Research Direction in Realizing Sustainable IoT Based Smart City Ecosystem

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Abstract. In order to achieve sustainable goals within urban context, IoT based smart city is a popular concept to endeavor. The utilization of IoT technology is the backbone of this concept. This paper explores the current development of IoT based smart city ecosystem and suggests some issues to be followed up. In this ecosystem, stakeholders are basically categorized into Users, Devices Producer, Middleware Developer and Apps Developer. It is found that the future challenges of IoT based smart city are circling around coordination activity among these stakeholders.

Keywords: smart city ecosystem, sustainability, internet of things.

1. Introduction

Nowadays, most of the people on this planet live in urban areas. According to the United Nations, 54% of world’s population was living in urban areas in 2014, and it is projected that 66% of world’s population will live in the urban area by 2050 [1]. This urbanization trend has a direct impact on the growth of the cities and creates significant challenges for the cities’ services and infrastructure, including scarcity of resources, inadequate infrastructures, energy shortage, human health concerns, and demand for better economic opportunities [2]. It is approximated that the cities consume 75% of the world’s energy and 60% of all water allocated for human use. Moreover, it also produces 80% of greenhouse emissions [3]. This rapid expansion of the cities has leaded the urgency to manage the cities in sustainable manner, a harmony in the aspects of profit, people, and planet.

To manage cities in sustainable manner, government needs to orchestrate multiple systems at once in concert. These systems are including several city governance domains like city administration, transportation, education, health care, public safety, housing, infrastructure, and utilities [4]. Since the systems are essential for urban living, those systems should perform uninterruptible while maintaining its services quality. To this end, tremendous management effort is required to monitor, report, and intervene the systems [3].

In general, management of the systems mentioned above is assigned to the relevant private or public-sector entities [3]. In such condition, coordination between the entities is often difficult and inefficient because of various obstacles in technical, administrative and political domain that may
leads to performance issue of the city systems [3]. To address this coordination issue, a new way in governing the city that can integrate the entities in managing city’s systems is need to be developed.

2. Literature review

2.1. Smart City
A new way in governing the cities is by utilizing intelligent devices and broadband technologies in the smart city concept [3,5]. There are range conceptual definitions of smart city. It is differentiating due to different context and circumstances in each case of smart city implementation [4]. However, [6] has laid the foundation of smart city definitions. They defined smart city as an instrumented, interconnected, and intelligent city. Instrumented means that the city has set of instrumentation devices enables the capture and integration of live real-world data. Interconnected means the city has capacity to integrate the information gathered from the instrumentation devices into an enterprise-computing platform and communicate the data into various city services. Intelligent refer to the ability in analyzing the interconnected information into insights that drive decisions and actions that improve process outcomes or system, organization, and industry value chains.

Further, [6] construct 5 layers of smart city structure as shown in Figure 1. In this structure, it is shown that the primary information comes from a bunch of sensors that capture live real-world data to be further analyze to in the upper layers to guide or automate decisions or actions to improve a certain city function.

![Figure 1. Smart city structure [6]](Image)

From this structure, interconnected sensors that generally referred the internet of things (IoT) is inevitably required as the inherent feature of the smart city, since it has ability to automatically share data, interact and combine services whenever and wherever is required [3].

2.2. Internet of Things
IoT is an evolution of the current internet into a network of interconnected objects that harvesting data from the physical environment that become source of information of analytical tools, applications and
services in certain domain [7]. There is a definition for IoT that do not restrict in any standard of communication protocol such that allow smart technologies to be developed and deployed using available state-of-the art protocol at any given point in time [7]. The definition is, “Interconnection of sensing and actuating devices providing the ability to share information across platforms through a unified framework, developing a common operating picture for enabling innovative applications. This is achieved by seamless large scale sensing, data analytics and information representation using cutting edge ubiquitous sensing and cloud computing”.

Based on the above the definition, [7] summarize three components of IoT, namely: a) Hardware, in which consist of sensors, actuators and embedded communication hardware b) Middleware, in which consist of on demand storage and computing tools for data analytics and c) Presentation, in which consist of visualization and interpretation tools which can be widely accessed on different platforms and can be designed for different applications.

IoT devices applied in city infrastructures supply enormous amount of data, generally defined as big data, to be further utilizes in various applications supporting city operations. To be able to utilize these big data efficiently and secure, managing these big data flow requires orchestration from dedicated parties known as IoT operator [8]. Particularly in relation with big data flows, [8] suggest four layers for IoT ecosystem in smart city context as shown in Figure 2.

As shown in Figure 2, at the first layer, there are city infrastructure and citizens as the objects and users that become the enablers of smart city ecosystem. A city infrastructure is where cities’ utilities are operates (e.g., energy facilities, water source, street light, parking area, road, etc) and citizens are the users of various smart city services that enhance their life quality. From this first layer, data harnessed by IoT devices implemented in the second layer, and then be collected by middleware solution in the form of standardized APIs that enable interaction with data generated by the IoT devices in open data model at the third layer. Based on the open data delivered by standardized APIs, at the fourth layer, public private partnership (PPP) entity is formed as the IoT service operator to govern the data delivery to third-party application developer. By using apps-store like model, IoT service operator grants API access for third party developer to develop their applications, analytical tools, and services. The developed apps then will be distributed to users by apps store like Apple apps store or Google play store. Regulated access by the IoT service operator can beneficial to citizens since it will generate services that give positive impact on citizens’ life quality. On the other hand, utilities provider will also get benefit by improved control over their infrastructure [8].

Many cities around the world have rolled out smart city initiatives based on IoT technologies. This initiatives are leveraging smart technologies in improving city’s services, including transport infrastructures, energy distribution networks, and natural resources. For example, City of Melbourne, Australia rolled out smart city initiative in three focus groups of potential IoT applications, which are citizens (health care, emergency services, defence, and crowd monitoring), transport (traffic management and infrastructure monitoring) and services (water, building management, and environment) [4]. Another example, in Santander, Spain, more than 5000 IoT devices already deployed both at static locations (streetlights, facades, bus stops) as well as on mobile vehicles (buses, taxis) [9]. This IoT project, SmartSantander is a unique, city scales IoT experimentation project in developing applications and services for a smart city [3,9]. Several services are already deployed on SmartSantander platform are outdoor parking management, environment monitoring, participatory environmental sensing, irrigation and garden monitoring, and point of interest augmented reality, and energy smart metering [9].
3. Discussion

Based on literature study to the selected articles, there are several challenges in smart city digital ecosystem need to be address such that smart city’s services can be sustain and beneficial for all involved stakeholders. Adopted from [8], this paper proposes to categorize these challenges in three categories, namely governance, financial, and technological. Challenges related with interaction of stakeholders within the ecosystem are grouped in governance category, while related with financial and business aspect of the ecosystem are grouped in financial category, and on the other hand challenges related with technical and technological aspect of the ecosystem are grouped in technological category. Table 1 lists the challenges in each category.

| Category     | Challenges                                              | Author          |
|--------------|---------------------------------------------------------|-----------------|
| Governance   | Cooperation between involved stakeholders               | [8,10,11]       |
|              | Users or organizational diversity                       | [11]            |
|              | Resistance to change                                    | [11,12]         |
|              | Data and privacy policy                                 | [8,12,13]       |
| Financial    | No clear business model                                 | [8,10,13,14,15] |
|              | High investment and continuation of funding             | [8,12]          |
|              | Lack of appropriate return on investment methodologies and metrics | [8,10] |
| Technological| Big data handling                                       | [8,16,17,18,19] |
|              | Interoperability & integration                          | [8,10,11]       |
|              | IoT devices standard                                    | [12,13]         |
|              | Technology infrastructure limitation                     | [12]            |
|              | Security & privacy threats                              | [11,12,13,15]   |

Figure 2. IoT ecosystem in smart city context [8]

Table 1. Smart city challenges
Particularly in governance category, most of the challenges are related with coordination of the stakeholders within the ecosystem and its derivatives, including challenges related to user behavior and data policy. These are important challenges, since at its core, smart city is not one-way initiative by the government, but it is massive interaction between numbers of stakeholders, components, services and technologies [20]. Smart city loop shown in Figure 3 shown simple illustration of the interaction [21].

To be fully benefit from new possibilities brought by smart city, it is important to get the stakeholders involved in smart city loop cooperate in a coordinated way [20,21]. Further, research shows that coordination between the involved stakeholders in smart city ecosystem is the key to realize smart city benefit and to ensure long-term sustainability of smart city initiative [8,10,11,12,20,22].

To provide direction in addressing coordination issue smart city ecosystem, this paper proposes several research questions to be further elaborate. These research questions are the following:

**Question 1:** Who are the stakeholders involved in the ecosystem of IoT based services in smart city context, including their roles and interests?
This questions is proposed to define clearly all the stakeholders involved in the in the ecosystem of IoT based services in smart city context, particularly in relation with big data flows. Clear definitions of involved stakeholders including their roles and interests in the ecosystem are important to get comprehensive coordination architecture. Desired outcome in answering this question are list of all involved stakeholders in the ecosystem, roles of each stakeholder in the ecosystem, interests of each stakeholder in the ecosystem.

**Question 2:** How the coordination architecture between stakeholders should be arrange, such that satisfy the interests of each stakeholders?

This question is proposed to define coordination architecture that address relationship structure between stakeholders incorporating their interests in the ecosystem of IoT based services in smart city context. To be able to orchestrate the stakeholders in the ecosystem properly and ensure long-term sustainability of the ecosystem [22], the coordination architecture should encompassed business model that beneficial for each of the stakeholders, in which including functions performed by each stakeholder, services offered, funding structure, and business terms between involved stakeholders [22].

Desired outcome in answering this question is to have coordination architecture of stakeholders in the ecosystem of IoT based services in smart city context, encompassing business model of the ecosystem that beneficial for each stakeholder.

**Question 3:** What are the performance criteria that can evaluate sustainability of the IoT based services ecosystem in smart city context based on defined coordination architecture?

This question is proposed to define performance criteria of the coordination architecture developed in previous question. The goal of the performance criteria is to measure the impact of the coordination architecture with certain configured parameter, to sustainability of IoT based services ecosystem in smart city context. Desired outcome in answering this question is to have performance criteria that reflect the impact of the coordination architecture to sustainability of IoT based services ecosystem in smart city context.

**Question 4:** How to evaluate the coordination architecture, such that can achieve certain level of defined performance criteria?

This question is proposed to defined methodology to evaluate the coordination architecture to achieve certain level of performance criteria defined in previous question. Simulation modeling using system dynamics or agent based model (ABM) technique is proposed methodology to be further explored to evaluate the coordination architecture. Desired outcome in answering this question is to have a simulation model developed using system dynamics or ABM technique that can be parameterize to evaluate the coordination architecture to achieve certain level of performance criteria.

Elaborating on the above research questions hopefully can provide direction in addressing coordination challenges that has become significant impediment in realizing sustainable IoT based smart city ecosystem.

4. Conclusion

This paper proposes several research questions as recommended direction for further research in addressing challenges in smart city ecosystem, especially in coordination domain as the significant impediment in realizing sustainable IoT based smart city ecosystem. Four research questions mentioned in this paper, ultimately leads to the needs of architectural perspective of IoT based smart city ecosystem that can represent relationship of involved stakeholders in the ecosystem. Further, this architectural perspective can be the based to develop simulation model that can be parameterize to evaluate the performance of the ecosystem.

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