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Towards sustainable smart cities: A review of trends, architectures, components, and open challenges in smart cities

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ABSTRACT

Smart city is an application of Internet of Things (IoT) notion. Unceasing growth of population and urbanization have intensified innovative ways to handle urbanization with minimal impact on environment, citizen lifestyles, and governance. Initial integration of information communication technology (ICT) into city operations have promoted telicity, information city, and digital city concepts. Later, the conception of IoT has founded the smart cities, which support the city operations intelligently with minimal human interaction. Smart city emerged as a solution to address the challenges arise with exponential growth of urbanization and population. However, smart city concept is still evolving and not mainstreamed throughout the globe due to technological, economical, and governing barriers. Therefore, this paper aims to deliver the essence of smart cities. The paper presents a brief overview of smart cities, followed by the features and characteristics, generic architecture, composition, and real-world implementations of smart cities. Finally, we present some challenges and opportunities identified through extensive literature survey on smart cities.

1. Introduction

The concept of connecting everyday objects via the existing networks became highly favorable with the emergence of smart devices and their recent advancements. Internet of Things (IoT) resulted from the evolution of conventional networks that connect zillions of connected devices. Technological advancements in ubiquitous computing (UC), wireless sensor networks (WSN), and machine-to-machine (M2M) communication have further strengthened the IoT notion (Silva, Khan, & Han, 2017a; Khan, Silva, Jung, & Han, 2017). Facilitating UC via uniquely identifiable smart devices without or minimal human interaction is being the de-facto principle of IoT (Gubbi, Buyya, Marusic, & Palaniswami, 2013; Khan, Silva, & Han, 2017). Moreover, connected smart devices share own information and access authorized information of other devices to support contextual decision-making (Vermesan et al., 2015). Owing to the extensive attention gained from various interest groups, IoT notion has pioneered striking applications with its expansion i.e. smart home, smart city, smart warehouse, smart health, and so forth (Islam, Kwak, Kabir, Hossain, & Kwak, 2015; Jabbar, Khan, Silva, & Han, 2016; Jin, Gubbi, Marusic, & Palaniswami, 2014; Khan, Silva, & Han, 2016). Smart city has become the spotlight in last few decades, due to dramatic urbanization all over the world. Performing city operations with aid of ICT made cities efficient in various aspects. However, incorporating ICT to perform city operations does not fully interprets a smart city (Hollands, 2008). Smart city has been favored among other urban models i.e. telicity, information city, and digital city, since it represents the abstraction of all other models (Mohanty, Choppali, & Kougianos, 2016). The smart city is an application of the IoT (Silva et al., 2016), hence it inherits the underlying operational mechanisms from IoT. As shown in Fig. 1, IoT provides essential building components for smart cities i.e. data generation, data management, and application handling.

In generic terms, smart city is an urban environment that utilizes ICT and other related technologies to enhance performance efficiency of regular city operations and quality of services (QoS) provided to urban citizens. In formal terms, experts have defined smart city considering various aspects and perspectives. A popular definition states that a smart city connects physical, social, business, and ICT infrastructure to uplift the intelligence of the city (Harrison et al., 2010). In another comprehensive definition smart city is defined as an advanced modern city that utilizes ICT and other technologies to improve quality of life (QoL), competitiveness, operational efficacy of urban services, while ensuring the resource availability for present and future generations in terms of social, economic, and environmental aspects (Kondepudi, 2014). The utmost goal of initial smart cities was to enhance the QoL of urban citizens by reducing the contradiction between

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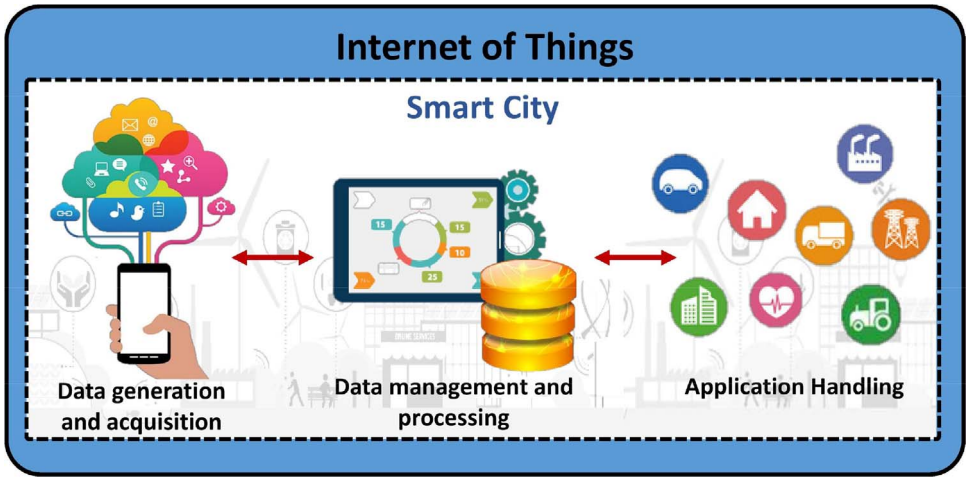

Fig. 1. Contribution of Internet of Things In building Smart City.

demand and supply in various functionalities (Zanella, Bui, Castellani, Vangelista, & Zorzi, 2014). Accommodating QoL demands, modern smart cities especially focus on sustainable and efficient solutions for energy management, transportation, health care, governance, and many more, in order to meet the extreme necessities of urbanization (Ejaz, Naeem, Shahid, Anpalagan, & Jo, 2017).

The United Nations (UN) projected that 66% of the world population will be urban by 2050 (United Nations, 2014). In this era a large portion of resources of the world is preoccupied by cities, as a fact in modern world, 75% of the total energy is consumed by the cities (Mohanty et al., 2016). This perpetual energy consumption generates nearly 80% of the greenhouse gases that causes unfathomable adverse effects on the environment (Nam and Pardo, 2011a). Considering the fact, experts in both industry and academia agreed upon smart city as the ideal solution to address the challenges occur from drastic urbanization, population growth, deterioration of energy sources, environmental pollution, etc. Nevertheless, not every smart city are essentially similar in requirements, contributions, components, and characteristics. Therefore, International Organization for Standardization (ISO) provides globally agreed standards to assure the quality, safety, and performance of a wide range of smart cities. Hence, we can claim that adherence with smart city standards offer innumerable benefits in deploying and managing smart cities, while facilitating real-time performance monitoring (The British Standard Institution, 2014).

The research community came up with a plethora of experimental and real-time smart city solutions owing to expedience and significant attention drawn towards sustainability during the recent past. However, a majority of the proposed works belongs to experimental lab based testbed category. Transforming a testbed scenario into the real world is a laborious and a complicated task, since testbed limitations i.e. limited scalability, lack of user environment, mobility restrictions, and lack of heterogeneity preclude the practical implementation. Even though, Oulu smart city architecture (Ojala, 2010) and Citysense (Murty et al., 2008) offer service provision and experimental testbed, these architectures lack in compensating heterogeneity of IoT devices, scalability, and mobility support. Some testbed experiments (e.g. Kanseigenie (Sridharan et al., 2010)) serve heterogeneity of IoT devices, though the deployed environment is extremely different from the actual urban environment. Hence, direct extension of original tools and mechanisms used in testbed setting is not feasible in real-world deployments. WISEBED (Coulson et al., 2012) is another testbed based solution that provides a comparatively large heterogeneity in IoT devices. Moreover, SmartSantander testbed was proposed to offer mobility experiments exploiting a large-scale IoT device framework, which involves real urban citizens in the experiments (Sanchez et al., 2014).

The rest of the paper is organized as follow: Section 2 elaborates on different features of a smart city. Following to thorough analysis of recent works, in Section 3 we present a generic smart city architecture, which confirms with many proposed architectures. Section 4 elaborates on the composition of a smart city. Real-world implementations of smart cities around the world are presented in Section 5 and challenges and future trends are identified in Section 6. Finally, the conclusions are presented in Section 7.

2. Features of a smart city

Smart city comprises of attributes, themes, and infrastructure. Attributes of a smart city are also known as characteristics of smart city. Since the continuous progression of a smart city relies on themes, they are also called as pillars of the smart city. In fact, infrastructure is an essential feature for any smart city, which provides the operational platform. This section elaborates on aforementioned features considering a generic smart city deployment.

2.1. Characteristics of a smart city

Composition of multiple attributes builds a smart city. According to Saruja et al., a majority of smart city proposals consists of four main attributes i.e. sustainability, QoL, urbanization, and smartness (Mohanty et al., 2016). Few sub attributes are concerned under each attribute. Infrastructure and governance, pollution and waste, energy and climate change, social issues, economics, and health are the sub attributes that come under sustainability. The ability of a city to uphold the balance of eco system in all aforementioned aspects, while serving and performing city operations is known as the sustainability. Emotional and financial well-being of urban citizen indicates the QoL improvement. Urbanization attribute focuses on technological, economical, infrastructural, and governing aspects of the transformation from rural environment to urban environment. The smartness is defined as the desire to improve social, environmental, and economic benchmarks of the city and its inhabitants.

From 1980s, sustainability has been considered as a predominant paradigm in urban development. In fact, prevalent attention on sustainability played a major role in the emergence of smart cities. Sub attributes of sustainability adhere to the triple bottom line notion (Barton, 2010; Rydin, 2012; Wheeler & Beatley, 2014). The triple bottom line concept contemplates about interrelationship and interdependence among sub attributes shown in Fig. 2. Cities of the modern world are increasingly developing by utilizing natural resources. Thus, it is crucial to scrutinize the ramification of scarcity of non-renewable energy sources. Consequently, safe guarding natural heritages and energy sources has become a compelling demand in maintaining