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Enabling Technologies for Smart City Services and Applications

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***Abstract*— Smart mobile devices are fast becoming the epicentre of people's lives. Most smart phones are currently embedded with powerful and programmable sensors such as GPS, gyroscope, microphone, camera, accelerometer etc. These sensor-enabled smart-phones would form an important element of the future networked-infrastructure. A new wave of services is bound to erupt from such connected infrastructure and smart devices that will influence all aspects of our social ecosystem. In the context of Smart Cities, this position paper and the associated invited talk presents the Mobile Technology perspective of the Smart-city architecture by presenting a conceptualized framework and highlights the open and emerging research challenges in this landscape.**

Keywords-Smart City, IoT, Mobile Sensing, Smart Applications

I. INTRODUCTION

The Internet from the time of its inception three decades ago has undergone many stages of evolution. It was originally conceived to be a productivity-centric networked infrastructure that connected end-users with information. It began with the era of content portals and web sites where the search engines acted as a facilitator between the end-users and the information. With information that was available on the internet becoming richer and the rapid increase in the number of Internet users, originated the social web that not only connected information but enabled connection between people. Social networks such as facebook and myspace, digital market places such as amazon and ebay, and VoIP services such as Skype empowered the social web where the end-users were not merely consumers but were active producers of the information on the internet [1].

With the advent of mobile phones, there has been a steady shift in communication from fixed to mobile and this is reflected in the increase in the number of mobile internet users in the last five years [2]. The advancement in mobile communication technologies has enabled "Anytime, Anywhere" access to information and related services thereby steering the focus from information access to the information context. Technologies such as artificial intelligence, ontology and intelligent agents [3,4] etc, are on the verge of transforming the social web into semantic web where the context-awareness transforms mere information to valuable knowledge.

The internet, having connected information to people and people to people, is heading towards connecting objects, places, things and everything that could benefit from being connected. When everything is connected to and is aware of everything else, Internet would emerge as an intuitive, context-aware, intelligent platform enabling smart services. Figure 1 depicts the evolutionary stages of the Internet as discussed above.

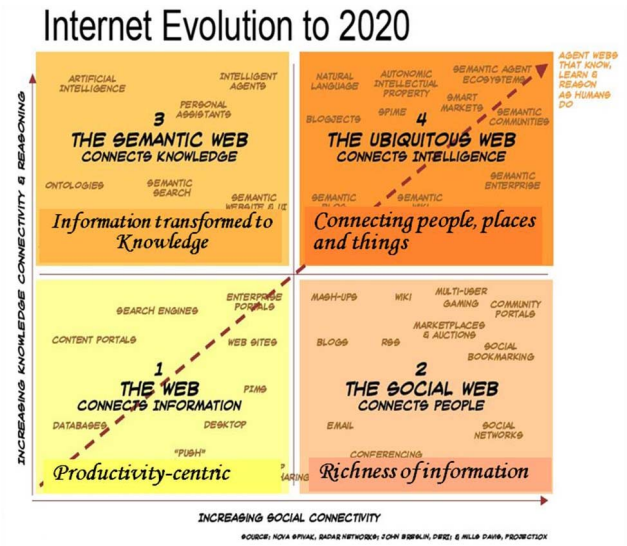

Figure 1: Internet Evolution (Source: Nova Spivak Radar Networks; John Breslin, Deri; and Mills Davis, Project10x)

First batch of connected objects in the market today are the electronic appliances such as microwave, gaming stations, Camera etc. With the advancement in embedded sensors and RFID technology [5], every object and process in the society could be connected that would yield tremendous process and human efficiency. Consequence of such a connected future is being researched from different perspectives and under different names such as Internet of Things [6], Smart City[7], Future Internet[8] etc,. However, the larger goal of all the above research remains the same, i.e, to revolutionize the human interaction with the earth in the same profound way as the internet has managed to revolutionize personal and business interactions[11].

Sensor-enabled smart objects including the smart-mobile devices are proving to be the elements of the future networked -infrastructure. A new wave of services is bound

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to evolve from such smart infrastructure and smart devices that will influence all aspects of our social eco-system. The range of applications would encompass several essential service verticals such as energy, Sanitation, Health Care, Transport, Farming, Governance, Automation, Manufacturing etc. Applications and technologies that can enable services around these capabilities require to be developed. Internet of Things (IoT) provides for intelligent Machine-to-Machine (M2M) and Machine-to-User (M2U) communication and enables provision of the essential services. A set of such services and the intelligent infrastructure form the basis of what has come to be called as Smart Cities

This paper presents the Mobile technologies that enable smart services and applications in order to make the visions of "Smart Connected Future" possible. In Section II, the paper presents the envisioned "Smart City" architecture followed with valuable observations on how the current day smart-phone could catalyze the creation of smart services. Finally, the paper presents a conceptualized architecture to discuss open issues and challenges and the emerging research directions in the "Smart City" landscape.

II. SMART CITY ARCHITECTURE AND BUILDING BLOCKS

An acceptable definition of "Smart City" within the European sub-continent is that "A city can be defined as 'smart' when investments in human and social capital and traditional (transport) and modern (ICT) communication infrastructure fuel sustainable economic development and a high quality of life, with a wise management of natural resources, through participatory governance"[9].

Based on the above definition and the study conducted by the Smart-Cities working group, Europe[7], Smart City can be identified along six main dimensions namely; Smart Economy, Smart People, Smart Governance, Smart Mobility, Smart Environment and Smart Living.
These six areas are further characterized by defining factors such as[13]:

- Smart Economy includes factors around economic competitiveness such as innovation, entrepreneurship, trademarks, productivity and flexibility of the labour market as well as the integration in the (inter-)national market.
- Smart People is not merely described by the level of qualification or education of the citizens but also by the quality of social interactions regarding integration and public life and the openness towards the "outer" world.
- Smart Governance comprises aspects of political participation, services for citizens as well as the functioning of the administration.
- Smart Mobility relates to aspects of availability and accessibility of information and communication technologies and modern and sustainable transport systems.
- Smart Environment is described by attractive natural conditions (climate, green space etc.), pollution, and resource management and also by efforts towards environmental protection.
- Finally, Smart Living comprises various aspects of quality of life as culture, health, safety, housing, tourism etc.

Figure 2, depicts the three basic building blocks of the smart-city architecture based on the above definition.

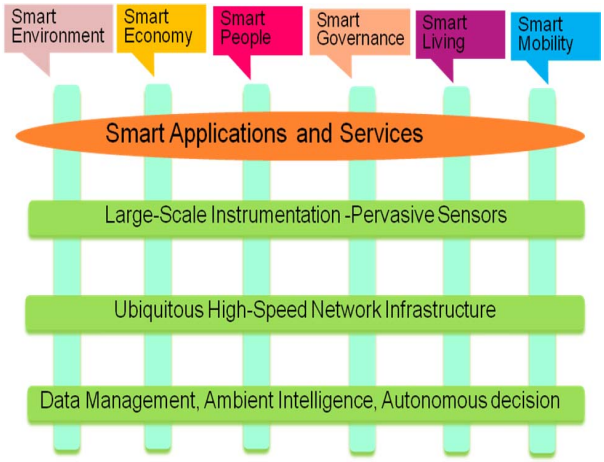

Figure 2: Building Blocks of Smart City Architecture

The most fundamental requirement to enable the smart city vision is the large scale instrumentation of the city's infrastructure, which includes structural, utility, transport, environmental, government and industrial manufacturing infrastructure with sensors, actuators, tag, and readers and other sensing devices. Today's mobile devices which are embedded with numerous sensors could well form part of this sensor-fabric. Foster and Sullivan forecast by 2013 sensor industry would be as huge as $70B business [10] reflecting the critical role of sensors in the smart-city agenda as mentioned above.

This underlying sensor fabric needs to be coupled with a large-scale deployment of high-speed network infrastructure that not only supports the exponential growth in the number of connected devices but also meets the specific needs of the various vertical industries. The network infrastructure is required to facilitate mobility, connection and transmission of information across various verticals and distribute services and products to the end users. It is projected that the proposed 1 trillion nanoscale sensors and actuators that are expected to instrument the city infrastructure would need a network infrastructure that is equivalent to a 1000 internets[11].

The third critical requirement of the smart city agenda is the efficient management of the aggregated smart data coming from the various verticals. The panoramic access to data spanning across the six domains of the Smart-City architecture enable information to be transformed to intelligence and this intelligence can be beamed through the smart applications and services that are created on the top of the three building blocks. Smart City services and applications are the key in achieving efficiency and accuracy of operation of this complex Smart City ecosystem.

III. SMART CITY SERVICES AND APPLICATIONS

In the context of "Smart City", based on the definition and the architecture of Smart Cities presented in Section II, the characteristics that make the smart city infrastructure "Smart" can be summarized as follows:

- Real world awareness that is brought about by the sensors merging the physical world with the virtual world, it is the real-time sensing of the real-world information in a totally automated manner makes for a smart infrastructure.
- Knowledge Engineering approaches that enable to make sense of the aggregated real world data add smartness to the applications and services.
- Lastly, the panoramic access to data and gaining new insights enables to maximize synergies across various verticals through interlinking the knowledge obtained from the disparate domains.

But, the infrastructure alone does not yield smartness; it is the applications that make the infrastructure smart. Hence, it is essential to tap the potential offered by the smart infrastructure to foster smart service and app creation.
Based on the smartness indicating factors described above, the current day smart-phones are an ideal candidate to catalyse smart applications and services.

A. Mobile Phones – A Catalyst for Smart City Applications

Smart-Phones today are embedded with a huge array of sensors and computing and communication resources. They are diminishing the difference between the virtual world and the real world by capturing the physical world data and making the mobile device more context-aware. The interesting part of the mobile sensing is that these smart sensors are constantly mobile in a given environment and further more they are attached to an interesting entity such as the end-user. The all-pervasive nature of mobile phones lays out an extensive sensing fabric in the society thereby ticking off the first defining requirement for smart-city application.

Secondly, most mobile devices are currently integrated with mobile cloud, which enables the offloading of mobile services to backend servers. This offers an unprecedented scalability and availability of vast computing resource which is useful for collecting large-scale sensor data. Data analysis may also be conducted in the back-end servers for intelligent usage of the collected data. This enables knowledge engineering and ticks off the second requirement of smart city application.

Last but not the least, the advancement in mobile access technologies will in the near-future offer high-speed LTE access on all mobile devices. This would enable mobility and facilitate interlinking of data across vertical domains.

The mobile apps are reachable to a vast majority of user-base through established app dissemination channels that exist today such as the app stores/markets. Furthermore majority of smart-phone platforms are open and programmable thereby offering very low entry barrier for third -party developers.

Having established the critical role played by mobile phone sensors in the Smart City agenda, we propose a three-plane Smart City Framework for Smart Service creation and dissemination.

The proposed framework as depicted in Figure 3 is referred to as Gather-Share-Govern (GSG) framework.

The Gather plane consists of Mobile sensing devices, which includes both smart-phone based sensors, non-phone based mobile sensors such as MSP(17) and other portable and wearable sensors based on RFID tags, actuators and sensors. This plane acts as the viewing glass and is focused mainly on the learning of the physical world information.

The Share plane consists of the network infrastructure as well as the service offered by the existing internet infrastructure that facilitates the inter-linking of data. The collected data could be made available to the users on sharing platforms that include the currently existing twitter and facebook channels.

The last plane called the Govern plane basically consists of the mobile cloud that stores, analyses and enables the creation of smart/intelligent services and applications. These smart applications in turn help govern the smart-city agenda.

The fascinating part of this framework is how the aggregated mobile sensor data is channeled back to the mobile devices in a form that is more refined and purposeful than when it was originally collected. This dissemination occurs in the form of smart mobile applications through appstores and app markets.

Smart Mobile applications can be categorized based on their scope or scale of sensing as follows[12]:

- Smart personal mobile apps such as personal heart rate monitors, or generic health monitors. Here the scale of mobile sensing Is limited to the personal mobile device[15].
- Smart group apps using techniques such as crowd sourcing. Here the scale of sensing is extended to a larger group and requires sharing and exchange of gathered sensor data[14].
- Smart community apps are the ones whose scale of sensing is vast and extends to a large community[13]. A particularly useful community app would be to understand the urban dynamics and help in solving the problems of urbanisation.

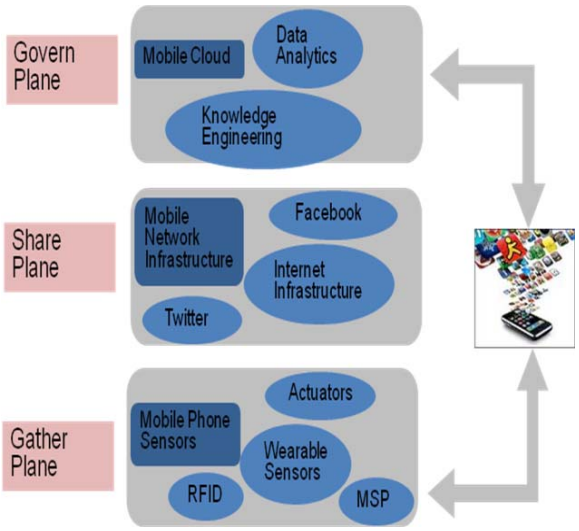

Figure 3: Mobile Sensing-based Smart City Framework

IV. Open Issues and Conclusion

As mentioned earlier, concept of Smart cities are being researched from various perspectives, Internet of Things(IoT) addresses the network perspective of smart cities, while Machine2Machine Communication addresses the communication perspectives and Future Internet addresses the service perspective of Smart Cities. |Each paradigm has many unanswered questions and open issues. The common subset of research challenges faced by all the above mentioned research directions can be summarized as follows:

Scalability: With the rapid increase in number of smart devices coupled with heterogeneous type of devices, applications and interactions, Scalability is a primary technical challenge on the road to large-scale deployment of sensors and sensing environment. Heterogeneity mentioned above poses issues related to Inter-operability.

Privacy and Security: Huge of volume of sensor data that is expected to be aggregated and analyzed in the mobile cloud brings with it issues relating to security and privacy. Data Processing and miningof vast amount of data poses the challenge of offering unified enriched and interoperable data description models. Similarly the freshness of data and maintaining other temporal requirements is also a big challenge.

Ubiquitous access, including mobility and service continuity enabling access and availability to data and services within the Smart city is still one of the primary challenges.

Lack of Testbeds: Many large IoT, and Smart city application deployments are jeopardized by the lack of testbeds of the required scale, and suitable for the validation of recent research results. Many existing testbeds just offer experimentation and testing limited to small domain-specific environments or application specific deployments. While those may fulfill the needs as proof-of-concepts, they do not allow conclusive experimentation.

Last but not the least, Smart City deployment involve different non-technical stakeholders, hence many non-technical constraints must be considered such as users, public administrations, vendors, government etc,.

In conclusion, once these technical barriers are overcome, the mobile devices and technology have the potential of catalyzing the process of smart city deployments. Mobile phone sensing systems have the capability of providing both micro- and macroscopic views of cities, communities, and individuals, and thereby facilitating smart mobile applications and services.

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