the information via other persons or machines.

III. PROPOSED ARCHITECHTURE FOR SMART CITY

Developing the architecture is usually the initial step in the direction of a solution. It actually depends on the applications that would use the platform, but designing the general architecture which can fulfil the requirements for all applications and services is one of the challenging parts in smart cities. There are many architectures available, such as M2M architecture [11] and cloud based architecture [1], which have a specific requirements for design and implementation. Most of the works related to IoT architecture have been from the wireless sensor network perspective [8].Creating a widespread architecture for the Smart City is a complicated job, mainly because of the exceedingly large diversity of objects and devices, link layer technologies, and services that may be associated in such a system. There is also a high degree of interdependency between various infrastructures of a smart city, which adds to the complexity of community data analysis.

IoT consist of many things like smart phones, tablets, cameras, sensors and so on. Every day the number of objects increase and the way to collect the information among the objects change. Consequently, objects produce a huge amount of data and information. Cloud computing is an ideal technique to support this amount of information, and run many services on top of it. In our proposed architecture cloud computing is used to solve the big data issues and challenges. In addition, cloud computing provides access to all the resources such as mobile devices, sensors, actuators, and tags any time, from any location. Applications which interact with sensors and objects around us should have special requirements to deal with big data, and also they should have appropriate computational ability to compute big data.

In this section we will introduce a new architecture for smart cities which can solve some of the above challenges. Our architecture (Figure 1) consists of three layers which are sensing layer, network layer and control layer.

A. *Sensing Layer and data collection*

Heterogeneity is one of the important characteristic of sensing layer, which often contains a variety of subnetworks adopting different communication technologies [12]. In order to overcome the difficulty of collecting data in heterogeneous networks, we need a generalized framework for data collection. This framework should retrieve data continuously or at random intervals.The objects in IoT are so small and most of them have a limitation on computation and energy. Therefore algorithms have to be designed to use energy more efficiently as this is crucial.

There are generally three sensing resources in our architecture: wireless sensor network (WSN), RFID and crowdsourcing.

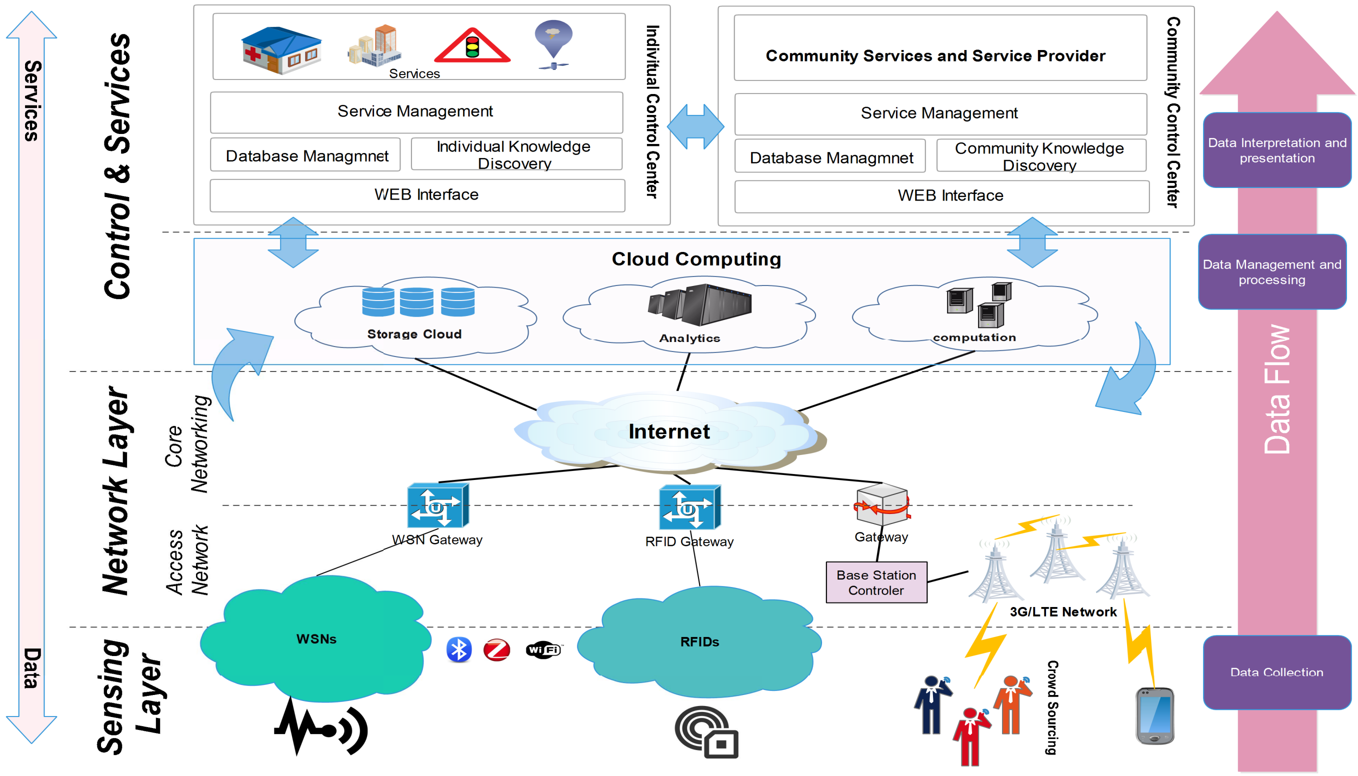

Figure 1- Proposed architecture for smart cities

WSNs play a crucial role in the sensing layer; it enables the collection, processing and analysis of data in any kind of environment. RFID technology provides us with the ability to install the tags on an entire object and monitor them remotely so we can use it in any kind of application, from transportation to supply chain management. Also passive RFID tags help us to equip many objects with sensor capability and connect them to the network with no concern for energy consumption.

Based on the expansion of social networks and the increasing number of mobile devices, citizens share their social activity and observation in interactive environments [13]. With this participatory sensing, service providers are able to collect data easier than through other methods.

B. Network Layer

In this layer, we provide the communication infrastructure to deliver the data from sensing layer to control layer and vice versa. One of the major parts of communications in our architecture is the internet, so we need to adapt the entire platform to IP technology in order to route the data through the internet. In the network oriented vision of IoT, many alliances and councils try to adapt the IoT to IP technology. For instance, 6LoWPAN [14] and Internet0 have followed the approach of reducing the complexity of IP stack to achieve the protocol designed to route IP over everything [5]. In the proposed architecture the focus is on how to connect objects to each other for information exchange rather than on bringing IP technology to the things and objects. For this purpose, we consider the gateway as an interface between the sensing layer and core networking layer to translate the protocols used in the sensing layer to IP. Also a large number of users use mobile phones and telecommunication networks such as 3G or LTE, so we need another gateway to connect these networks to the internet. Furthermore, in the proposed architecture we aggregate the data which is collected from multiple sources if needed.

C. Control and Services

In order to work with thousands of applications in smart cities and also working with various service providers, cloud based architecture has been proposed in Figure 1. This architecture allows developers, service providers and data miners to join the network and offer their services.

In the proposed architecture a distinction is made between community services and individual services, therefore the task is separated into two control centers. In order to communicate with other entities such as remote users or monitoring section, the web interface may be considered as a general interface for control centers. Each control center consists of a database management, knowledge discovery and service management section. These sections are responsible for retrieving data from data bases, applying some data mining algorithms to find interesting patterns in the data, registering and managing the services which are provided by multiple service providers. To achieve these goals a powerful computational resource is needed, hence we consider the cloud based analytical and computational module. All the data that is collected from the sensing layer is processed on the fly on its way to the database. The control center does not need to communicate with each entity and sensor individually in order to get data. The notable difference between community control center and individual control center is the type of knowledge discovery methods that is applied to data. Furthermore service providers at the community level are more interested in providing the service for the community than for individuals. As shown in Figure 1 there are some conceptual relationships between the control centers, database cloud, and analytical cloud, but the actual data path is among the core networking layer.

D. *Addressing scheme*

One of the crucial parts in Internet of Things and smart cities is how objects are uniquely identified. It is important to recognize millions of objects and devices and supervise them remotely. So, all connected devices and those which are going to connect have to be identified by a unique identifier. In addition, object location can be used as part of the identifier. The method used to address the objects and devices should be scalable with network expansion.

In order to solve the scalability and performance issues, IPV6 is used. In contrast, we still have a problem at the interface between the Sensing layer and network layer, so a different protocol may be introduced such as 6LoWPAN and the gateway used to translate the address at the interface.

E. *Quality of service*

Based on the variety of protocols and technologies such as wired and wireless and due the heterogeneous networks and variety of services in smart cities, providing the QoS for the entire network is one of the challenging problems. Each application has its own requirements and its own QoS parameters. We have two types of real time network traffic in our platform: delay sensitive traffic and delay tolerant traffic which may be recognized by data related applications with different QoS requirements. Therefore, our QoS mechanism should be a built in algorithms for the entire network.

F. *Data processing*

Data collected from a variety of sources in the sensing layer is transferred to the control layer via the core networks. This data may also have been aggregated if necessary. After collecting data, we can convert it to knowledge and store it in the database or consume it in real time. Computational intelligence techniques such as genetic algorithms, evolutionary algorithms, Data mining algorithms and neural networks are necessary [12]. Moreover, real time temporal abstraction can be based on rule-sets rather than these techniques.

G. *Privacy*

Privacy of citizens is one of the important issues when the cities become smart. In [15] the authors have presented the basic model for citizen privacy which consist of five dimensions: query privacy, location privacy, owner privacy, foot print privacy and identity privacy. The model which was presented can be applied to any aspect of citizen privacy and any kind of smart city. However its success will depend on some inherent aspects that should be addressed. There is a need for an intermediary layer that would receive the data from various data publishers in a smart community, and analyze and prepare it for use in various applications. In the proposed architecture we consider such a layer (control and services), and it is easy to apply the privacy model to it.

IV. SMART CITIES APPLICATION

Smart cities provide good infrastructure for developing a large number of applications. These applications can help citizens and governments to improve the quality of life and simplify the services which are offered by city administrators. Moreover, some of the environments around us are equipped with intelligent objects but they do not have ability to connect to other objects and devices. Smart city approaches have the potential capacity for running many applications such as transportation, healthcare, smart environment, personal and social domain. Smart city construction can be divided into three sections: infrastructure; construction of platform; and application construction. Application construction is one of the important parts for smart city development. In this section we review the top three useful applications which can run on the proposed smart city architecture.

A. *Transportation*

In recent years, many vehicles such as cars, trains, bicycles and airplanes are becoming equipped with sensors. These types of sensors can collect some information about the location, speed, and status of objects. By having such information we can manage traffic, routes and air pollution in cities. Also by equipping parcels and shipment packages with RFID tags we can track them easily and monitor the status of transported goods in a convenient way. As an illustration we have many applications such as assisted driving, mobile ticketing, environment monitoring, and augmented maps in the transportation category.

B. Healthcare

There is a rapid progress in developing smart healthcare and health monitoring in non-clinical environments around the world. Wearable technology is one of the promising technologies which can help us monitor healthcare remotely in a smarter way. Due to the ability to decrease sensor size and design accurate sensors nowadays, wearable sensors are becoming a growing trend [16].

The data gathered from sensors is important as it can then be processed into some form of useful information. Data mining is one of the viable methods applicable to the processing of the large amount of health data, such as vital signs, collected from wearable sensor networks. The question is whether working on integrated health data and mining has benefit for the community, and whether it is actually relevant [16].

At-home sensor monitoring systems and wearable ubiquitous technology form an instrumental component of a smarter city. Patients are becoming more active in taking care of their daily lives and improving their health problems. According to the US Census statistics in 2009, health care spent $2,486B, out of which home health care generated $68B [17]. The importance of human health sensing technology has been speculated to address stress management, preventive attention to falls, chronic disease supervision, and tele-monitoring rudimentary physiology in rural locations. Using intelligent sensor-based technology to improve healthy living is a key aspect of our proposed research plan.

C. Public Safety

Cities with larger populations often have higher crime rates. But large cities that also suffer from poor education and high unemployment rates create a breeding ground for criminal activity. In recent years crime recording and reporting is carried out using technological methods which have enhanced efficiency of outputs. This data is not only a record of crime details; it also provides any existing relations between crime scenes and an offender's modus operandi [18]. For many years, criminologists and statisticians have been using their skills and knowledge to predict time and location for the occurrence of the next set of crimes, with different degrees of success. Since September 11, the use of data mining has considerably increased in different areas such as crime detection, and behavioral profiling. Behavioral profiling looks for suspicious behavior using available digital information found in diverse databases and recognizes patterns of criminal activities in order to find perpetrators. Data mining, as with criminal analysis, has the same overall goal: the detection and prevention of crimes. With a smart city platform you would install cameras and sensors around the city to automatically monitor criminal activities. Also there is potential to predict the crimes based on the citizens activity in social networks [19].

V. SMART COMMUNITY HEALTHCARE – A CASE STUDY

Over the years there has been a tremendous growth of mobile technology and the abundance of end-user biometric devices[20]. However, social and medical problems will exist if the technology infrastructure planning is overlooked. We believe that our social communities require immediate medical facilities such as real-time monitoring of children, elderly and sick, proper diagnosis as a result of heart-attacks, preventive methods as a result of influenza outbreak and well-connected secure health-care system.

In order to prove the architecture that we proposed, we created a small test bed. The architecture shown in Figure 2 contains physiological sensors (heart rate, blood pressure, patient position, oxygen saturation, air flow, GSR, body temperature and EMG) which are connected to a Raspberry Pi/ Arduino board. The raw data have been collected from the sensors and converted to a stream and transmitted to the mobile phone via Bluetooth technology. Also we acquire weather condition from weather stations and aggregate our data with weather status.

Our control center consist of 4 separate conceptual servers: database server, web server, analytic server and service management server but all are located in one physical server.

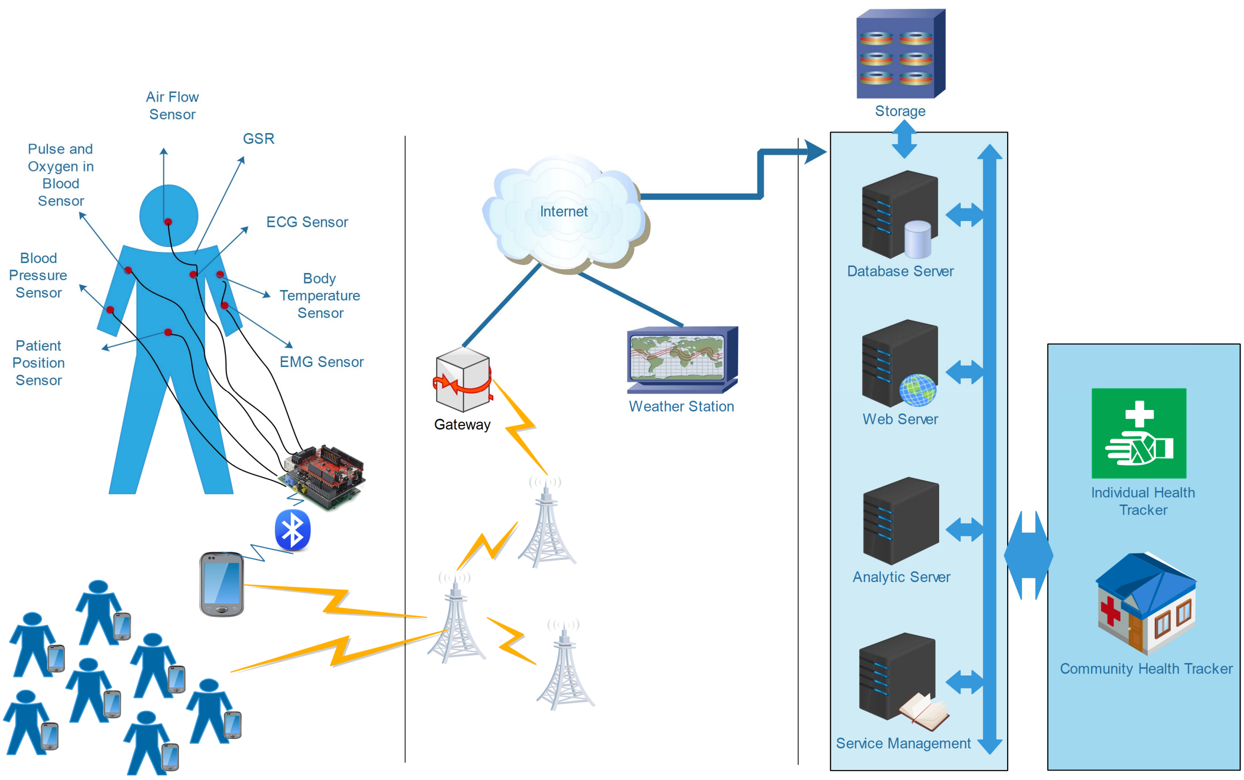

Figure 2- Smart healthcare

The aggregated data have been transferred to our control center via a web service and can be passed as a data stream to our analytic server in order to find the anomalous patterns, while simultaneously we store the data stream on our local control center database. Service management server controls the services who want to use the analytical data such as individuals or community health trackers.

The significance of our proposed architecture is to illustrate the benefits of enabling real-time pervasive computing in healthcare situations and furthermore prove that such technology can be viewed as helpful by the community.

VI. CONCLUSION

Cities have changed a lot over the last century. As populations have risen cities are faced with a scarcity of resources and have to re-think their approaches to management. Within the next 35 years the world's cities will double in size [2], therefore smart cities are needed to manage this sharp increase. In this paper we proposed a cloud based general architecture for smart cities that allows the community service providers, city management and citizens to access the real time data which has been gathered from the city through IoT to ensure the provision of essential services and improved quality of life for city inhabitants.

In future work we will demonstrate an extended version of this architecture through the integration of Apollo [21], a remote monitoring approach demonstrated within the context of monitoring neonatal intensive care unit graduates in the home. We will further demonstrate its integration with Artemis Cloud [22], a cloud based service for online health analytics for use within the community to support personalised online health analytics.

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