Internet of Things Applications: Current and Future Development

Chapter · July 2016

DOI: 10.4018/978-1-5225-0287-6.ch016

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Innovative Research and Applications in Next-Generation High Performance Computing

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A volume in the Advances in Systems Analysis, Software Engineering, and High Performance Computing (ASASEHPC) Book Series

Information Science REFERENCE
An Imprint of IGI Global

Published in the United States of America by
Information Science Reference (an imprint of IGI Global)
701 E. Chocolate Avenue
Hershey PA, USA 17033
Tel: 717-533-8845
Fax: 717-533-8661
E-mail: cust@igi-global.com
Web site: http://www.igi-global.com

Library of Congress Cataloging-in-Publication Data

Names: Hassan, Qusay F., 1982- editor.
Title: Innovative research and applications in next-generation high performance computing / Qusay F. Hassan, editor.
Description: Hershey : Information Science Reference, 2016. | Includes bibliographical references and index.
Identifiers: LCCN 2016007158| ISBN 9781522502876 (hardcover) | ISBN 9781522502883 (ebook)
Subjects: LCSH: High performance computing.
Classification: LCC QA76.88 .H38 2016 | DDC 004.1/1--dc23 LC record available at https://lccn.loc.gov/2016007158

This book is published in the IGI Global book series Advances in Systems Analysis, Software Engineering, and High Performance Computing (ASASEHPC) (ISSN: 2327-3453; eISSN: 2327-3461)

British Cataloguing in Publication Data
A Cataloguing in Publication record for this book is available from the British Library.

Chapter 16
Internet of Things Applications:
Current and Future Development

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ABSTRACT

The Internet of Things (IoT) brings connectivity to about every objects found in the physical space. It extends connectivity not only to computer and mobile devices but also to everyday objects. From connected fridges, cars and cities, the IoT creates opportunities in numerous domains. This chapter briefly surveys some IoT applications and the impact the IoT could have on societies. It shows how the various application of the IoT enhances the overall quality of life and reduces management and costs in various sectors.

INTRODUCTION

The Internet of Things (IoT) is the future of the Internet. It provides societies, communities, governments, and individuals with the opportunity to connect and obtain services over the Internet wherever they are and whenever they want. The IoT enhances communications on the Internet among not only people, but also things. The IoT introduces a new concept of communications which extends the existent interactions between human and computer's applications to things. Things are objects of the physical world (physical things) or of the information world (virtual things). Things are capable of being identified and integrated into the communication networks. Physical things such as industrial robots, products and electrical equipment, are capable of being sensed, actuated and connected to the Internet. More specifically, a physical thing can be described as a physical object equipped with a device that provides the capability of connecting this physical object to the Internet. The International Telecommunication Union (ITU) defines a device in the IoT as a piece of equipment with the mandatory capabilities of communications,

DOI: 10.4018/978-1-5225-0287-6.ch016

and the optional advanced capabilities of sensing and actuating (ITU, 2005). On the other hand, virtual things are not necessarily physical or tangible objects. They can exist without any association with a physical thing. Examples of virtual things are multimedia contents (Francesco, Li, Raj, & Das, 2012), and web services which are capable of being stored, processed, shared and accessed over the Internet. Notwithstanding this, a virtual thing may be used as a representation of a physical thing as well. For instance, most of today's computer databases and applications use some sort of virtual representation of physical entities i.e. the use of objects or classes in object oriented programing approaches (Rumbaugh, Blaha, Premerlani, Eddy, & Lorensen, 1991). Therefore, communications in the IoT can occur between not only the users and things, but also exclusively between things. This includes "physical things" to "physical things" communications, "virtual things" to "virtual things" communications, and "physical things" to "virtual things" communications. This heterogeneity of communications extends computation and connectivity on the Internet to anything, anyplace and anytime. As a result, the IoT is expected to be seen everywhere and in numerous application domains, such as manufacturing, smart cities, agriculture and breeding, environmental management, smart homes, and in a variety of service sectors among many others.

From a networking perspective, the IoT can be described as a heterogeneous network that combines together several wired and wireless networks, including low-power wireless networks and personal area networks, with an increasingly complex structure (Elkhodr, Shahrestani, & Cheung, 2014). This heterogeneous network connects a mixture of devices together. It encompasses devices which connect to the Internet using various types of wireless and LAN technologies such as Wi-Fi, RFID, ZigBee, Bluetooth, and 3G or 4G technologies among other evolving communication technologies.

The term IoT, while it may sound odd, was first coined in 1999 by the founders of the original MIT Auto-ID Center Kevin Ashton (Ashton, 22 July 2009). Auto-ID refers to any broad class of identification technologies used in the industry to automate, reduce errors, and increase efficiency. These technologies include barcodes, smart cards, sensors, voice recognition, and biometrics. Therefore, the initial vision of the IoT was to tag physical objects, using RFID tags, and to uniquely identify these objects using RFID transponders or readers. RFID technology has enabled users to identify and track objects within a relatively small networked environment e.g. within a warehouse. As Neil Gershenfield noted as early as 2000, the cost of individual RFID tags had dropped below a one cent, making their adoption within diverse business areas not just technically possible but economically feasible as well (Neil, 2000).

Nowadays, the IoT has grown from RFID tags to a global infrastructure of connected things. The current advance in technologies has extended the vision of the IoT by encompassing other technologies such as sensor networks. The IoT has now more potential to provide an intelligent platform for the collaborations of distributed things via local-area wireless and wired networks, and/or via a wide-area of heterogeneous and interconnected networks such as the Internet. This is inspired by not only the success of RFID technology, but by the advance of wireless communication technologies and their wide range and low-power consumption capabilities.

Consequently, the availability of information coming from non-traditional computer devices in the digital world will, in great parts, lead to improving the quality of life. If the IoT spreads to all sectors of the daily life, then information technology would be taken to a whole new level. Over the next couple of years, it is predicted that the industrial value of the Internet of Things will surpass that of the Internet 30 times over, and to be a market that is worth more than $100 billion dollars (Clendenin, 2010). On the other hand, it is estimated that there will be more than 20 billion devices connected to the Internet by 2020 (Lomas, 2009). The number of connected devices rises to over 50 billion as predicted by Cisco (Evans, 2012).

The IoT will revolute many industries and elevate communications on the Internet. The opportunities offered by the IoT are endless. IoT services provide the user with numerous services and capabilities. The obvious ones are the ability to control and monitor the physical environment remotely over the communication networks. Typical examples are the ability of closing a door or receiving smoke alert notifications remotely over the Internet. However, the revolution in technology actually occurs when things and group of things are connected together. The interconnection of things allows not only things to communicate with each other, but also offers the opportunities of building intelligence and pervasiveness into the IoT. The interconnected network of things, along with backend systems involved in a number of collaboration activities with the users and other things, in tandem with cloud computing systems, Big Data, web services, and Location Based Services, will transform not only communications on the Internet but also societies (Elkhodr, Shahrestani, & Cheung, 2013). The IoT will enable the sharing of information between different domains which leads to improving the overall quality of services (Zorzi, Gluhak, Lange, & Bassi, 2010). For example, the ability of sharing health information between different healthcare professionals such as nurses, doctors, and pharmacists will enhance the quality of healthcare (Parwekar, 2011). Consequently, it is expected that the IoT will penetrate many industries. It is regarded as a new wave of technology that will not only benefit the everyday user, but also offer many organizations promising businesses opportunities.

Henceforth, this chapter surveys some of the most envisioned IoT applications and the impact the IoT could have on various aspects of life. It explores some of the major opportunities offered by the IoT. Given that the possibilities promised by the IoT are enormous and are only limited to our imaginations, the chapter mainly focuses on a few interesting IoT applications rather than attempting to survey all anticipated IoT applications. For instance, one important area in which the IoT is promising to revolute is healthcare. The aim of bringing the IoT to the health sector is to enhance healthcare and medical service delivery; hence, saving more lives. Assisted living, remote health monitoring, smart homes, smart water, automation, industrial manufacturing, and transportation, are some of the other sectors that will be enhanced through the application of the IoT (Atzori, Iera, & Morabito, 2010). Nonetheless, the IoT will be used in many areas for the purpose of enhancing the quality of services, efficiencies and safety. For instance, vehicle-to-vehicle communications and smart roads (Foschini, Taleb, Corradi, & Bottazzi, 2011), that sense and control traffic flow are examples of these applications which contribute towards improving the safety on roads and efficiency of the transport system, specifically in congested cities.

In the rest of this chapter, the Section "IoT in Healthcare" describes the many areas of healthcare that benefit from the adoption of the IoT technologies. The section "Smart Home" transitions the reader from the typical smart home scenario to a new vision of IoT smart home systems. Other interesting IoT applications such as smart water, smart cars, smart lighting and structural health monitoring systems are discussed under the Section "Smart Cities: A holistic Vision". The chapter then concludes by highlighting some of the main challenges facing the realization of the IoT.

IoT DEVELOPMENT IN HEALTHCARE

Healthcare is an important aspect of the society. The healthcare services and communication technology industry have the potential for growth in specialized e-health services such as electronic health (e-health), remote monitoring systems, home and community care among many others. The IoT offers numerous opportunities which improve the healthcare services and operations. The IoT promotes a wider approach to healthcare by addressing the health needs of a population as a whole instead of individuals, and by stimulating practices that reduce the effects of diseases, disability and accidental injuries. Additionally, combining healthcare applications with other areas of the IoT stimulates sustainability in healthcare (Boulos & Al-Shorbaji, 2014). It is established in the healthcare community that prevention of diseases is as equally important as providing medical treatments (Fries, Koop, Sokolov, Beadle, & Wright, 1998). Consequently, the IoT creates the opportunity of maintaining sustainable environments for a healthier lifestyle. Other contribution the IoT provides is in reducing the implications of climate change on the health and well-being of the population (Vermesan et al., 2011). It is essential for the future sustainability of healthcare to enable healthcare providers and services to integrate sustainability principles within their organizations such as, energy and water efficiency, and environmental compliances among many others. Also, it is critical to foster environments that protect and promote the health of communities. Hence, the IoT plays a significant role towards the realization of a sustainable environment, which in turn contributes to a better approach to healthcare.

In terms of IoT applications in healthcare, monitoring of medications and the delivery of drugs are amongst the various envisioned application in this domain (Laranjo, Macedo, & Santos, 2012). The use of IoT aims at making the field of medicine more efficient than it has been in the past. People are able to receive and share information about illnesses and treatments more efficiently. The IoT allows individuals to acquire medical or treatment information in real-time and help in the early detection and prevention of diseases (Zhao, Wang, & Nakahira, 2011). Thus, it helps individuals to escape contacting a given disease, or to treat diseases as early as possible. The backend system responsible for operating the IoT health application(s) will be able to maintain important health records of patients. In e-health, this information is termed as Electronic Health Records (EHR) (Kalra & Ingram, 2006). Therefore, combining the IoT with EHRs systems will improve access and retrieval of healthcare related information, the availability and sharing of EHRs between different healthcare organizations.

The IoT in healthcare is expected to improve remote health monitoring systems as well. Remote health monitoring technology provides solutions for monitoring patients at home. These systems aim to deliver higher quality of care and reduce the cost on patients and governments without affecting the quality of the healthcare services provided (Elkhodr, Shahrestani, & Cheung, 2011b). The use of a remote monitoring system allows biomedical signals of a patient to be measured ubiquitously during his or her daily activities. Such a system allows the collection of medical data and signals related to patients' bodies, such as their heart rates, remotely via the Internet. There are also benefits associated with improving the quality of care and services, such as reliability, accessibility, frequency, accuracy and availability (Elkhodr, Shahrestani, & Cheung, 2011a).

An IoT based remote monitoring system is capable of detecting any changes in the person's body conditions, and monitoring their vital medical signs. The availability of the collected data by this system on the Internet, and the ability to access this data in real-time by various other systems and entities such as healthcare providers and medical centers, open the door to numerous opportunities. For instance, an alert system can be designed based on analyzing the EHRs received by the remote monitoring systems (Baig & Gholamhosseini, 2013). In the case of a medical emergency, the system can be configured to alert the healthcare professionals, emergency services, relatives and others concerned parties. Also, the system can provide insight into the health condition of a monitored person so the necessary help can be provided as early as possible, and thus, saving patients' lives.

Additionally, the IoT services can help in the monitoring, early detection, prevention and treatment of several illnesses (Pang et al., 2015). This includes diabetes, heart disease, cancer, seizures, and pulmonary diseases, among others. Such diseases usually require constant monitoring of body actions, so the person needs to be under a constant watch. Traditionally, the medical practitioners and healthcare professionals are responsible for the constant monitoring of patients. However, patients' monitoring is costly and not as effective as it ought to be (Lara et al., 2012). For instance, the doctor is not capable of constantly watching over one patient with an undivided attention.

An example of how the IoT can improve patients' monitoring is the integration of Body Sensor Networks (BSN) with others IoT health systems (Savola, Abie, & Sihvonen, 2012). As an example, a BSN system can monitor the patient's body functions using a biodegradable chip or by using some wearables wireless Biosensor devices (Ozkul & Sevin, 2014). This chip or Biosensor device will be capable of monitoring the vital signs of the patient. They detect any anomaly in the bodily functions of the patient and report such problems to the IoT system. The IoT system can then makes the necessary action such as alerting a healthcare professional. Also, it allows healthcare professionals to make better diagnosis of diseases and communicate effectively with patients. In case of emergencies, the healthcare professional, or depending on how the system is designed, can alert an ambulance team for assistance.

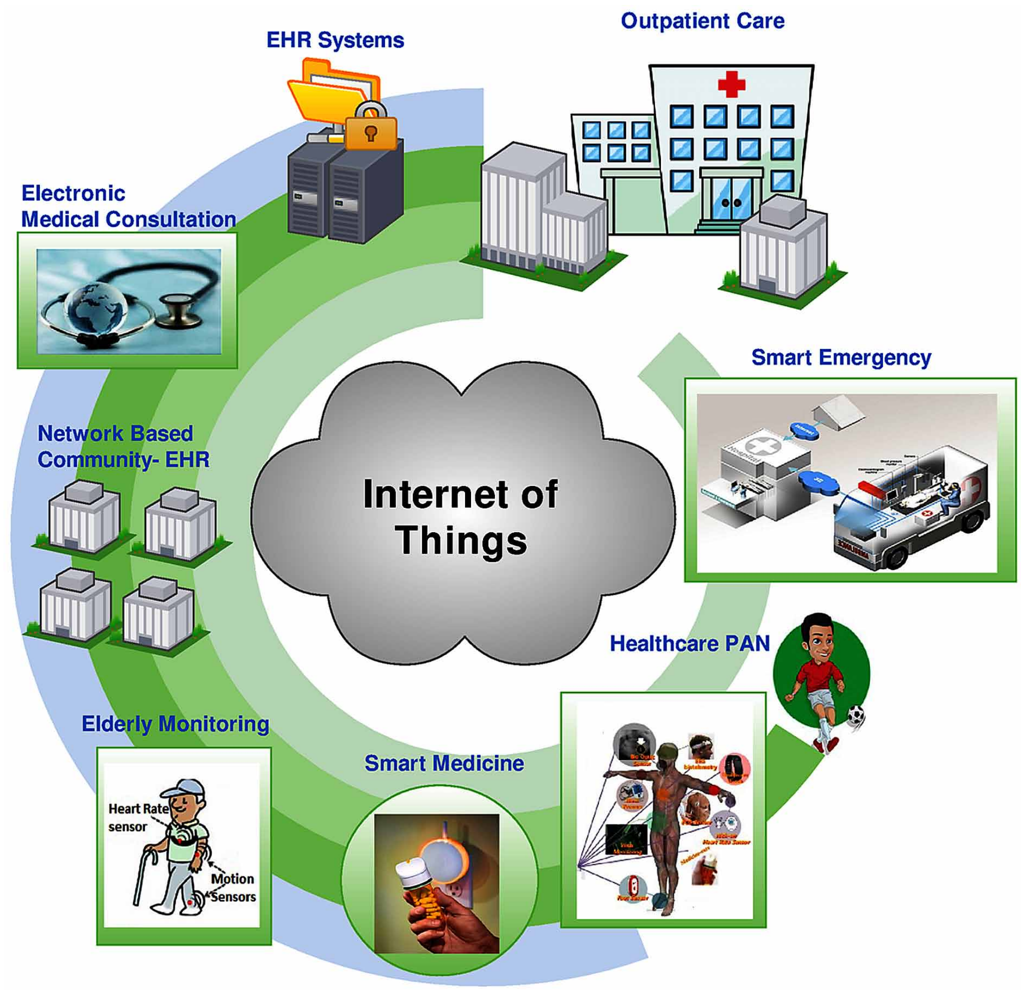
Therefore, IoT health monitoring systems can be seen as an environment of surrounding intelligence which aims to provide a platform for remote monitoring and assistance to patients or the elderly in their homes or on the move (Elkhodr et al., 2011a). Monitoring patients in the early stages of their diseases can increase their chances of survival. It will also help healthcare providers to react before a serious medical condition such as, a heart attack or diabetic emergency occurs. The use of remote monitoring systems could also help reducing medical errors since electronic health records (EHRs) are digitally available via the IoT (Scurlock & D'Ambrosio, 2015). The digital availability of EHRs makes its retrieval and access more accurate and organized. This will not only help in reducing medical errors, but also provide speedy access to data, while maintaining access control privileges as well.

IoT applications in healthcare also extend to personal area networks (PANs) (Neuhaeuser & D'Angelo, 2013). In a PAN, individuals are capable of tracking their bodily functions using various wearable technologies such as a wearable smart sensor, a smart wrist device or a smart watch. As the technology and IoT evolve, wearable technologies in healthcare are evolving as well. Therefore, this evolvement of technologies will result in providing the capabilities which allow individuals to monitor various aspects of their health. Examples of these health aspects are the monitoring of blood pressure, sugar and insulin levels, medicine intakes, heart beats, sleeping patterns, calories intake, exercises levels and others. The capabilities offered by the IoT in this regards are vast. Healthcare professional will be able to access remotely these information and provide treatment if necessary. This enhances the sharing of information and self-administration of health problems in addition to the early detection of diseases.

Consequently, IoT healthcare applications encompass various sensors and monitoring devices. These devices are generally synchronized and interconnected with one another for the purpose of enhancing information sharing (Vermesan & Friess, 2013). Figure 1 is an example of an IoT based healthcare system which provides an array of healthcare services. It shows that an IoT system can be designed to combine together the followings healthcare subsystems:

- **The Healthcare Personal Area Network Application:** This application involves the use of personal devices in closed or local area setups. Examples are wearable technologies that can be used for the self-monitoring and administrating of a person's health.

Figure 1. An example of an IoT based healthcare system



- **Elderly Monitoring:** This application relies on a set of sensor devices which monitor the health condition of an elderly. The system can be used to collect information relating to the physical activities such as dietary and sleep patterns of the elderly as well. Importantly, the system allows healthcare professionals and care takers to monitor the health condition of elderlies in real-time. It implements alert and notification strategies in the case of emergencies such as automatically calling an ambulance when needed.
- **Smart Medicine:** This application involves the administration of medications. It ensures that patients are taking the right medicine, with the correct dose on time as specified by their healthcare professionals. The system can also alert a doctor in case a patient does not take his or her medication as prescribed.
- **Community Based EHR:** This includes outpatient care and electronic medical consultation subsystems that involve the digitation of health care operations. These subsystems collectively enhance eHealth services by reducing medical errors, saving cost and increasing efficiencies.

- **Smart Emergency:** The smart emergency application is centered on collaborations and sharing of information between the various healthcare subsystems. It is an important component in each of the healthcare subsystems described above. Obviously this is due to fact that emergency services, such as calling an ambulance, are required in medical emergencies. However, the smart emergency application operations are not only limited to providing the service of automatically calling an ambulance. They involve other advanced services such as communicating the status of the patient automatically back to the hospital during transport including the required treatment. This process improves emergency services in hospitals as well. It helps with the better allocations and distribution of patients in hospitals in a given geographical area. Thus, ensuring that there is a space to accommodate the transported patient. Moreover, they help in the optimization of the medical resources and services such as X-ray services and CAT scans.

Therefore, the ability of accessing health information instantly and remotely via the Internet enables healthcare professionals to access a new category of information which was unknown to them before. An example of this information includes the factors which might affect the patient's health, such as any daily routine activities. Gaining insight into the life of a patient helps in providing a better treatment approach. Generally, traditional remote monitoring applications lack the interoperation that the IoT can provide. Ambient Assisted Living (AAL) will be possible with the introduction of an IoT based system that works effectively with other IoT devices such as sensors and actuators. For instance, people will know how many times they have taken their medications, and when they need to take them next (Vermesan & Friess, 2013). Patients will be able to obtain pharmaceutical information regarding the type of medicine required instantly and in real-time. This includes information about the right dosage, allergy advice, side effects among others.

Pharmaceuticals

The pharmaceutical industry is directly associated with the healthcare industry. It is concerned with the manufacturing, distribution, storage, and administration of medications prescribed to patients. There are various ways through which the IoT will be of use to the pharmaceutical industry. For instance, the use of sensors or RFID technology on medications during supply and consumption enhances the proper use and safe intake of these drugs. The IoT helps in ensuring that medications are transported and stored in the right conditions (Melo et al., 2011). Also, the IoT improves the administration of medicines.

Accordingly, an IoT health application, through the use of sensors and other forms of devices, ensures that drugs are stored in an ideal environment in terms of temperature, sunlight exposure, among other important environmental factors (Atzori et al., 2010). Furthermore, the use of sensors and RFID technology helps in the identification of counterfeit drugs (Taylor, 2014). RFID technology in that sense can be used to monitor a certain medication right from manufacturing till consumptions as well.

Child Monitoring

Child monitoring is another area of healthcare which the IoT promises to enhance. An IoT based monitoring application, through the use of sensors and other IoT devices, is capable of monitoring the health and conditions of an infant or a child (Hoy, 2015). Therefore, parents or guardians will be able to find out whether their kid is sleeping, breathing well, seated or lying down properly, and whether it is mobile or not (Rost & Balakrishnan, 2006). The IoT technology will provide the capabilities of remotely monitoring the status and health conditions of a child outside their homes as well such as at a childcare center. This technology allows the design of a notification system which extends to parents, guardians, care takers, teachers, childcare workers, healthcare professionals, emergency services and many others. This enhances the current child monitoring systems in use which are, in most cases, limited to providing an alert when a baby makes a noise or cries. Henceforth, the enhancements introduced by the IoT promise to revolute child monitoring in the healthcare industry. The real-time availability of data that can be collected from a child contributes towards the design and development of other innovative IoT health solutions. For example, by using an IoT based child remote monitoring system, the capabilities of monitoring a child's social activities and group interactions go beyond monitoring his or her physical health (Kinnunen et al., 2016). It extends to monitoring the child mental health as well (Sula et al., 2013). The IoT will now offer insights into kids' activities such as the way they interact with their friends, families, teachers and strangers. The advantages of gaining insights into the social and general activities of a child are numerous. They help in the fight against bullying and identifying psychological problems, among other behavioral issues at a very early stage. Additionally, the results obtained from analyzing the collected data can be used to identify malnutrition among kids and, thus, the design and administration of healthier diets. Child abuse, domestic violence and alcohol related problems are among other social issues in which the IoT helps in the early detection and prevention (Pereira & Santos, 2015).

IoT Health Application Requirements

Table 1 is an effort to summarize the general requirements for IoT healthcare systems. It categorizes the requirements based on three application categories: Healthcare providers (e.g. a hospital), Remote monitoring systems, and health Personal Area Networks (e.g. personal fitness). Access point (AP) mobility, traffic type, location, and security are among the requirements defined for each of the aforementioned applications. However, it is noted that these requirements vary depending on the application's design and its requirements. Within the IoT space, several heterogeneous sets of devices may use various communication strategies amongst them to provide services. Thus, the requirements change from a network topology to another and from an application design to another even within the same application domain (e.g. different applications designed for remote monitoring systems). Consequently, Table 1 should be regarded as an attempt to define the requirements of IoT healthcare applications in specific cases rather than standardizing these requirements. The work in (Elkhodr, Shahrestani, & Cheung, 2016) reviews a variety of wireless technologies. These technologies are strong candidates for supporting communications in the IoT. It highlights an assortment of communication technologies such as ZigBee, IEEE 802.11ah and Bluetooth Low Energy. Each of these technologies caters for specific application requirements in the IoT.

SMART HOME

The smart home is another area in which the IoT promises to grow. The IoT enables everyday household objects, electronics and appliances to communicate with one another either locally or via the Internet. Thus, it allows the user to control these household items in various ways (Vermesan & Friess, 2013). The smart home system will be capable of connecting different types of objects in the house, and thus providing the user with the capabilities of not only monitoring but also controlling these objects. This

Table 1. General IoT healthcare systems requirements

	Healthcare Providers	Remote Monitoring Systems	Health PAN
Environment type	Commercial building e.g. hospital, clinic	Home, Nursing home, Community care	Home, Gym, Casual run
Location	Indoor	Indoor (high), Outdoor (low)	Indoor, Outdoor
Mobility requirement	Very Low (e.g. walking to the toilet, X-ray room)	Low (e.g. casual walk)	Low-medium (e.g. running)
Actors	Examples are: Electrocardiogram, heartrate monitor, blood pressure monitor	Examples are: heartrate monitor, blood pressure monitor, fall detection sensors	Examples are: wearable devices, heartrate monitor, pace detector
Devices Mobility requirement	Fixed (High), Mobile (Low)	Fixed (High), Mobile (Low)	Fixed (High), Mobile (High)
Device to AP Communication	Mainly Unidirectional (e.g. monitoring)	Bidirectional (Send and receive)	Unidirectional, (send)
Traffic type	Real-time and Event-based (emergency)	Real-time or Periodic, event-based	Event-based or Periodic
Coverage needed	Depends on the design: multi-story medical center requires higher density and extended coverage area	Independent home living model can have low coverage (e.g. around the house); Community care center might require extended coverage	Depends on the application design and AP mobility requirements
Reliability requirement	High	High	High
Security Requirement	'Higher than Commercial-grade'	Range from 'Higher than Commercial-grade' to 'Commercial-grade'	'Commercial-grade'

includes the ability of monitoring the objects' statuses and controlling the environment e.g. checking if a light is left on or closing a door remotely etc. This can be achieved by equipping normal household objects with smart sensors and actuator devices (Mainetti, Patrono, & Vilei, 2011). The IoT also improves the security of homes. The smart home system will be able in real-time to identify residents of the house, visitors and strangers. Thus, the system enables the detection of potential security breaches or risks (Schneps-Schneppe, Namiot, Maximenko, & Malov, 2012). Other features of the smart home system are the ability to monitor changes in various areas of the house such as monitoring the water level in a swimming pool, water leakage from pipes, and electricity consumptions. Users are able to know about their energy consumption levels in real-time and are able to make necessary changes. The system can provide recommendations to users which help reducing electricity consumptions during peak hours for example (Mohsenian-Rad, Wong, Jatskevich, Schober, & Leon-Garcia, 2010).

Apart from providing information, monitoring and controlling the general appliances of the house, the IoT will bring connectivity to various unconventional objects. Thus, in addition to smart fridges, smart ovens and other smart appliances, a new category of smart products will emerge which have the capability of connecting to the Internet directly or indirectly via the smart home network. Some of these smart products have already started to emerge or are under development. The followings are examples of these smart products:

- Smart Door and Window Locks (Jaykumar & Blessy, 2014).
- Smart Garage Door Openers.

- Smart Doorbells.
- Networked Cameras and Video Storage & Viewing.
- Smart Lighting Controls (Li, Suna, & Hua, 2012).
- Smart Thermostats.
- Multi-Sensors Detection Devices.
- Smart Blinds and Drapes.
- Smart Wall Outlets, Plugs, and Power Strips.

Most of these devices operate using low-power wireless technologies and connect via the smart home local network to the Internet.

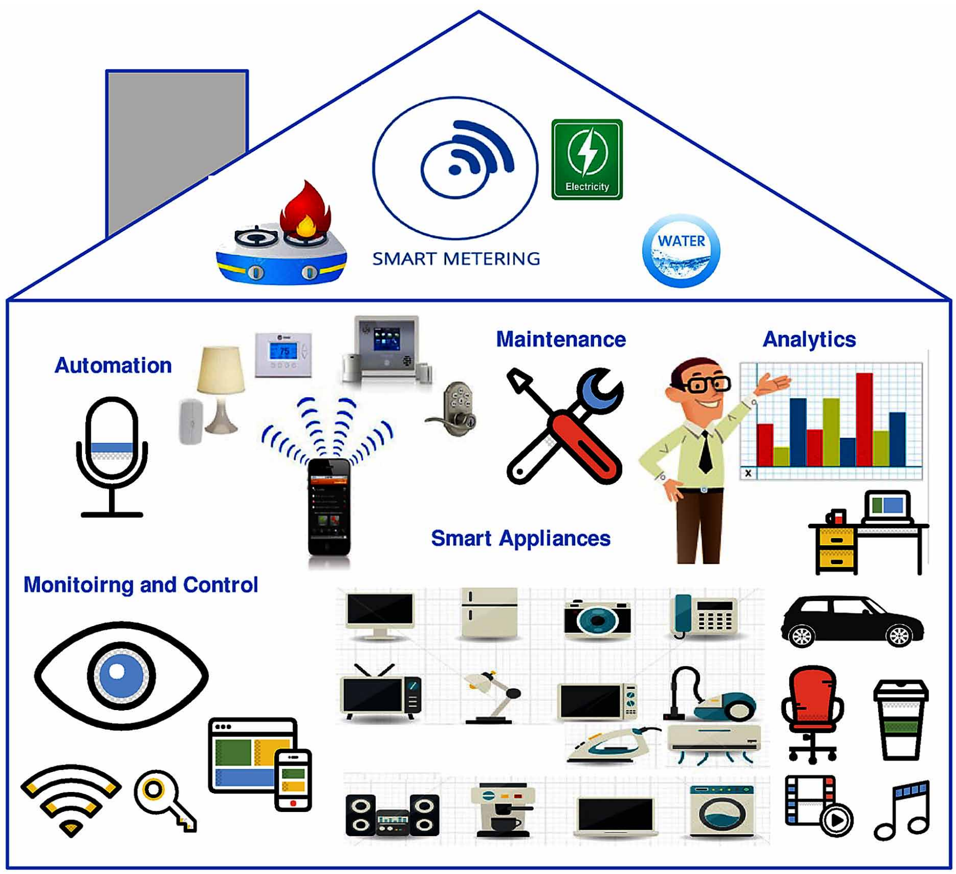
From Traditional Smart Home Systems to the IoT

Most of the existent smart home systems use devices at the lower end of the envisioned capabilities. Typically, these devices are capable of storing data, responding to user commands from smartphones, tablets and computers, and sending alerts over Bluetooth or Wi-Fi. They generally operate in a standalone manner. The IoT brings a new type of home management, integration of devices, surveillance, intelligence and more importantly connectivity to these devices. Intelligence may be contained completely within a device, combined with platform intelligence in the cloud, or reside almost completely within a platform to which the device connects to perform some functions.

Therefore, smart home devices incorporate the capabilities inherent in the IoT and provide enhanced benefits. Smart home devices can be static objects, such as smart plugs or lights that simply report their properties. They can also be sensors that measure the physical conditions of an object or its status, actuators that perform operations (opening doors, turning on or off appliances), or devices that combine both of these services. Therefore, the IoT enables users to manipulate these devices through an interface which could be in the form of a smartphone application, tablet, or computer that remotely operates the device in the home. Significantly, the IoT system will enable these devices to be queried or controlled by other platforms, controllers, or IoT applications that coordinate multiple objects without the interference of the human user. In addition, the data collected from smart home devices can be integrated with external data collected from other IoT systems, e.g. a healthcare system, which create value-added services. Therefore, the user benefits from added intelligence, modeling, and weaving of information which enable the smart home system to make better decisions on behalf of a user, or to provide personalized and optimized services (Chan, Campo, Estève, & Fourniols, 2009).

Therefore, by integrating the smart home system with the IoT, smart home devices will be capable of communicating with each other. They will also be capable of obtaining information from or controlling the physical environment based on the user's preferences. They can use information external to their specific environment to enhance the operation of that device to the user's benefits. Ultimately, homes will evolve to have their own ecosystems. However, the provision of such information will require the sharing of information among the stakeholders (Da Xu, He, & Li, 2014). This raises numerous concerns in terms of security, privacy, management and others (Wilson, Hargreaves, & Hauxwell-Baldwin, 2015). Figure 2 is an example of a smart home system. It shows that the IoT brings connectivity to a number of appliances such as TVs and fridges and to unconventional objects such as light switches, electricity sockets, and gas leak sensors among others.

Figure 2. An IoT smart home example



IoT Smart Home Application Requirements

Table 2 summarizes some of the IoT Smart Home Application requirements. As with the application's requirements of the IoT in healthcare discussed in the section "IoT health application requirements", the requirements of the smart home system vary according to the application design and its specific requirements as well. Initially, as shown in Table 2, the application environment of smart home applications is indoor within the home building. Devices are mostly in the form of sensors and actuators in addition to smart appliances and consumer electronics which are generally stationary. Sensors and actuators will be deployed in the home in appropriate locations. A number of these devices are likely to be powered by batteries. The typical coverage of such a network of devices is the entire home, with an estimated maximum number of no more than few hundred devices per household (Basu, Moretti, Gupta, & Marsland, 2013). The payload data being transmitted can be estimated to be very small with no stringent latency or jitter requirements (Qin, Denker, Giannelli, Bellavista, & Venkatasubramanian, 2014). Multimedia real-time devices such as an IP camera will have specific requirements to their sensing device counterparts. Many wireless technologies such as ZigBee, and Wi-Fi can be employed in such IoT space.

Table 2. IoT smart home application general requirement

Category	Comment
Environment type	Home (building)
Location	Indoor
Mobility requirement	Stationary
Actors	Multimedia devices, IP cameras, Sensors, Actuators, Smart Appliances, Smart phones.
Devices Mobility Requirement	Stationary
Device to AP Communication	Bidirectional (Send information; and receive instructions)
Traffic type	Varies from: ● Multimedia Real-time traffic - few megabytes every second ● Periodic- few 100 bytes every few seconds ● Event-based- few 100 bytes per event
Coverage needed	Indoor
Reliability requirement	Medium
Security Requirement	Commercial-grade

SMART CITIES: A HOLISTIC VISION

Over the past few years, the definition of "Smart Cities" has evolved to mean many things to many people. Yet, one thing remains constant: part of being "smart" is utilizing information and communications technology (ICT) and the Internet to address urban challenges (Clarke, 2013). A city-wide network of sensors provides real-time valuable information on the flow of citizens, noise and other forms of environmental pollution, as well as traffic and weather conditions. This enables the local authorities to streamline city operations including better environmental management, cost reduction, and economic improvement, and social and environmental sustainability. A smart city is the result of an incremental process of connecting the various facets and applications of the IoT together. The inter-communication, collaboration and exchange of information amongst the various IoT devices and systems will ultimately lead to the realization of a true vision of a smart city. Thus, connecting e-health systems with smart homes, smart streets, smart parking, smart water, smart bridges and the rest of the various applications envisioned in the IoT, will provide the digital infrastructure necessary for building the smart cities of the future. This digital infrastructure enables people to actively contribute to, and becomes part of the drive for sustainable development, as well as to self-manage their home, environment, natural recourses, and their own health for a better life and sustainable future.

The smart city technology brings together almost all of the other applications of the IoT. These include systems which provide services such as water leakage detection, flood detection, pollution detection, traffic control, smart roads, healthcare applications, smart home, among others.

It is important to note that this technology may not be able to succeed without the implementation of proper policies regarding the disclosure and sharing of information (Vermesan & Friess, 2013). All parties involved need to be willing to share information and for that to happen, suitable management, security and privacy challenges need to be overcome. The rest of this Section discusses the major developments which may contribute to building the IoT smart city.

Smart Water

Perhaps, the IoT cannot interfere with the climate and make the sky rain; but the IoT, through various applications in smart homes and smart cities, can enhance water consumption. Thus, the IoT helps in reducing water wastage by improving the efficiency of water consumption. This is of a great importance particularly in places where drought is an issue (Sanchez et al., 2014). The envisioned developments in water IoT based infrastructure systems are numerous. An IoT based water system can be used to improve water's quality, transportation, consumption (TongKe, 2013), supply and demand, leakage, treatment, pollutions, and storage facilities such as in household tanks or on a larger scale such as in reservoirs (Wu, Chen, & Lei, 2012). For instance, an Australian company is using networked sensors connected to the Cloud to monitor water runoff at construction sites (Pearce, 2009). Libelium ("Open Aquarium - Aquaponics and Fish Tank Monitoring for Arduino," 2014) is another company which uses the IoT to improve water consumption efficiency in aquariums and gardens. It utilizes a platform consisting of wireless sensors which automates the control and maintenance tasks within an aquarium or a garden.

In an aquarium environment, Libelium's platform use sensors which monitor various aspects of water such as temperature, conductivity and pH levels ("Open Aquarium - Aquaponics and Fish Tank Monitoring for Arduino," 2014). Also, the platform utilizes a pump and actuator devices which regulate water temperature, feed the fish and administer medication. The platform simulates day and night cycles by controlling light intensity as well ("Open Aquarium - Aquaponics and Fish Tank Monitoring for Arduino," 2014). The platform sends wirelessly information collected by the sensors and actions triggered by the actuators to a web or mobile interface. This interface enables users to monitor and control their aquarium. In gardening, Libelium uses a platform which monitors plant conditions and facilitate care. On one hand, the platform utilizes a set of sensors which collect environmental and soil related information such as moisture, temperature and humidity. On the other hand, the platform controls water irrigation, lights and oxygen using actuators. These are just few examples that showcase how an IoT water system could form an important integral part of other IoT systems. The integration of water's systems in the IoT leads to improving not only the efficient consumption of water but also the overall management of gardening, crops and aquariums (Duan, 2014).

Moreover, an IoT based water system can be set to remotely determine the status and working condition of a water's device (open or closed, on or off, full or empty, etc.). A pump can be remotely turned on or off to adjust the flow of water through a water transportation system. Pumps, gates and other equipment with moving parts in the water infrastructure can be monitored for vibration and other indications of failure. If a water pump is leaking or about to fail, the user or the relevant parties will be alerted so the necessary action can be taken. Connected smart water filters can report their statuses whether they are clean and functioning properly (Robles et al., 2014). The IoT system can measure water pressure in pipes to find leaks faster in the water transportation system or the presence of certain chemicals in the water supply and maybe even organic contaminants (Muhic & Hodzic, 2014). Another focus for water savings should be landscape irrigation in parks, medians and elsewhere. This is a major use of water in cities (Mylonas & Theodoridis, 2015). Nationwide, it is estimated to be nearly one-third of all residential water use and as much as half of this water is wasted due to runoff, evaporation or wind (Farbotko, Walton, Mankad, & Gardner, 2014). In agriculture, the application of IoT water systems combines weather data with other sensory data such as moisture, heat, type of soil and the relative exposure to sunshine at a particular time of the day for a more efficient use of water (Dlodlo & Kalezhi, 2015).

Water Transportation

The IoT will also be applied in the water management sector through various ways. This will enhance water quality and distribution to various parts of the world. By sensing portable water and movement from one place to another, an IoT WSN based system will be capable of communicating with the cloud or other systems to show information on the quality and movement of waters in cities (Bohli, Skarmeta, Victoria Moreno, Garcia, & Langendorfer, 2015). The Radio Frequency Identification (RFID) application connects with various services providers in the city and various other stakeholders to give information about the reliability and quality of the water being transported within a given community. The idea behind the IoT is to interconnect the available applications with one another via local network setups or the Internet. This enhances the sharing of information which in turn improves the quality of goods and services, and thus quality of human life (Fan & Bifet, 2013). For instance, the IoT capabilities can be extended to other areas associated with the water transport industry as well (Misra, Simmhan, & Warrior, 2015). The IoT system will be capable of not only monitoring the quality of water or detecting water leakages during transport, but also that of the truck itself and the driver. The safety of the driver, including his or her behavior also enhances road safety as the system will be able to report any incidents to the relevant parties. The IoT will be capable of enhancing the performance of the water transport sector, as well as other transport sectors by promoting the sharing of information in real time (Misra et al., 2015).

Water Pollution

The IoT will be capable of detecting pollution in water reservoirs, and natural water systems such as rivers (Kar & Kar, 2015). The system uses a ranges of sensors that detect chemical leakages and analyzes the purity of water (ZHU & PAN, 2015). The sensors communicate with other IoT applications providing valuable information on water quality. For instance, the sensors will be able to detect waste from factories dumped into a river and alert the relevant authorities, and the local communities that could be affected by the presence of these chemicals or waste. The IoT water monitoring system can be used for monitoring and detecting pollution of waters as well e.g. ocean waters (Tiwari, 2011). Thus, the IoT can help maintaining the safety of the marine ecosystem. It does that by detecting and reporting the individual and industrial activities that could be harmful to the marine life (Domingo, 2012).

Water Leakages

Water is an important natural resource. Wasting water is attributed to a number of factors including water leakage either during transport, storage or consumptions (TongKe, 2013). Therefore, the IoT can help conserving this important natural resource by reducing leakages. An IoT water monitoring system utilizes smart water sensors that can detect water leakages in a tank or pipe (Lundqvist, de Fraiture, & Molden, 2008). The sensors can be used to measure the pressure levels in pipes and their variances. The system can be used to detect pipe bursting in real-time (Y. Kim, Suh, Cho, Singh, & Seo, 2015). Thus, it enhances the real time response to such leakages which in turn reduces water wastage. Nonetheless, the system could be used to prevent possible pipe bursts. It does that by monitoring water levels and pressures within water systems; which allow the early detection of faults and accelerate incidents and response management (Chowdhury, Bhuiyan, & Islam, 2013).

Flood Control

IoT devices will be capable of detecting flooding in rivers (Tai, Celesti, Fazio, Villari, & Puliafito, 2015), dams and water reservoirs by measuring the water levels and ensuring that all changes are detected when they occur (Gubbi, Buyya, Marusic, & Palaniswami, 2013). The system alerts the concerned parties regarding the changes in water levels and provides options for responding to such changes. This technology will also be important for the detection of flooding of seas by detecting changes in water levels and any abnormal activities. Floods can be disastrous and their effects are damaging to the economy, including the obvious loss of life and property. The IoT may not be promising a complete solution to flooding, but it contributes by providing a better way of controlling or responding to flooding alerts. Additionally, the IoT can be used to predict and detect the rise in water levels, and to predict tsunami such as the work proposed in (Kawamoto, Nishiyama, Yoshimura, & Yamamoto, 2014). This can be achieved by combining weather data such as rains, wind directions and other information such as water flow on ground. Communicating and combining this information in an IoT system contribute towards the design of a better and effective response system to this natural disaster. Importantly, the ability of predicting flooding in rivers or seas can help in building solutions which prevent flooding, or at least reduce their impact.

IoT Metering

IoT metering systems, including smart grid systems, are an interesting IoT area. IoT metering is concerned with the metering of water, gas, and electricity (Benzi, Anglani, Bassi, & Frosini, 2011) within a smart home environment or on a larger scale e.g. within a city. Typically, metering applications rely heavily on sensor network technologies. For example, in environmental and agricultural monitoring systems, the IoT system uses wireless sensors for the monitoring of water, gas and electricity consumptions (Erol-Kantarci & Mouftah, 2011). IoT metering is mainly concerned with metering the consumption of those resources by providing the user with important usage statistics. This provides the users with important statistical information such as the time when water is mostly consumed, the devices which are consuming electricity the most among others. Additionally, IoT metering applications can be extended to provide advanced analytics functionalities as well (W.-H. E. Liu, 2010). Thus, apart from simply logging the resource consumptions such as time, the device in use and the amount of water, gas or electricity being consumed, the IoT metering system can provide fruitful recommendations. Examples include providing recommendations on how to save energy e.g., by turning a washing machine on during off peak hours only, boiling water using an electrical kettle instead of using a gas stove etc. On a larger scale, smart grid applications are concerned with optimizing the energy sector within a city or even across a country (S. A. Kim, Shin, Choe, Seibert, & Walz, 2012). A smart grid application can combine and make use of the following systems and services:

- Renewable Energy Management, including the management of solar energy and wind farming harvesting services, which help in optimizing energy consumption.
- Reducing overall demand on the grid by shifting usage and energy consumption to off peak time.
- Systems which store energy, using batteries, generated at off-pick time.
- Systems which detect disturbance or failure in the grid: This leads to better management of supply fluctuation by isolating the area under disturbance.

Tables 3 outlines some of the general requirements for IoT metering applications. It shows that IoT metering has applications in indoor and outdoor areas with traffic ranging from continuous, burst to periodic. Metering devices are usually in the form of sensors and small control devices which are most likely stationary and require little to no mobility requirement.

Smart Cars

Industry experts estimate that every car will be connected to a communication network by 2025, and the market for connected vehicle technology will reach $54 billion by 2017 (*Connected Car Forecast: Global Connected Car Market to Grow Threefold Within Five Years*, 2014). Car technology is evolving from a car being controlled by the driver to partially automated cars, and to fully automated self-driven vehicles (Nelson, 2015). Such automated vehicles also referred to as driverless cars are capable of navigating through a city or driving upcountry without any human control. For the realization of a fully automated vehicle, such as a driverless car, truck or bus, a series of complex interactions and technology advancements are needed. Driverless vehicle technology integrates a network of connected devices in the form of sensors, motion detectors and actuators (Chong et al., 2013). It includes internal sensors that determine the vehicle's speed, direction of traffic, location, gas or petrol level, and temperature of the vehicle among other performance metrics (Braun, Neumann, Schmidt, Wichert, & Kuijper, 2014). It also includes external sensors which allow the car to communicate with its environment.

The near future will see the introduction of connected vehicles onto the roads. This will create high demand for control and interaction technology, and this is where the IoT comes in. For example, the IoT will be capable of providing information on the traffic, on what routes to follow and helping in controlling and reducing road congestions (Foschini et al., 2011). The IoT system will also control car speed depending on roads and traffic conditions. The IoT system will be capable of showing engine diagnostics, and other car features, in terms of their conditions and functionality. The fuel and lubricant levels, mechanical part statuses and conditions can be controlled and monitored by the IoT system and

Table 3. General requirements for IoT smart grid applications

Category	Comment
Environment type	Urban, sub-urban, rural, home
Location	Indoor and Outdoor
Mobility requirement	Stationary
Actors	Meter devices (electricity, gas, water), automation and control devices
Devices Mobility Requirement	Stationary
Device to AP Communication	Bidirectional (sending metered data; and control)
Traffic type	Varies from: ● Continuous ● Periodic ● Burst
Coverage needed	Indoor (High), Outdoor (Low -depends on the app's design)
Reliability requirement	High
Security Requirement	Commercial-grade

communicated to the car's owner or the relevant party. This enhances car longevity by avoiding engine knocks and other forms of system failures (MacGillivray et al., 2014). Also, the car system will be controlled via audio-visual enhancements, including voice recognition to enhance in-car safety. The IoT can be used to prevent car thefts (J. Liu & Yang, 2011). The technology will enhance the tracking and retrieval of stolen vehicles, and will be able to communicate with all the concerned parties.

Vehicle-to-X Technology

As the IoT revolution unfolds, automotive innovation and value creation will be shifting to the boundaries with other IoT applications such as home automation, smart grids, smart cities, healthcare and retail. Vehicle-to-Infrastructure (V2I) (Chou, Li, Chien, & Lan, 2009), and Vehicle-to-Retail (V2R) (Siddiqui 2014) are projected to be the dominant segments with respectively 459 and 406 million vehicles featuring smart car IoT applications by 2030, followed by V2H (Vehicle-to-Home) and V2P (Vehicle-to-Person) with 163 and 239 million vehicles, respectively. Meanwhile, Vehicle-to-Grid (V2G) services will be offered on 50 million vehicles in 2030 (Staff, 2014).

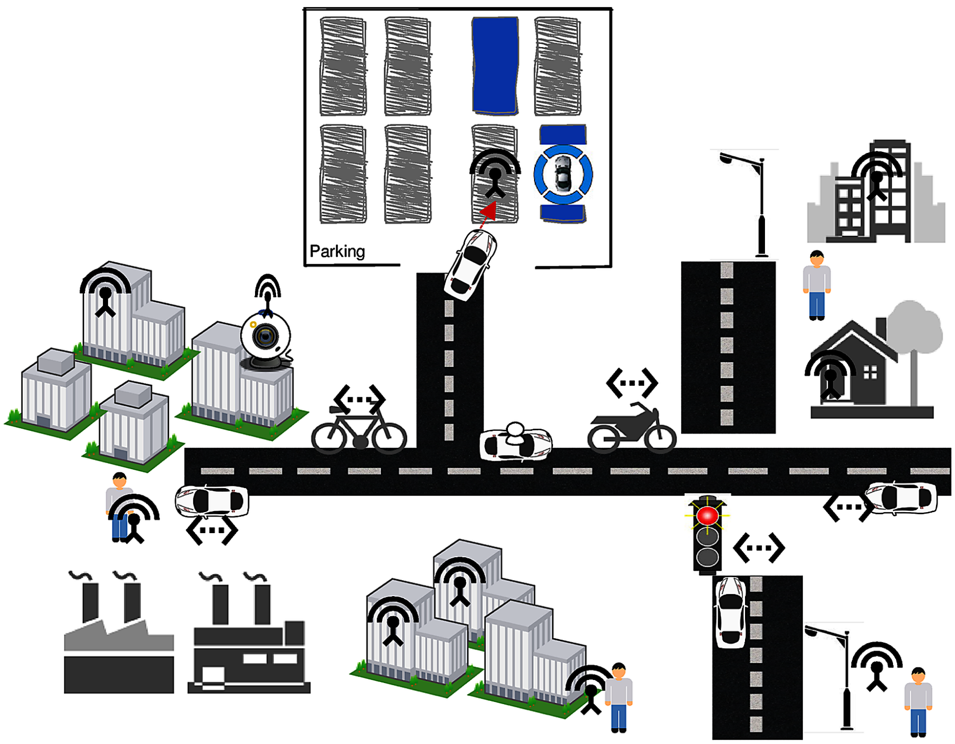
Therefore, the IoT is promising to revolute the connected and driverless car industry. The IoT offers the capabilities of connecting cars not only to the Internet, but also to their surroundings. Therefore, an IoT smart car may interact with surrounding roads, buildings, traffic lights, pedestrians, emergency and police vehicles and personnel. Also, it interacts with other vehicles and people, in order to provide real time information for better self-car maneuvering. In addition to optimizing routes and fuel consumption, minimizing traffic congestions, the IoT in this space plays a role in reducing noise and air pollutions, and ideally improving roads safety. The IoT will find its way in accommodating services related to green energy and sustainable energy resources as well. For instance, in the case of a smart electric connected car, the IoT will be able to provide information regarding nearby electric recharging stations (Hess et al., 2012) and the rate at which the solar panel are harvesting energy (assuming solar energy plays a role in powering the electric car). The IoT can provide information regarding the number of sunny hours on a particular day, in a particular location or during a journey of travel such as in the study presented in (Nwogu, 2015).

Nevertheless, the opportunities offered by integrating the IoT with smart vehicles are endless. The IoT opens the door to various technological innovations which will transform not only the way we perceive the car industry, but also the way cars are integrated in future smart cities. For instance, Figure 3 shows how smart cars, using the IoT, can communicate with other cars, traffic lights, and pedestrians.

Smart Parking

Smart parking is one of the emerging enablers for smart cities. A smart parking system operating as part of the IoT network can be used to enhance parking efficiency such as the study presented in (Pala & Inanc, 2007). It provides information on various parking areas, security levels and available parking spaces in a given area. It works by collecting and distributing real-time information about where parking is available to smart cars which are already connected to the IoT infrastructure. The power of an IoT smart parking system lies in its ability to track the movements of vehicles and availability of parking spaces in real-time such as the system proposed in (Lu, Lin, Zhu, & Shen, 2009). Thus, the system will be able to automatically direct a driverless car to an allocated parking space. It does that using an automated allocation system which analyzes in real-time information relating to traffic conditions, availability of

Figure 3. Vehicle to X connectivity



parking spaces in nearby car parks, among others. Apart from saving fuel, time and making life easier for the user, the technology helps reducing emissions and road congestions. From the government perspective, the IoT helps with law enforcement such as the enforcement of parking limits. Another application of smart parking in the IoT is linking a smart parking system with dynamic pricing platforms, where prices scale based on parking supply and demand (Polycarpou, Lambrinos, & Protopapadakis, 2013). It can also offer drivers parking options based on the price and proximity of their intended destination. Additionally, the data provided and generated from smart parking systems can be leveraged by retailers in a mall or store to predict the rush and accordingly manage workforce allocation. This will result in an improved quality of life in the city. This will also help in keeping the records on the levels of emissions in a city, making it possible for local authorities to apply pollution control measures with enough prior knowledge.

Other Smart City Applications

Smart Lighting

Smart lighting entails the provision of automated lights in public streets that change dynamically according to street activities or weather conditions (Castro, Jara, & Skarmeta, 2013). Smart lighting is also known as intelligent street lighting (Yue, Changhong, Xianghong, & Wei, 2010) and adaptive street lighting (Dramsvik, 2009). A smart lighting system controls lighting based on the weather condition, day and night cycle and movements of road users, e.g., vehicles, pedestrians, motorcyclists and cyclists.

Smart lights dim when no activity is detected, but brighten when movement is detected. This type of lighting mechanism is different from traditional, stationary illumination, or dimmable street lighting systems that dim at a pre-determined time. Smart lightings are turned on automatically by sensors that detect when lighting is required. Thus, the IoT enables street lights to communicate with one another. For example, when a passer-by is detected by a sensor, the smart lighting system communicates this information to neighboring street lights. These lights will then brighten providing people with light along their path (Carrington, 2013).

Obviously, smart lighting applications contribute to better approaches of saving energy. Additionally, it reduces chances of thefts and accidents by providing visibility in sensitive areas or by detecting certain motions. The motion detectors will be capable of controlling individual street lights in various areas of a city (Perandones et al., 2014). Smart lighting systems also could be combined with other IoT applications such as air quality monitoring systems (Zanella, Bui, Castellani, Vangelista, & Zorzi, 2014). An urban IoT system may provide a service to monitor the energy consumption of the whole city. Thus, it enables the authorities and individuals to get a clear and detailed view of the amount of energy required for particular services such as public lighting, transportation, traffic lights, control cameras, and heating/cooling of public buildings. Additionally, the system can be used to provide features such as identifying the main energy consumption sources. This feature allows the optimization of energy consumption by setting priorities among different devices and applications (Zanella et al., 2014). Accordingly, smart lighting systems play an important role in smart grid applications as well (Güngör et al., 2011).

Structural Health

Structural Health Monitoring (SHM) systems are used to monitor the conditions of buildings and other physical structures such as bridges (Farrar & Worden, 2007). SHM systems implement damage detection plans and characterize strategies for engineering structures. SHM systems involve the process of observing and monitoring a physical structure over time. A typical SHM system uses an array of sensors which periodically collect measurements from a monitored physical structure. The system samples the collected data and extracts related damage-sensitive information. It then uses statistical analysis methods to determine the structural health status of a physical structure (Dawson, 1976). The Rio-Antirrio Bridge in Greece is an example of an SHM system (Tselentis et al., 2007). It uses more than 100 sensors. These sensors monitor traffic and the bridge structure condition in real time (Parcharidis, Foumelis, Kourkouli, & Wegmuller, 2009). Other examples of SHM systems is the Hong Kong Wind and Structural Health Monitoring System (WASHMS) (S. Kim et al., 2007). WASHMS has four different levels of operation: sensory systems, data acquisition systems, local centralized computer systems, and a global central computer system. The WASHMS system measures the structural behavior of the bridges continuously. Both the WASHMS and Rio-Antirrio systems provide an early warning system for structural health of the relevant monitored bridges.

Recent researches on IoT structural health monitoring systems can be classified into two categories. The first category involves sensor technologies for collecting measurements such as in (S. Kim et al., 2007). The second type of research is centered on developing theoretical algorithms which process the data collected by sensors. The frequency response method has often been used for the analysis of data in these systems (Huang, Xu, Li, Su, & Liu, 2012). Significantly, the IoT contributes to SHM systems by providing Internet connectivity and real-time monitoring features. The IoT connects SHM systems with other areas of the IoT such as driverless car systems, environmental monitoring systems, road congestion systems and forecast systems among many others.

Smart Environment

The IoT can be used to detect noise which goes above a given level of decibels in various parts of the city especially in bars and restaurants. This will ensure efficiency in dealing with noise pollution and making it possible for authorities to react to too much noise in real-time. This is in addition to monitoring noise produced by cars in the city, and residential and industrial areas. This helps in the better planning of residential and industrial areas. An example of noise monitoring system in the IoT is the study presented in (Su, Shao, Vause, & Tang, 2013).

There are many ways through which the IoT technology will be able to help in the environmental management. Some of these applications have already been discussed such as monitoring leakages in rivers, flood control and water pollution. However, there are several other ways through which the technology could enhance the conservation of natural resources such as:

- **Detecting Forest Fires:** The IoT can be used to monitor the presence of combustion gases, and provide information on forest fires as soon as possible. This ensures that the response unit can act early to prevent a disaster (Debnath, Chin, Haque, & Yuen, 2014). Forest fires have been known to spread very fast and widely, with adverse environmental and economic effects. The IoT promises an easier job for the authorities in terms of responding to fires in the forest ecosystems around the country.
- **Monitoring Snow Level:** This enhances the provision of important information concerning skiing and also it makes it possible for the authorities to detect potential avalanche risks in real-time (Debnath et al., 2014). This information will be used to enhance the efficiency of the skiing sport as well.
- **Earthquake Detection:** One of the most devastating natural disasters are earth quakes. When they do occur, they leave behind a trail of huge destructions, including loss of life and property. The IoT technology can be used for the early detection of earthquakes using reliable sophisticated sensors. The IoT enhances earthquake early detection systems such as in (Chi, Chen, Chao, & Kuo, 2011). The future will see the application of IoT to detect earthquakes even hours before they occur. This will make it possible for the authorities to communicate with the people early enough to facilitate evacuation of the most vulnerable neighborhoods.

Waste Management

The technology of connecting things to the Internet will also make it possible for cities to control waste disposal (Debnath et al., 2014). From a logistics perspective, the waste-management process requires tremendous organization. The key objective is in collecting, sorting, and processing waste as efficiently as possible. With the introduction of the IoT in this area, multiple wastes related sites, whether collection companies, recycling plants or power companies that handle waste, can seamlessly schedule deliveries, with one part of the process feeding the next. Research and industry leaders are already working on new IoT solutions for waste management such as smart connected bins. For instance, in (Hong et al.,

2014) an IoT-based smart garbage system (SGS) composed of a number of smart garbage bins (SGBs), routers, and servers has been proposed. Each SGB, which plays a role in collecting food waste, is battery operated for mobility, and considering the convenience to residents, performs various operations through wireless communications. Pollution control is another area relating to waste management. The IoT provides information about pollutants, polluters and the levels of pollution in real time in a given area; thus, contributing to the overall management strategies of rubbish, recyclable and biodegradable waste.

Enhanced Security

The IoT will see the introduction of an increased number of vigilance and highly informed alert systems, which will be capable of fully securing homes, cars, workplaces, recreational places and other properties (Vlacheas et al., 2013). IoT security systems offer a myriad of features including door and window sensors, motion detectors, and video recording mechanisms. The IoT will facilitate access control and ensure that a person has the right permission to access authorized information at the right time and location. Biometric and facial recognition will enhance the automate access to services and resources. The IoT also contributes towards fighting crime, thefts and terrorist activities.

IoT Smart City Requirements

The previous sections provided a vision of a holistic smart city consisting of numerous heterogeneous applications which include various smart city scenarios and related applications. The growth of smart cities within the IoT encompasses the development and connection of several urban and rural geographical areas together. Ultimately, the IoT interconnects a wide range of applications including emergency services, healthcare, smart home, smart metering, and smart roads among others. However, each of these applications delivers a range of complex services to individuals, businesses, and governments within a variety of national, regional, and state administrative structures. This poses numerous integration challenges in the IoT.

Therefore, within this diversified system, it is a tremendous task to define the requirements for smart cities in the IoT. For the realization of a true vision of a smart city in the IoT, several incremental processes of developments and technologies are needed. They include revolutionary advancements in communication technologies, device hardware and software development, and new service architectures. For instance, in many of the smart city applications surveyed in this chapter, there is a need for a wireless technology with a simplified architecture that supports low energy consumption. However, in many other applications, the requirement of having a higher data rate is more important than energy requirement. Consequently, in the context of this mounting complexity and platformization, interoperability between the different facets of IoT is exceptionally vital and can be considered as the crucial requirement for smart cities in the IoT. No matter what technology, topology or device is being used, interoperability has to be achieved for the realization of the IoT. Additionally, one particular challenge in the context of smart cities relates to the open data business model. As services become pervasive and ubiquitous, the matter of making databases accessible by IoT applications and services will become more important. Transparency towards the end user on how his/her information is being used, with clear opt-in options and secured environments, has to be the starting point when providing services that leverage personal data.

CONCLUSION

This chapter provides a survey of some of the interesting applications projected in the IoT. It explores applications in many areas of health, smart homes, and smart cities. The chapter illustrates how the various applications of the IoT enhance the overall quality of life. The IoT becomes fruitful when various IoT applications are connected together. Thus, the chapter provides examples on compound IoT applications that emerge from combining smart services from different areas. It shows that the IoT sponsors the move from standalone closed systems towards open systems and platforms that support multiple applications and services. Hence, several IoT scenarios are reported. These scenarios combine data from different sources, linking several things, including devices, peoples and the environment to deliver and share information, enhancing business value, quality of life, and creating new business opportunities.

Nevertheless, to realize the unique and futuristic characteristics of the IoT, many challenges need to be overcome. There is a need to maintain scalable, private, secure and trustworthy operations in the IoT. With billions of things equipped with sensors and actuators entering the digital word using a vast array of technologies, incorporated into devices like lights, electric appliances, home automation systems and a vast number of other integrated machinery devices, transport vehicles, and equipment, as shown in this chapter, management of things become very challenging. Moreover, the growth in connected devices to the communication networks translates into increased security risks and poses new challenges to security and privacy. A device which connects to the Internet, whether it is a constraint or a more powerful device, inherits the security risks of today's computer devices. Therefore, it is essential that things are securely connected to their designated network(s), securely controlled and accessed by authorized entities. Many IoT applications require that data generated by things to be collected, analyzed, stored, dispatched and presented in a secure manner. Furthermore, there are security and privacy risks associated with things to things communications as well. This is in addition to the risks relating to things-to-person communications. For instance, the chapter describes many interaction scenarios where things are accessed by other things independently from the user. This highlights the need for end-to-end security and privacy protection solutions. As such security and privacy solutions should guarantee that things are accessed only by authorized entities in a secure manner. They should ensure that things are not leaking information or disclosing private information about their operations or their users to unauthorized entities. They also need to ensure that things are not used miscellaneously to impinge on the privacy of users.

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KEY TERMS AND DEFINITIONS

eHealth: Also written e-health, eHealth, and E-health, is an acronym for Electronic health and a term used for managing health information in the digital world during their digital storage, electronic process and communication.

EHR: Stands for Electronic Health Record. EHR is also known as EPR (Electronic Patient Record) and EMR (electronic medical record). The term represents a patient's health record or his or her information in digital format.

Interoperability: The ability of devices to communicate on the Internet of Things regardless of their make, model or the communication technology in use.

Internet of Things: The future Internet. It can be described as a heterogeneous network that combines several devices, services, people, and wired and wireless technologies together.

Low Power Wireless Technologies: Wireless technologies that consume low energy. Typically, devices that use low power wireless technologies are characterized by their low cost as well.

M2M: Machine to Machine communications is a term used to describe communication between two devices with minimal human interference.

Smart Cities: The city of the future where technology and communications plays a vital role in everyday activities.