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IoT Based Smart Cities: A Survey on Enabling Technologies, Applications and Challenges

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Abstract - *Increasing population density in urban centers demands suitable provision of services and infrastructure to meet the needs of city inhabitants, surrounding residents, workers and visitors. The utilization of information and communications technologies (ICT) to achieve this objective presents an opportunity for the development of smart cities, where city management and citizens are given access to a wealth of real time information about the urban environment upon which to base decisions, actions and future planning. The aim of this article is that of providing a comprehensive review on the concepts of smart cities and their applications. Moreover, this survey describes the IoT technologies for smart cities and the main challenges are explained.*

Keywords*— Internet of Things (IoT), Smart City, Smart Grids, RFID, WSN, ZigBee.*

I. INTRODUCTION

According to a prediction based on a survey, it is estimated that 70% of the world's population (over 6 billion people) will live in cities and nearby regions by 2050. Due to the rapid growth of the population density in urban cities, infrastructure and services are required to provide the necessities of the city residents. The cities need to be smart so as to survive as platforms that allow economic, social and environmental safety. A smart city is defined as the ability to integrate multiple technological solutions in a secure fashion to manage the city's assets – the city's assets include, but not limited to, local departments information systems, schools, libraries, transportation systems, hospitals, power plants, law enforcement, and other community services [1]. Smart City is driven by Internet of Things (IoT) which is the network of physical objects, devices, vehicles, buildings and other items that are embedded with electronics, software, sensors, and network connectivity, which enables these objects to collect and exchange data. The Internet of Things allows objects to be sensed and controlled remotely across existing network infrastructure, creating opportunities for more-direct integration between the physical world and computer-based systems, and resulting in improved efficiency, accuracy and economic benefit. Experts estimate that the IoT will consist of almost 50 billion objects by 2020[2]. This paper presents a review of the IoT-based smart city,the architecture of IoT. IoT technologies associated with the Smart City services, the main applications of the IoT for smart cities and future challenges and trends of Smart cities.

II. IoT ARCHITECTURE

The IoT should be capable of interconnecting billions or trillions of heterogeneous objects through the Internet, so there is a critical need for a flexible layered architecture. The basic model is a 3-layer architecture with Application Layer, Network layer and Perception Layer.

A. Perception Layer

Perception layer, represents the physical sensors of the IoT that aim to collect data that will be the key for process initiation. This layer is defined with sensors and actuators to perform different functionalities such as querying location, temperature, weight, motion, vibration, acceleration, humidity,and other necessary parameters.

B. Network Layer

Network Layer transfers data produced by the Perception layer to the Application layer through secure channels. Network uses various technologies such as RFID, 3G, GSM, UMTS, WiFi, Bluetooth Low Energy, infrared and ZigBeefor transferring Data the subsequent layer. This layer also takes care of data management processes.

C. Application Layer

The application layer provides services requested by customers. For instance, the application layer can provide temperature and air humidity measurements to the customer who asks for that data. The importance of this layer for the IoT is that it has the ability to provide high-quality smart services to meet customers' needs. The application layer covers numerous vertical markets such as smart home, smart building, smart transportation and smart healthcare.

III. IoT TECHNOLOGIES ASSOCIATED WITH SMART CITIES

IoT allows the integration of different types of information and communication technologies, enabling the interaction Person-to-Machine (P2M) or Machine-to-Machine (M2M). The technologies involved have been adapted to ensure interoperability and to meet the connectivity requirements from the IoT perspective. In this section, the main technologies that are being implemented in IoT solutions for Smart Cities are presented.

A. Wireless Sensor Networks (WSN)

A WSN is a collection of low-power devices that are distributed in a geographical area bounded to perform some monitoring task. The sensors and the so-called sink node, where all the information are gathered, are wirelessly connected. The sensor nodes have the ability to locally store and process data and to communicate with other nodes in the network for collaboration purposes.

B. Radio-Frequency Identification (RFID)

Radio-Frequency Identification (RFID) is the use of radio waves to read and capture information stored on a tag attached to an object. These systems consisting of readers and tags are playing a key role in the context of the IoT. By applying these technologies to any involved object, it is possible to carry out their automatic identification and assign a unique digital identity to each object, in order to be incorporated in the network and related to the digital information and service [4].

C. Near Field Communication (NFC)

Near Field Communication is considered as a wireless technology that uses high frequency for data transmission. NFC uses the same communication principle that RFID where reader devices have a coiled antenna that produces a magnetic field which energize the general passive tags allowing the data transmission between them. Nowadays many smartphones have this embedded technology that can be used in many applications including payments and identification cards.

D. 6LoWPAN

It describes the transmission of IPv6 packets over the IEEE 802.15.4 networks Protocols. This technology applies to Personal Area Networks (PAN) and the initial aim was to define ways of using IP (Internet Protocol) to be applied even to small devices and low power. The technology specifies how to apply IPv6 routing in wireless networks by compression and definition of specific headers [5].

E. ZigBee

It is a Communication protocol based on the IEEE 802.15.4 standard, commonly working at 2.4 GHz. It is widely used in the industry of home automation having great acceptance because it offers excellent communication features for applications that do not require high speed and in which there are power consumption limitations.

F. Z-Wave

It is a wireless communication protocol originally designed for home and buildings automation, with specific functions related to the control of lighting systems, ovens, refrigerators and security devices. Typical messages in this protocol are not significantly large because it was designed to offer small control messages and so critical data such as alerts or alarms could not be sent.

G. Data Mining

Data Mining is a field that seeks to discover patterns in large volumes of information. Undoubtedly, this process significantly complements the IoT vision especially in a Smart City, because as stated in [6] is necessary to convert the data captured by IoT devices into knowledge to perform statistical studies, decision making and extract real value of the collected data. Data mining can find hidden information in IoT data, which can improve system performance or quality of services

IV. IOT APPLICATIONS FOR SMART CITIES

The IoT applications for Smart City is represented in Figure 1.

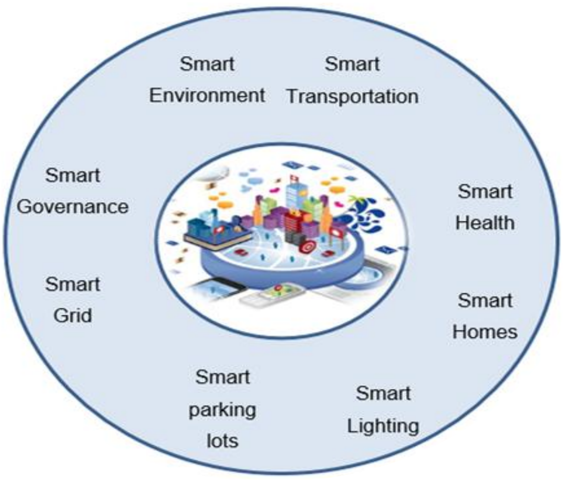

Figure 1 Applications of Internet of Things (IoT) for Smart City

A. Smart homes

Smart homes constitute a branch of ubiquitous computing that involves incorporating smartness into dwellings for comfort, healthcare, safety, security, and energy conservation. Remote monitoring systems are common components of smart homes, which use telecommunication and web technologies to provide remote home control and support patients remotely from specialized assistance centers. Smart homes offer a better quality of life by introducing automated appliance control and assistive services. They optimize user comfort by using context awareness and predefined constraints based on the conditions of the home environment. A user can control home appliances and devices remotely, which enables him or her to execute tasks before arriving home[7]. Ambient intelligence systems, which monitor smart homes, sometimes optimize the household's electricity usage. Smart homes enhance traditional security and safety mechanisms by using intelligent monitoring and access control

B. Smart Health

Smart Health includes remote monitoring, early prevention, chronic disease management, elderly care, medical treatment for institutionalized patients etc[8]. It allows us to establish intelligent connections assuring an effective healthcare system. Smart, wearable, interoperable, and more secure mobile medical devices can help healthcare professionals access patient data, drive care efficiency, and improve health outcomes from anywhere, leading to increased value for the patient. It replaces the process of having a health professional come by at regular intervals to check the patient's vital signs, instead providing a continuous automated flow of information. In this way, it simultaneously improves the quality of care through constant attention and lowers the cost of care in addition to data collection and analysis.

C. Smart Transportation

Intelligent Transport System helps cities to become smarter, manage traffic flow to reduce congestion, ensure safety compliance, and provide a cleaner environment. Traffic monitoring may be realized by using the sensing capabilities and GPS installed on modern vehicles, but also adopting a combination of air quality and acoustic sensors along a given road. This information is of great importance for city authorities and citizens: for the former to discipline traffic and to send officers where needed, for the latter to plan in advance the route to reach the office or to better schedule a shopping trip to the city centre[9].

D. Smart Governance

The number of available online services, their effectiveness and usage level and their level of interaction are important indicators of the "smartness levels" of e-government. Water, sewage, electricity and rates bills each have an ID tag which is read by the tag reader at the counter and automatically matched against user details in the database and update with payment is made.

E. Smart parking lots

The smart parking service is based on road sensors and intelligent displays that direct motorists along the best path for parking in the city[10]. The benefits deriving from this service are manifold: faster time to locate a parking slot means fewer CO emission from the car, less traffic congestion, and happier citizens. By using short range communication technologies, such as Radio Frequency Identifiers (RFID) or Near Field Communication (NFC), it is possible to realize an electronic verification system of parking permits in slots reserved for residents or disabled, thus offering a better service to citizens that can legitimately use those slots and an efficient tool for quickly spot violations.

F. Smart Environment

Sensors can be installed across the city which measure temperature, relative humidity, carbon monoxide, nitrogen dioxide, noise and particles. If any of the parameters go above a set threshold, the GPS enabled sensors send an alarm to a central node. The node in turn sends the information to the cell phones of the habitants.

G. Smart Grid

Smart Grid integrates energy generation, transmission and distribution network with control methods, integrated communications, real-time monitoring and two-way flow of electrical power and information. Smart Grid enables electricity companies and grid system operators to reduce capital expenditure, effective asset management, manage demand, increase renewable capacity, comply with regulations and enhance customer engagement [12].

H. Surveillance systems

In a smart city, security is the most important factor from the citizens' viewpoint. For this purpose, the whole smart city should be continuously monitored. However, analyzing the data and detecting crimes are very challenging. New scenarios proposed to enhance the security of the smart city are discussed in [13].

I. Smart Lighting

This service can optimize the street lamp intensity according to the time of the day, the weather condition, and the presence of people. In order to properly work, such a service needs to include the street lights into the Smart City infrastructure. It is also possible to exploit the increased number of connected spots to provide WiFi connection to citizens. In addition, a fault detection system will be easily realized on top of the street light controllers.

V. IOT CHALLENGES FOR ACHIEVING SMART CITIES

A. Security and privacy

When all the data are collected and analyzed in a common IoT platform, the system can be subjected to several attacks (e.g., cross-site scripting, and side-channel). This demonstrates the need for comprehensive security architectures that protect systems and data from end to end. This includes research in efficient applied cryptography for both system and data security, non-cryptographic techniques for security, and frameworks for helping developers more easily develop secure systems on heterogeneous devices. Even with cryptographic security services that are capable of running on resource constrained IoT devices, we need research to enable users of all skill levels to securely deploy and use IoT systems despite the limited user interfaces available with most IoT devices.

B. Availability

Availability of the IoT must be realized in the hardware and software levels to provide anywhere and anytime services for customers. Availability of software refers to the ability of the IoT applications to provide services for everyone at different places simultaneously. Hardware availability refers to the existence of devices all the time that are compatible with the IoT functionalities and protocols. Protocols such as IPv6, 6LoWPAN, RPL, CoAP, etc., should be embedded within the single board resource constrained devices that deliver the IoT functionality. One solution to achieve high availability of IoT services is to provide redundancy for critical devices and services [16].

C. Mobility

Mobility is another challenge for the IoT implementations because most of the services are expected to be delivered to mobile users. Connecting users with their desired services continuously while on the move is an important premise of the IoT. Service interruption for mobile devices can occur when these devices transfer from one gateway to another. [14] proposes a resource mobility scheme that supports two modes: caching and tunneling to support service continuity. These methods allow applications to access the IoT data in the case of the temporary unavailability of resources. The enormous number of smart devices in IoT systems also requires some efficient mechanisms for mobility management.

D. Interoperability

End-to-end interoperability is another challenge for the IoTdue to the need to handle a large number of heterogeneousthingsthat belongto different platforms. Interoperability should be consideredby both application developers and IoT device manufacturesto ensure the delivery of services for all customersregardless of the specifications of the hardware platform that theyuse. For example, most of the smartphones nowadays supportcommon communication technologies such as WiFi, NFC, andGSM toguaranteetheinteroperabilityindifferentscenarios. Also, programmers of the IoT should build their applications to allow for adding new functions without causing problems or losing functions while maintaining integration with different communication technologies. Beside variety of protocols, different interpretations of the same standard implemented by different parties presents a challenge for interoperability.

E. Large scale

Some specified scenarios in IoT applications require the interactions between large numbers of embedded devices which are possibly distributed over wide area environments. The IoT systems provide a suitable platform that can analyze and integrate data coming from different devices. However, such large scale of information requires suitable storage and computational capability collected at high-rate which makes typical challenges harder to overcome. On the other hand, the distribution of the IoT devices can affect the monitoring tasks because these devices must handle the delay related to dynamics and connectivity

F. Reliability

Reliability refers to the proper working of the system based on its specification. It has a close relationship with availability as by reliability, we guarantee the availability of information and services over time. Reliability is even more critical and has more stringent requirements when it comes to the field of emergency response applications [15]. In these systems, the critical part is the communication network which must be resilient to failures in order to realize reliable information distribution.

G. Big data

Considering about 50 billion devices, it is certainly necessary to pay attention to transferring, storing and recalling and also analyzing such a huge amount of data produced by them. It is obvious that the IoT infrastructures will be some of the major resources of big data.

H. Sensor networks

Sensor networks can be considered as one of the most important technologies to enable the IoT. This technology is able to shape the world by providing the ability of measuring, inferring, and understanding environmental indicators. Recent developments and enhancements in technologies have provided devices with high efficiency and low-cost to employ remote sensing applications in large-scale [17]. In addition, smartphones are associated with a diversity of sensors and, consequently, they enable a variety of mobile applications in several areas of IoT. To this end, the major challenging task is to process the large-scale data of the sensors in terms of energy and network limits and various uncertainties.

V. CONCLUSION

With rapid expansion and the growth of cities, making them smart becomes vital. The Smart City concept aims to make better use of public resources, improving the quality of services offered to the citizens and reducing the operational cost for the public administration. In this work, we presented an overview of IoT in the context of smart cities, and discussed how it can enhance a city's smartness. We also identified the challenges and risks associated to IoT deployment and adoption in the smart city environment. As part of our future work, we plan to survey the different solutions and recommendations to address several of the challenges of IoT and smart cities we have discussed in this paper and in particular the security challenges and issues.

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