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INTERNET OF THINGS AND SMART CITIES:
TOWARDS A SUSTAINABLE FUTURE

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Abstract: In this paper we explore the concept of "smart city", which is likely to drive the digital economy forward in the coming years.

The paper starts by explaining why Information and Communication Technologies (ICTs) holds the promise of creating new opportunities for improving the quality of our lives. Also, a global information and communication network superstructure is emerging as the Internet morphs into the Internet of Things (IoT). IoT will help to meet a considerable number of current challenges in literally all application domains, in addition to contributing to sustainable growth.

The article then concentrates on the "smart city" concept, which is achieved through the use of ICT-intensive solutions in order to solve complex challenges and meet objectives regarding overall development. Some of the most important application domains of the pervasiveness of IoT-based technologies are presented, in addition to examples of smart cities currently under development.

Key-words: Information and Communication Technology (ICT); Internet of Things (IoT); Smart Cities.

1. Introduction

Public awareness for environmental issues has been increasing rapidly in recent years, with businesses and citizens alike, particularly those in the developed world, realising that being environmentally responsible, while at the same time embracing growth and prosperity, is not impossible.

World population has increased by over 3 billion since 1970 while, in the same period, the world economy increased threefold. Recent estimates project world population to increase from 7 billion today to over 9 billion in 2050; economic growth and prosperity is expected to continue, despite the recent recession. Both the economic growth and the 2 billion expansion in world population is expected to be responsible for a substantial increase in energy demand. In addition, urban areas are likely to attract virtually all of the expected growth in world population, increasing by 85 per cent by 2050, from 3.4 billion in 2009 to 6.3 billion in 2050, or about 70% of the world population.

For several years, great effort has been devoted to the study of environmental issues, such as water pollution, toxic waste dumping, illegal deforestation, open burning and indiscriminate land clearing, and natural resources depletion. This anthropogenic (or human-made) environmental impact has many causes with potential harmful effects to current and future generations.

In this context, Information and Communication Technologies (ICTs) holds the promise of helping to address such societal challenges, creating new opportunities for improving the quality of our lives. More specifically, the Internet of Things (IoT), a global information and communication network superstructure, will help to meet a considerable number of current challenges in literally all application domains. The IoT is a network of physical objects or "things" in which objects that form part of our everyday lives are embedded with electronics, software, sensors and connectivity, allowing them to communicate through various networks, including the Internet.

As mentioned previously, it is expected that about 70% of the world population will live in urban areas by 2050. Therefore, cities face major challenges. The use of ICT-intensive solutions is expected to help solve these complex challenges and meet objectives regarding overall development.

This article is organised as follows. Section 2 focuses on the role of ICT in reaching the goals of urban sustainability, while Section 3 discusses the complex challenges in integrating the various systems, in order to manage the city as a whole, which will make up the cities of tomorrow.

2. ICT as a Fundamental Building Block for Creating Smart Cities

Information and Communications Technology (ICT) is the use of both traditional computer-based technologies and digital communication technologies in order to manipulate information in a digital form.

A recent estimate of worldwide total money expenditure for the ICT market reached USD $3.5 trillion (Luxembourg & Sommer, 2013). In the UK alone, according to the UK Government, the ICT industry is worth £58 billion annually (UKTI, 2014). This market includes areas such as software development, mobile devices, cloud computing, data centres and cyber security.

Since the introduction of the first commercially available microprocessor (the Intel 4004) in 1970 and the introduction of one of the most popular microcontrollers (the Intel 8051) in 1980, the processor has driven the innovation process in virtually all areas of knowledge. A processor is a central processing unit (CPU), that is, an arithmetic logic unit and a control unit, in a single integrated circuit (or chip). A microcontroller is a computer on a single chip (in addition to a CPU, it includes memory and input/output peripherals). In 1971, the Intel 4004 processor held 2,300 transistors, while a more recent processor has typically over 1 billion (Intel, 2014). The number of transistors in a processor is an important characteristic as it describes their complexity and allows professionals to estimate performance and capabilities.

It was in the 1960s that renowned scientists such as Alan Turing, Douglas Engelbart and Gordon Moore observed this miniaturisation or projected downscaling in integrated circuits. In particular, Gordon E. Moore postulated that the number of transistors on integrated circuits was doubling approximately every two years (Moore, 1965). This became known as Moore's Law. Table 1 illustrates this trend for some of the historical processor milestones developed by Intel. The column Process (also known as photolithography) refers to the semiconductor manufacturing technology used to manufacture the processor (the smallest feature on a chip).

Processor	Transistor count	Date of Introduction	Process
4004	2,300	1971	10 μm
8088	29,000	1979	3 μm
80486	1,180,235	1989	1 μm
Pentium 4 Willamette	42,000,000	2000	180 nm
Intel Core i7-4770K	1,400,000,000	2013	22 nm

Table 1: Transistor count for a selection of processors

The trend in miniaturisation, and its logical consequence of improved performance/efficiency and overall cost reduction, occurs not only in the computer industry but in most of all other industries as well, including vehicle engine downsizing and mobile phones.

Advances in hardware are being matched by advances in software development. Software systems are now ubiquitous: they are used in education and science, to control manufacturing processes, schools and universities, in the health industry, finance and government and in many other areas. In addition, virtually all electrical equipments include software (embedded applications using microcontrollers). Software systems are used in many types of different application domains, including: stand-alone applications, system software, embedded systems, engineering/scientific software, web applications, data collection systems, and artificial intelligence. According to Pressman (2010), computer software is "the single most important technology on the world stage".

The pace of ICT development is so impressive that even professionals in the area underestimate the power of future technology progress. Two examples of recent developments, which probably wouldn't be possible only a few years ago, are described next.

Researchers at Georgia Tech have developed the technology for a single chip device to provide real-time 3D ultrasound imaging from inside the heart, coronary arteries and blood vessels. The silicon chip integrates ultrasound transducers with processing electronics and, measuring 1.5 mm in diameter, it can travel and operate inside blood vessels, which can provide higher resolution images than devices used from outside the body (Gurun, 2014). After the development of this prototype, researchers expect to conduct animal trials to demonstrate the device's potential applications.

Bioengineers at Stanford University have developed Neurogrid, a multichip board to simulate a million brain neurons with billions of synaptic connections in real time (Benjamin, 2014). Neurogrid uses 16 Neurocores, each of which supports 65,536 neurons, integrated on a circuit board that consumes three watts and costs about USD $40,000. Neurogrid, which is 9,000 times faster and uses considerably less power than a typical PC, is currently being used for controlling a small prosthetic arm in the lab in real time. In the future, a chip as fast and efficient as the human brain could open up unimaginable possibilities.

The rapid evolution in both hardware and software is also responsible for what is known as mixed reality environment, i.e. an experience where the real and virtual worlds are combined, creating new opportunities for improving the quality of our lives. This is discussed in the next paragraphs.

2.1 Computer-mediated reality

Computer-mediated reality is the ability to modify a user's visual perception, typically through the use of a wearable computer or hand-held device such as a smartphone or tablet, altering the reality by adding to or subtracting information from it (Mann, 1994; Mann, 2002).

A special case of mediated reality is augmented reality (AR). Augmented reality is formally a medium, not a technology; even though technology is required for it to be experienced (Craig, 2013). Computer-mediated reality enables different ways of approaching augmented reality through different application areas, different styles and using different technologies. In order for AR applications to be produced and consumed some basic elements are needed, e.g. cameras, sensors, processors, and displays. Amongst the many areas that can benefit the most with the possibility of superimposing virtual elements on a real-world environment the following are worth mentioning: architecture, tourism, construction, science, education, virtual games, art, medical, sports and entertainment.

Augmented reality requires basically three components:

1. A real-world environment with some kind of reference, enabling the interpretation and creation of the virtual environment;
2. A camera of other device capable of capturing and then transmitting an image of the real-world environment;
3. Software to interpret the real-world environment image transmitted by the camera and then supplement it with elements such as sound, video, graphics or global positioning satellite (GPS) data.

Smartphones and tablets with considerable computational performance and equipped with a set of advanced features have enjoyed a rising popularity for the past few years. Advancements in technology and software have made this possible. Computational performance and speed is mainly due to various system features, which may include: the use of two or more processors (typically multi-core), an on-chip graphics processing unit (GPU), fast cache memory and a powerful instruction set. In addition to standard features such as connecting to the Web, e-mail, phone calls and texts, advanced features of these electronic devices may include: high-resolution displays, infrared remote control, near field communication (NFC), accelerometer, gyroscope, compass and GPS sensor. By combining AR with mobile computational technology with Web access we enter the realm of mobile augmented reality (MAR).

A wide variety of MAR examples has been developed and is discussed elsewhere. They include Layar[1], junaio[2], Wikitude[3], Word Lens[4], Yelp[5] and Nearest Tube[6]. As an example, Sky Map, a free and open-source Google app for the Android phones, is an AR application designed to assist users to learn about the night sky (Google, 2014). By pointing the phone to the sky the user can find out more information about the stars, planets or constellations. The app uses GPS and compass data (in addition to the date and time) to show a labelled map of the area the user is observing. Another way to use the app is to find the location of a specific object at a given moment. After searching for the object, the app directs the user towards the object.

In recent years, major multinational players such as Sony Corp., Google Inc. and Microsoft Corp., have been increasing their research and development expenditure and applying for AR- related patents. In particular, they are advancing technology and software as a way to create more interactive games through the use of AR.

These are just some of the potential uses of AR. In the near future, this kind of immersive, supplemented reality will become part of our daily lives, with a positive impact on several aspects of everyday-life. And the near future might be a novel paradigm known as the Internet of Things (IoT).

2.2 Internet of things (IoT)

The Internet of Things (IoT) is an emerging global Internet-based information and communication network superstructure that connects things (or objects) with software. An object can be a physical resource, an animal or a person. These objects are provided with communication technology and their

1 https://www.layar.com/products/app/
2 http://www.junaio.com/
3 http://www.wikitude.com/app/
4 http://questvisual.com/us/
5 http://www.yelp.com/yelpmobile
6 http://www.acrossair.com/apps_nearesttube.htm

own unique identifier (an IP address[7]) and thus have the ability to automatically transfer data over a network without requiring human interaction, interacting and cooperating with each other to reach common goals (Atzori et al., 2010).

Core enabling device technologies for the IoT include Radio Frequency Identification (RFID) technology – probably the most important technology for the IoT –, infrared sensors, global positioning systems, Electronic Product Code (EPC) technology, and embedded sensor/actuator nodes, in addition to various wireless network technologies such as Bluetooth, Near Field Communication (NFC) and ZigBee.

A recent estimate by analyst house Gartner (2013) predicted that "the total economic value add for the Internet of Things will be $1.9 trillion dollars in 2020". To put this into perspective, Evans (2011) estimated that in 2020 there will be 50 billion connected devices; as a comparison, the 2012 UN estimate show world population to grow from the current 7.2 billion to 7.6 billion in 2020 (in other words, there will be about 6.6 more connected devices than human beings).

The Internet of Things will help to meet a considerable number of current challenges in literally all application domains, leading to remarkable improvements in the quality of life in addition to contributing to sustainable growth. Miorandi and co-workers (2012) identified six markets with a potential leading role to leverage the capability of IoT technologies: homes/buildings, cities, environment, health care, business and product management, and security. Possible applications and impact areas for each of these markets are enumerated next (Atzori et al., 2010; Miorandi et al., 2012; Libelium, 2014):

- **Homes/buildings**: energy and water supply consumption monitoring; remote control appliances; intrusion detection systems;
- **Cities**: waste management; optimisation of physical city infrastructures (e.g., road networks, power grid, etc.); traffic congestion control systems; smart lighting; noise monitoring system;
- **Environment**: forest fire detection; control of CO_2 emissions; leakage detection in rivers; control pollution levels in the sea; river flood detection;
- **Health care**: improve quality of life, in particular for the elderly and the disabled; fall detection; patients surveillance/tracking in hospitals; assistance in building access, transportation, information and communication; intelligent wheelchairs;
- **Business and product management**: supply chain control through, for instance, real-time product availability and monitoring of storage conditions; reduce shoplifting; fighting counterfeiting; advising customers of the presence of allergic components;
- **Security**: restricted areas access control; water leakage detection; hazardous gases measurement.

7 An IP address, in full Internet Protocol address, is a unique identification number used to identify each device in a computer network.

In Europe, the US, Japan, and many other countries, a considerable number of research and policy initiatives, as well as key-importance standardisation activities, are addressing the large potential for IoT-based capabilities. As an example, the European Union funded a large number of research and development (R&D) projects within its Seventh Framework Programme, investing over 300 million Euros.

With a new ecosystem of smart applications and services, the Internet of Things will undoubtedly leverage the potential of augmented reality. As reported by Domingo (2012), the IoT can offer assistance and support for people with disabilities. About 15% of the world's population is estimated to be living with disability. The IoT can create enabling environments by offering people with disabilities assistance in building access, transportation, information and communication, allowing them to participate in the social and cultural life. This increases their autonomy and self-confidence.

The IoT holds the promise of improving and simplifying the life of human beings, in addition to contribute to sustainable growth. However, privacy, security and trust for both people and businesses should be guaranteed.

Innovations in information technology are driving the "smart city" concept. This concept is discussed in some detail in the next section.

3. Smart Cities: the Cities of Tomorrow

Cities face and will continue to face complex challenges to meet economic development and quality of live objectives (Schaffers et al., 2011). To react to these challenges, several new city concepts have been tried by policy makers and authorities. Naturally, several novel concepts of cities emerged and evolved, such as smart cities (Caragliu et al. 2009), eco-cities (Roseland, 1996), sustainable and ubiquitous cities, among others. Each of these concepts had specific objectives and tried to solve specific problems that start to emerge, namely, sustainable development and expansion, improvement of citizens' transport and quality of life, citizenship, etc.

It is important to understand that there is no order in time these concepts emerged and all can be applied independently according to the objectives and the possibilities of a particular city. So, what are the foundations and the objectives of each of these concepts?

Firstly, an eco-city is built on the principles of eliminating all carbon waste and to produce energy entirely through renewable sources. By incorporating the environment into the city management and stimulating green enterprises and ecological industries, it aims at stimulating economic growth and reducing poverty.

A sustainable city is designed to take into account the environmental impact of its inhabitants. In this city, the needs of energy, water and food of its inhabitants are minimized and, at the same time, air pollution (CO_2 and methane emissions) and water pollution (Register, 1987; Lehmann, 2010). Its purpose is to meet the needs of the present populations without sacrificing the needs of future generations. Therefore, it should be able to feed itself with minimal reliance on the surrounding countryside, as well as power itself with renewable sources of energy.

A ubiquitous city, an exclusively Korean idea according to Anthony Townsend, is a concept of integration of ubiquitous computing within an urban environment. It can be described as a merge of information systems and social systems, where virtually every device and service is linked to an information network through wireless networking and RFID tags and sensors.

Finally, smart cities are cities where investments in human and social capital and traditional (transport) and modern (information and communication technologies, ICTs) communication infrastructure fuel sustainable economic development and a high quality of life, with a wise management of natural resources, through participatory action and engagement (Caragliu et al. 2009). To Seisdedos (2012), the smart city concept essentially means efficiency, but efficiency based on the intelligent management and integrated ICTs and active citizen participation, which implies a new kind of governance and a genuine citizen involvement in public policy. In fact, a smart city provides the required infrastructure for citizens and officials to make more intelligent decisions. In doing so, it plays an essential role in dealing with challenges relating to ecological, social, cultural, and economic sustainability (Khansari et al. 2014; Komninos, 2002).

3.1 City development challenges and the need for smart cities

It can be concluded that these city concepts evolved mainly around ecological and environmental friendly perspectives, the sustainability of cities' expansion and the use of ICT to link information, government and citizens as well as the management of transport and energy consumption.

The first concept, which aims to achieve a low ecologic footprint, is the most frequently used concept, as it is easy to make mandatory the use of renewable energies, particularly in countries with adequate climate. Most of the existing modern cities that want to become eco-cities try to implement changes to make better use of renewable energy sources, namely wind and sun, a decrease on the use of energy needs for cooling and heating of buildings, etc.

The second aims at building self-sufficient urban areas, where all amenities are all produced and treated in the same city. Although this concept allows for a better management, it has to be though and build from scratch. A system of small sustainable cities, or townships, in India around large cities has been put in place in order to better plan the continuous expansion of urban areas (Rai, 2012).

The third concept is based in a "simple" model where all services and citizens are linked to a central datacentre which shares information between citizens, companies and authorities. However, this concept seems to be passive, as the information is given as requested and no further use is done with it.

These three concepts are in sort of embraced by the concept of smart city, which aims at reducing the environmental footprint by using exclusively renewable energy sources, reusing or recycling waste, decreasing air pollution through the use of Personal Rapid Transit (PRT) and forbidding/limiting the use of individual cars. ICTs are present everywhere, monitoring and optimising energy consumption and production, sharing information among authorities and citizens, allowing citizens to interact with services, buildings and transports, allowing citizens to participate in the management and expansion of their city. In fact, the use of ICTs seems also to be fundamental to manage the costs of the services provided by the city. As expansion occurs, it is important to know costs and energy needs in order to better plan it.

Despite the sustainability and efficiency of smart cities, real implementation can be difficult to achieve. Existing infrastructure, both in terms of the physical city layout and existing local bureaucracy, are major obstacles to large-scale sustainable development. The high cost of the technological integration necessary for eco-city development is a major challenge.

Other challenges associated with city planning and management are also large. Cities that want to become more sustainable are faced with retrofitting existing structures and concurrent management of sustainable urban expansion and development. These represent costs beyond the capabilities of most cities. In addition, many cities around the world are currently struggling with budgetary issues, high rates of poverty, transportation inefficiencies and rapid population growth, which encourage reactive, coping policy. Therefore, while there are many examples worldwide, the development of these cities is still limited due to the vast challenges and high costs associated with sustainability.

3.2 Practical achievements

Ecological and sustainable development has showed to provide a strong impact in the economy due to the shift to renewable energy sources and the increase in the productivity, necessary for the reduction of energy needs.

Environmental standards were implemented, such as a progressive shift to more sustainable and efficient methods of transportation, such as public transportation or biking, and an increase of the environmental education in hopes of achieving better citizen involvement and cooperation. Additionally, sustainable cities also work towards becoming more densely populated because having citizens living closer and having them making shorter travel distances means a significant reduction on environmental costs of transportation.

In the social field, eco-cities promote the creation of jobs in environmentally friendly business sectors, therefore reducing poverty. Eco-cities aim to increase urban density while integrating “green infrastructure” or “green spaces” into the urban landscape by consciously distributing land spaces for residential and commercial purposes. Additionally, increased urban density reduces urban sprawl, thus, decreasing dependence on cars, therefore, avoiding much of the negative effects of car pollution. These practices that aim to reduce air pollution affects positively public health.

Finally, by endorsing water consumption reduction by employing technologies that reduce the amount of water needed for irrigation and sewage, new environmental construction practices, green roofs, vertical landscaping, recycling wastes and the use of renewable energy sources for individual household consumption, eco-cities promote a reduction of carbon emissions, a decrease of energy and water consumption and a reduction and reuse of residues.

3.3 Examples of eco-cities

Examples of eco-cities can be found around the world, such as: Curitiba in Brazil, Auroville in India, Freiburg in Germany and Stockholm in Sweden. Most of these cities have promoted changes in the transport infrastructure by prioritizing public transport and strongly limiting the use of individual cars and stimulated the creation of green areas and recycling initiatives by citizens. In Freiburg and Stockholm, the use of energy from renewable sources has been progressively mandatory and urban planning was pushed to a more intense level by stopping urban expansion by making mandatory the reuse of abandoned land in the city center.

Other examples are: Masdar City, in the United Arab Emirates, and Dongtan, in China. Masdar City will be cited here by the specificity of its example.

The Masdar City project is a clear example of an expensive laboratory smart city, and one of the most successful examples of a city entirely powered by renewable energies, where the buildings and spaces where studied to provide warm temperatures, where the water and electricity consumptions are continuously monitored and the wastes are recycled, etc. However, not all the solutions could be implemented, partly due to the global financial crisis, namely the production of potable water and the transport infrastructure. The water was sought to be desalinized by the sun but the elevated concentrations of salt turned the process much more expensive. The transport infrastructure, one of the most important problems that smart cities aim to solve, was sought to be entirely based on the use of PRT within the city and with parking silos in the boundaries of the city. However, that solution needed the buildings to be built over piers. Therefore, only a single PRT track of half a mile was built and the project turned to the use of electric or solar powered vehicles. Finally, the excessive control and need for effectiveness transformed this city in a kind of industrial campus, with little to no life after working time. In fact, the city lacked the natural chaotic nature of cities and, therefore, lacked a certain quality of life for citizens.

4. Conclusion

The Internet of Things will help meet a considerable number of current challenges in literally all application domains, leading to improvements in the quality of life in addition to contributing to sustainable growth. Markets with a potential leading role to leverage the capability of IoT technologies include homes and buildings, environment, health care, business and product management.

In the next few decades, with up to 70% of the world population living in urban areas, cities will continue to face complex challenges regarding, for instance, energy and water consumption, control of CO_2 emissions, quality of life, in particular for the elderly and the disabled, product management, and security and safety issues.

The smart city concept evolved mainly around ecological and environmental friendly perspectives. This concept is achieved through the use of ICT-intensive solutions. ICT are present everywhere, monitoring and optimising energy consumption and production, sharing information among authorities and citizens, allowing citizens to interact with services, buildings and transports, allowing citizens to participate in the management and expansion of their city and, thus, improving the quality of our lives.

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