Smart Mobile Technologies for the City of the Future

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***Abstract*—The Smart City concept is gaining popularity due to involving various technologies in public places in order to satisfy the citizens' needs. However, the success of the smart city paradigm is linked to the treatment and management of the amount of real time data, which can be at the moment most effectively approached with the help of cloud platforms. In this paper, we aim at discussing the most promising mobile cloud and data transmission technologies that are expected to make the city more "smart" and more affordable for the end-users. Hence, we also discuss Li-Fi as a future transmission of data through illumination that can enhance further the communication in a smart city as well as guarantee a wireless connectivity that meets the requirements of the citizens. Finally, we discuss the challenges and opportunities of these new technologies for the scientific community and suggest the future research directions that should go hand in hand with their deployment.**

***Index Terms*—Smart city, mobile cloud computing, cloudlets, Li-Fi, research roadmap**

I. Introduction

Nowadays, more and more attention is being paid to new concepts and technologies of the smart city. The new technologies are in the context of a smart city playing a crucial role in making a traditional city more affordable and livable. The concept of a smart city can be defined in different ways (Table I), with all of them having the same goals, which are to improve the efficiency, reliability, livability, sustainability and security of a traditional city. The Internet of Things (IoT) is one of the key technologies that are designed to support the growth of the smart city [19]. The IoT concept aims at making any kind of physical or virtual objects to interact with each other without human intervention. This innovation, in which digital and physical entities can be linked, can bring a number of benefits in the management of traditional public services, such as schools and transport. Therefore, IoT offers the best quality of service to the citizens by using the public resources in efficient and sustainable ways.

On the other hand, the notion of a smart city is not about involving new technologies in human's life, but more about making sense of the massive amount of data, which is generated and shared across several platforms. As a result, the concept of the smart city is become more importantly a source of data to influence decisions in the different fields. Further, the availability of different types of data, collected in smart environment, may perform certain actions without human intervention, increase the transparency as well as enhance the quality of service offered to the end-citizens. To make a better use of resources in smart cities, cloud computing is the leading technology to ensure the management of resources and handle the massive data collected in this smart environment.

Based on a pay-as-you-go model, cloud computing offers various services presented as XaaS (X-as-a-Service) to end-users in different domains. However, the evolution of cloud computing has caused significant changes in traditional IT, especially after the combination between mobile environment and cloud model. This later collaboration has created a new paradigm called *mobile cloud computing (MCC)* [17][18]. At first, MCC aimed at extending the capabilities of mobile technologies, i.e. battery limitations, storage, computing and wireless network connection quality issues. However, the mobile device, which offers strong flexible mobile applications, has become an important part of cloud platform that can provide cloud services at any time and place.

With the advancement of mobile cloud computing, the mobile devices have replaced personal computers by combining mobility, network connectivity and software functionality. As a result, the smartphone has become quickly the first screen.

As a growing number of mobile clients and their needs to consume cloud services remotely, the airwaves are becoming progressively clogged, making it more and more difficult to get a reliable and high-speed signal. Within the context of smart cities, Li-Fi technology, which is based on LEDs for the transfer of data, may solve the previous issues with the cheapest (or even free) cost of network services [20]. For example, the citizens can easily transform data using the street lamps as sources of Li-Fi network. Further, they can access the Internet via eco-friendly technology where traditional radio based wireless is not allowed, like underwater.

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Figure 1. Street lamps

Unlike the previous theoretical backgrounds, which focuses on the definition of what is the smart city concept [9][8] without taking into consideration the new transformation in cloud platforms as well as the existence of Li-Fi as a new eco-friendly network created for public places, we in this paper aim at discussing these new technologies together with the necessary elements for the growth of a smart city being built upon them. We start with a brief description of cloud models and their characteristics, with special attention being paid to mobile technologies and cloudlets. Then we highlight the use of Li-Fi as an eco-optical wireless communication designs to be deployed in public services. Finally, we present the major challenges and opportunities that shall form the basis for the research roadmap to be followed by the scientific community in the context of smart cities and these new promising technologies.

TABLE I
SMART CITY DEFINITIONS

Articles	Year of publication	Smart City Definitions
[1]	2000	"A city that monitors and integrates conditions of all of its critical infrastructures, including roads, bridges, tunnels, rails, subways, airports, seaports, communications, water, power, even major buildings, can better optimize its resources, plan its preventive maintenance activities, and monitor security aspects while maximizing services to its citizens."
[2]	2007	"A Smart City is a city well performing city built on the 'smart' combination of endowments and activities of self-decisive, independent and aware citizens."
[3]	2009	"A city to be smart when investments in human and social capital and traditional (transport) and modern (ICT) communication infrastructure fuel sustainable economic growth and a high quality of life, with a wise management of natural resources, through participatory governance."
[4]	2011	"Smart City is the product of Digital City combined with the Internet of Things".
[5]	2012	"Smart City is a city in which it can combine technologies as diverse as water recycling, advanced energy grids and mobile communications in order to reduce environmental impact and to offer its citizens better lives."
[6]	2013	"A smart city is a well-defined geographical area, in which high technologies such as ICT, logistic, energy production, and so on, cooperate to create benefits for citizens in terms of well - being, inclusion and participation, environmental quality, intelligent development; it is governed by a well-defined pool of subjects, able to state the rules and policy for the city government and development."
[7]	2014	"Smart cities are all urban settlements that make a conscious effort to capitalize on the new Information and Communications Technology (ICT) landscape in a strategic way, seeking to achieve prosperity, effectiveness and competitiveness on multiple socio-economic levels."
[8]	2015	"the Smart Cities initiative seeks to improve urban performance by using data, information and Information Technologies (IT) to provide more efficient services to citizens, to monitor and optimize existing infrastructure, to increase collaboration between different economic actors and to encourage innovative business models in both the private and public sectors."
[9]	2016	"A smart city consists of various kinds of smart things, such as smart energy, smart water, smart buildings, smart integration, smart public service, and smart mobility. These smart systems form the backbone of the city's efficiency, livability, and sustainability."

II. CLOUDLET:

The existence of several new smart devices has become possible due to availability of large cloud resources and services. However, the development and application of cloud computing faces many challenges especially regarding low latency, location awareness, and mobility support. The last terms are the most important key characteristics that influence several smart devices and objects, which are getting involved in human's life as in case of smart cities. To address the problems, researchers have introduced new solutions to bring the cloud services and resources closer to the user. We namely focus on the Cloudlet [10][25], which is a micro-cloud deployed in public places such as coffee shops, and immediately providing customized services by using virtual machine technology (Figure 1). In addition, it can act as an intermediate layer located between the distant cloud platforms and end-clients. Hence, it addresses latency issues by reducing communication delay, and providing software instantiated in real-time on nearby computing resources. However, many practical issues remain to be addressed, including the security and privacy of mobile client that are widely demanded, further effort is required to protect the overall offloading process.

III. MOBILE CLOUDLET:

To eliminate the communication latency and data roaming charges introduced by the cellular networks or other wireless networks, mobile cloudlet is another form of cloudlet node, where clients instantly exploit any kind of mobile devices, such as smartphones, tablets, and bus mounted computers (Figure 2). Thus, the client accesses directly to customized cloud service and gets increased execution time efficiency. The differences between mobile cloudlet and cloudlet are summarized in Table II.

TABLE II.
COMPARISON OF CLOUDLET AND MOBILE CLOUDLET

Features	Cloudlet	Mobile cloudlet
Mobility	Limited	Unlimited
Locality	Nearby area mobile users	Nearby area mobile users
Operating platform	Desktop	Mobile
Elasticity	Medium	Low
Network connectivity	Wired	Wireless
Communication latency	Varied	Varied
Mobile device energy	Less	Less
Context awareness	Low	High
Time execution of mobile application	Less	Less
Cost	Less/free	Less
Security	Medium	Low

Thanks to the mobility concept, mobile cloudlet for smart city is particularly attractive to end-clients, since it can move among different places and deliver the services to other citizens within proximity. Therefore, mobile cloudlet can minimize the application response time. As a result, mobile clients achieve reduced energy consumption, cost of network resource usage, and latency. However, the mobile cloudlet uses its own energy to provide the services, and it has to optimize its energy utilization. Further, the limited computing resources of mobile devices and the unstable connections between mobile cloudlet nodes due to node mobility are important issues to achieve an optimal performance of the mobile cloudlet.

A typical mobile cloudlet solution proposed in [11], where the authors present RMCC (RESTful Mobile Cloud Computing) framework, which is the first RESTful service-oriented solution in MCC that uses nearby smartphones for outsourcing. Further, it exploits the high multiplicity and proximity of smartphones to build a scalable cloud of proximate mobile devices with time-energy saving.

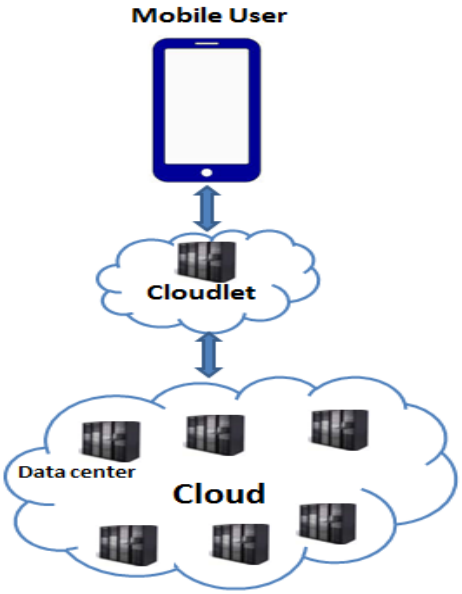

Figure 2. Offloading computing with cloudlet

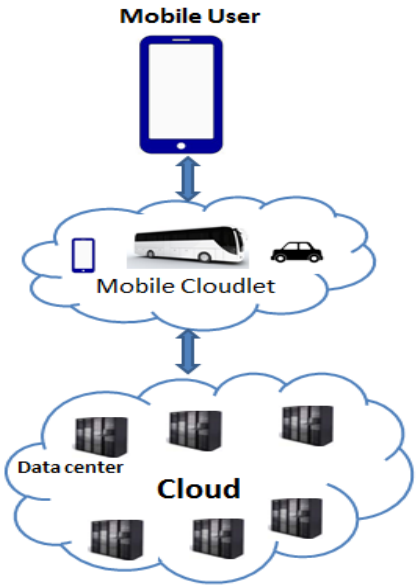

Figure 3. Offloading computing with mobile cloudlet

IV. MOBILE DEVICE CLOUD:

In the traditional mobile cloud computing, central cloud resources are always equipped and ready to start any computation task. Yet, many interesting works involve mobile devices as small computing units in cloud environment (Figure 3), where mobile devices cooperate to achieve the same goal which is computing operation. Hence, by dividing the task among mobile devices or mobile worker nodes, the cloud providers can speedup computing and conserve energy. In [12], authors change traditional desktop cloud servers to distributed mobile devices that work cooperatively to accomplish large parallelizable computational tasks. The authors also demonstrate that the solution is able to save 55%

to 98% of the energy consumption of conventional server based clouds while providing comparable computing speed. Still, the mobility of mobile clients prevents the utilization of mobile devices as ad hoc cloud of computing resources in a cloud system, because this kind of project must gather enough mobile devices to cooperatively accomplish large parallelizable computational tasks.

V. MIDDLEWARE:

In general, the middleware is developed to reduce the impact of heterogeneity in distributed systems, and acts as an intermediate that handles the interaction between them with a higher level of abstraction, hiding the complexity introduced by distribution. In [13] the authors define a distributed system as follows: "A distributed system consists of a collection of autonomous computers, connected through a network and distribution middleware, which enables computers to coordinate their activities and to share the resources of the system, so that users perceive the system as a single, integrated computing facility".

Heterogeneity notion is one of such challenges that face the advancement in smart environment especially mobile cloud computing [14]. As a result, the use of middleware has attracted many researchers to counter the problems with the non-uniform smart environment, such as multiple cloud services. In fact, the middleware is necessary to enhance the functionality and reliability of the interaction between heterogeneous smart applications and cloud services. Further, it offers the mechanism for adapting the cloud services in order to give adequate consumable cloud services on the end-clients.

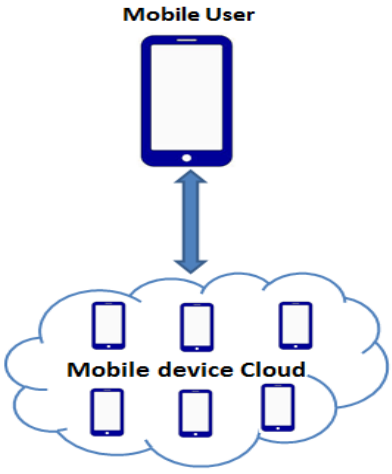

Figure 4. Offloading computing with mobile device cloud

In [15], the authors present MCM (Mobile Cloud Middleware) framework that addresses the issues of interoperability across multiple clouds, transparent delegation and asynchronous execution of mobile tasks that require resource-intensive processing and dynamic allocation of cloud infrastructure. Moreover, MCM can develop customer services based on service composition in order to minimize the number of offloading time needed in a mobile cloud application. Yet, security for mobile applications should be taken into consideration in the design of proposed middleware system.

VI. LI-FI:

To achieve more interesting smart applications, it is essential to introduce an eco-optical wireless communication in the city in order to satisfy the needs of citizens. In addition, this type of invention can protect the environment from the negative effects of radio frequency and encouraged the advancement of Eco-Friendly technologies.

In July 2011, Professor Harald Haas explained at the TED Global conference that it was now possible to design a wireless network from light emitting diodes (LEDs) [16]. The eco-optical wireless, called Li-Fi or Light-Fidelity is a new green technology which describes how visible light communication technology (VLC) is applied to high-speed wireless communication. It acquired this name due to the similarity to Wi-Fi, only using light instead of radio. The principle of Li-Fi technology is simple, relying on a light source at one end, like a LED, and a photo detector on the other end. When the LED is on, a digital 1 is transmitted, if it is off, a 0 is transmitted.

Different sectors that are already experimentally using Li-Fi that can be described as follows:

- *Medical environments:* Li-fi is integrated into medical devices which require isolation from EMI (Electromagnetic Interference) or RFI (Radio Frequency Interference). Li-Fi does not emit EMI or RFI. So it does not interfere with medical equipment and also it does not interfere with MRI scanners. Hence Li-Fi provides equipment and staff communications with no EMI and RFI problems. In this way, Li-Fi, which uses light as medium, is the best solution for communication in hospital campus, also for the people who are hypersensitive to radio frequencies.
- *Underwater:* Due to strong signal absorption in water, Wi-Fi does not work at where Li-Fi will work; also any RF operated gadget is not allowed in passenger aircraft. Here LEDs can perform dual function of illumination and communication.
- *Education systems:* As with the advancement of science the latest technology is the Li-Fi which is the fastest speed internet access service. So this will leads to the replacement of Wi-Fi at institutions and at companies so that all the people can make use of Li-Fi with same speed intended in a particular area.
- *Traffic management:* Street lamps, signage and traffic signals are also using LEDs. Thanks to Li-Fi, the communication with LED lights of the vehicles can reduce the number of accidents. Data can be easily transferred by making use of Li-Fi lamps with the street lamps; this can be involved for road safety and traffic management.

VII. CHALLENGES AND OPPORTUNITIES:

In general, the utilization of cloud models for the optimization of public services and visible light communication technology for the data transmission can be described as ones of the most sophisticated solutions to reach the main goal of a smart city, which is citizen satisfaction. However, there are many challenges that cease the advancement of this paradigm and require future efforts that are discussed in this section.

A. Mobile cloud social networks:

The term "Mobile Social Networks" (MSNs) refers to mobile applications that are developed based on social networks, such as Twitter, Facebook, and so on. In fact, these social networks, which allow people to express themselves, have become a strong bridge between virtual social communities and physical world information. Moreover, cloud platforms enhance further the capability of mobile social networking applications by storing and processing the personal data remotely. Therefore, MSNs provide great opportunities for researchers to understand the needs of people, and improve further the infrastructure of smart environments. For example, location based social networks (LBSNs) that can be used as parameter to select the services related to users' location [22].

To achieve the previous objectives, the social users must share their personal data, like name, job, credit card number or social security number. However, this kind of sensitive information can be used in illegal activities. For example, the cyber criminals can take the benefits of the published personal social information to trade stolen information. Consequently, security and privacy are the major challenges in smart environments, specifically in mobile social applications. These challenges impose serious considerations related to data security of citizens that are very sensitive, and any unauthorized access can have serious consequences. Accordingly, the success of smart environments, especially smart city paradigm, leads to these relevant research questions:

- How could the cloud providers save sensitive data and ensure security, privacy and ethical practices for the end-users?
- What are the best practices and strategies that cloud providers can use to manage the personal social information in the smart city?
- How to identify and extract the most relevant personal social information that can be used as criteria to determine and recommend the most efficient public services for the end-users?

B. Nearest cloud services:

The need for more mobile cloud applications with better processing speed becomes inevitable for smart environments. This is a strong reason for deploying cloudlets in public places, which represent intermediate layers located between the distant cloud platforms and end-clients. In others words, the users connect simply to the nearest cloudlet through a wireless network, like Li-Fi network, to consume the unlimited cloud resources remotely.

One of the most important functionalities for the success of cloudlets in relation to end-users' satisfaction is security. MiLAMob [24] is a middle which allows mobile consumers to access Amazon S3 by simplifying the authentication process in real time with minimal HTTP traffic. Moreover, it employs the OAuth 2.0 technique (E.g. Twitter, Facebook, Google+, and Personal Login) to identify the end-user, and use security tokens to handle the tedious authentication process to consume Amazon S3 data. Hence, this solution demonstrates how the middleware can enhance the consumption of cloud services by using the social networking features, especially authentication and authorization, to keep up the trust relationship between customers and cloud providers. On the other hand, cloudlets can also provide directly customized cloud services to the nearest users. Yet, this kind of cloud solutions should guarantee the integrity and availability of suitable customized cloud services for the end-clients. Therefore, we identified the following research questions associated with the security and availability of customized services on cloudlet platforms, which relate to the behavior of clients and quality of cloud services:

- What are the most important factors in smart city that need to be taken into consideration when developing solutions for scalable cloudlet models?
- How could cloudlet models based on VM supply the highest mobility of users, and ensure the scalability and elasticity of services as the remote cloud data centers?
- In case of the loss of network connectivity or mobility of clients, how could the mobile client find another cloudlet and continue the execution of mobile application in a real time?

C. Data transmission reliability:

Big data is one of the promising and timely technologies in this era. It plays an important role in making decisions in different domains of life, such as healthcare, business operations, tramway systems, and so on. However, this kind of technologies require ubiquitous network connectivity to support all the collected data, analyze it, and then link it in a way to extract the most important information. In this context, Li-Fi network is the best solution to enhance the communication in big data technology. Unfortunately, Li-Fi technology is experiencing some problems needed to be solved. One of these lacks is that the lights need to be ON, in case of street lamps, this is not a problem because we simply use the existing power lines during the night, but, in case of indoor, the energy may not be saved. Further, light is easily blocked by somebody simply walking in front of LED source. Consequently, data transmission can be easily obstructed by an opaque obstacle. Another problem is about the interference from external light sources that may interrupt the transmission of data, such as sun light or normal bulbs in the path of data

traffic. For these reasons, the researchers are already looking into solutions of these obstacles, which for example include an integration of Li-Fi with Wi-Fi or other data transmission technologies [21]. Nevertheless, Li-Fi technology still faces many challenges regarding:

- How to manage the energy in case of indoor?
- How to recommend another second network connectivity from the set of network services, like 3/4/5G, and ensure the data transmission reliability in case of data transmission failure with the primary Li-Fi network?

D. Mobile big data:

As mentioned in the previous section, the evolution of big data was driven by the rapid growth of application demands especially for mobile cloud applications, which produce large streams of data that need real-time processing, and storage spaces. Furthermore, mobile big data is characterized by generating mobile context-awareness that has become a challenging topic for cloud developers [23]. Yet, mobile big data is quickly created and becomes a hot topic for the upcoming research questions that are the following:

- How could the collected mobile big data from smart cities affect the design of cloud platforms?
- How to process and store data among mobile devices and cloud to optimize execution time, minimize price as well as save energy in the smart city?
- What are the best strategies and policies to negotiate services cost to mobile users in smart environment?

VIII. CONCLUSION:

To sum up, in this paper we discuss some of the most advanced technologies that are expected to make cities more "smart" in order to improve the life quality of citizens. Further, we highlight Li-Fi as a promising future eco-friendly technology in wireless communication for the smart city, and we discuss the research questions associated with the evolution of smart city.

We strongly believe that the "smart city" paradigm is an umbrella term for various technologies that will continue growing in terms of infrastructure and communications, and that although the industry and real deployment of these technologies is progressing in enormous speed, the scientific community should follow all these inventions with the studies of implications and consequences that these technologies could have on different aspects of the future life, and start with searching for the solutions before the problems are encountered in practice.

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