A Smart City Based on Ambient Intelligence

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SUMMARY   The United Nations (UN) reports that the global population reached 7 billion in 2011, and today, it stands at about 7.3 billion. This dramatic increase has been driven largely by the extension of people's lifetime. The urban population has been also increasing, which causes a lot of issues for cities, such as congestion and increased demand for resources, including energy, water, sanitation, education, and healthcare services. A smart city has been expected a lot to solve those issues. The concept of a smart city is not new. Due to the progress of information and communication technology (ICT), including the Internet of Things (IoT) and big data (BD), the concept of a smart city has been being realized in various aspects. This paper introduces the concept and definition of a smart city. Then it explains the ambient intelligence that supports a smart city. Moreover, it introduces several key components of a smart city.
key words: *a smart city, ambient intelligence, information and communication technology (ICT), Internet of things (IoT)*

1. Introduction

According to World Health Organization (WHO), the urban population in 2014 accounted for 54% of the total global population, up from 34% in 1960, and continues to grow [1]. It is estimated that the proportion of people living in an urban environment will exceed 70% by 2050. It is very challenging for cities to accommodate such a large amount of population, because it causes various issues such as congestion and increased demand for resources, including energy, water, sanitation, education, and healthcare services. To accommodate such a large amount of population, cities need to be smarter in various sense, such as traffic control, efficient use of resources, reduction of air pollution and carbon dioxide (CO2) emission, and reduction of costs.

A smart city is now attracting much attention to solve those issues. The concept of a smart city is not new. For instance, the concept of a smart sustainable city is presented in [2] in 2007. The similar concept, such as 'the eco-cities' is presented in [3] in 1997. Including those, there are various definitions of a smart city. One common thing among them is that a smart city exploits information and communication technology (ICT) extensively. Through ICT a smart city collects various kinds of data about people and environments. Then, based on the collected data it can provide various services, and also it can improve the environment by optimizing the usage of resources. Thus, it can be said that a smart city exploits big data (BD) extensively to make a city smart. The ambient environment realized by ICT is referred to as "Ambient Intelligence" where the environment itself has intelligence. The cornerstone of the ambient intelligence is the Internet of Things (IoT) that represents the ubiquitous presence of networked embedded devices (Things).

Many countries are planning and implementing a smart city or the similar concept, including Japan. For instance, Singapore is holding up "Smart Nation," which is defined as follows [4]: "A Smart Nation is one where people are empowered by technology to lead meaningful and fulfilled lives. A Smart Nation harnesses the power of networks, data and info-comm technologies to improve living, create economic opportunity and build a closer community. A Smart Nation is built not by Government, but by all of us - citizens, companies, agencies." This is almost the same concept as that of a smart city which will be introduced in the following sections. Also many cities adopted the concept of a smart city, such as Amsterdam [5], Vienna [6], Toronto, Paris, New York [7], Stockholm [8], London [9], Tokyo, Berlin [10], Hong Kong [11], Barcelona [12], and so on. For instance, Amsterdam has started to realize the concept of a smart city, particularly in the following four areas: living, working, mobility, and public space.

This paper introduces the concept and definition of a smart city. Then it explains the ambient intelligence that supports a smart city. Following the explanation of the ambient intelligence, it explains the IoT that is essential to realize ambient intelligence. Moreover, it introduces several key components of a smart city: smart energy, smart mobility, and smart healthcare. It is noted that each component of a smart city is, of course, realized by ambient intelligence.

This paper is organized as follows. Section 2 introduces the concept and definition of a smart city. Sections 3 and 4 explain ambient intelligence and IoT that support a smart city. Section 5 introduces several key components of a smart city, such as, smart energy, smart mobility, and smart healthcare. Section 6 presents the conclusion including some important component for a smart city.

2. A Smart City

A smart city is now attracting much attention in various fields and aspects. There are various definitions of a smart city, and with various terms, including those mentioned in Introduction, such as "smart sustainable city," "eco-city," "cyberville," "digital city," "electronic city," "flexicity," "in-

Table 1   30 keywords for a smart city [14].

ICT	Standard of living	Water
Adaptable	Employment	Utilities and energy
Reliable	Citizens	Telecommunications
Scalable	Well-being	Manufacturing
Accessible	Medical	Natural and man-made disasters
Security	Welfare	Regulatory and compliance
Safe	Physical safety	Governance
Resilient	Education	Policies and processes
Economic	Environmental	Standardization
Growth	Physical and service infrastructure	Transportation and mobility

formation city," "telicity," "wired city," "smart community," and "smart city" [13], [14]. A smart city is a place where people can live peacefully with little worries or difficulties supported by ICT and various kinds of technologies and frameworks, such as the IoT and BD. There are some definitions of a smart city. One of them defined by the US government is the following [15]: "A city that monitors and integrates conditions of all of its critical infrastructures including roads, bridges, tunnels, rails, subways, airports, sea-ports, 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." In [16] smarter cities are also defined as urban areas that exploit operational data, such as that arising from traffic congestion, power consumption statistics, and public safety events, to optimize the operation of city services. Optimization of city services based on BD collected by sensors is one of but not all the important aspects of a smart city.

One of the most comprehensive survey and definition about a smart city is presented by International Telecommunication Union (ITU) [14]. In ITU the following definition of a smart sustainable city was approved by the Focus Group on Smart Sustainable Cities (FG-SSC) Working Group 1 [14]: "A smart sustainable city is an innovative city that uses information and communication technologies (ICTs) and other means to improve quality of life, efficiency of urban operation and services, and competitiveness, while ensuring that it meets the needs of present and future generations with respect to economic, social and environmental aspects." As mentioned in this definition, ICT is a key factor to realize a smart city. Due to the progress of ICT, the time comes when we can expect and realize a smart city that improves quality of life in various ways with less burden on environments.

In ITU-FG-SSC key categories and indicators were also established and a list of 30 key terms was also identified [14]: The following eight (8) categories were identified to be key for SSC:

- Quality of life and lifestyle
- Infrastructure and services,
- ICT, communications, intelligence and information
- People, citizen and society
- Environment and sustainability
- Governance, management and administration
- Economy and Finance

- Mobility

A smart city should be people centric. In such a sense, the above categories, "People, citizen and society" and "Quality of life and lifestyle" are the main ones, while the others are for supporting people, though there are some other categories in a smart city not mentioned above. Same as true for the following six (6) primary indicators identified in [14]:

- Smart living
- Smart people
- Smart environment and sustainability
- Smart governance
- Smart mobility
- Smart economy

The 30 keywords listed in Table 1 were identified to be representative of an SSC. From these keywords, we can see what people are expecting for a smart city and what is supporting SSC. As shown in the above definition of a smart sustainable city, ICT will play an important and key role to realize it. The ambient environment containing ICTs are referred to as "Ambient Intelligence." In the following sections ambient intelligence and its similar concept IoT are explained, followed by introduction of some of the key components of a smart city.

3.   Ambient Intelligence

This section explains "Ambient Intelligence" that supports a smart city. "Ambient Intelligence" refers to the ambient environment containing ICTs to realize a smart city. There are several definitions about ambient intelligence. In [17] ambient intelligence is defined as "an emerging discipline that brings intelligence to our everyday environments and makes those environments sensitive to us." Ambient intelligence is based on various ICT related technologies, such as sensors, networks, pervasive computing, artificial intelligence, and so on [18]. The technical committee on ambient intelligence and sensor networks (ASN) emerged by merging two IEICE technical committees, the technical committee on Ubiquitous Sensor Network (USN) and the technical committee on Ad Hoc Network. The basic concept of ambient intelligence and ASN is shown in Fig. 1. In ambient intelligence sensing environments and obtaining data about them are essential tasks. Sensed data are locally processed and/or transmitted
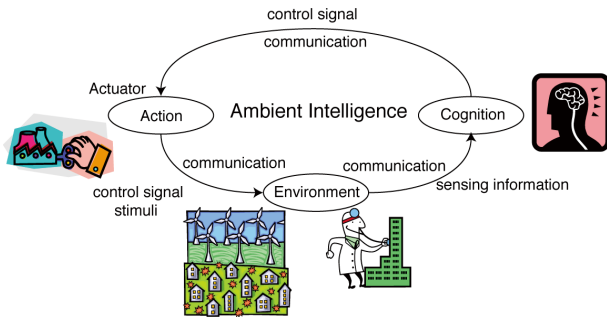
Fig. 1 Ambient intelligence.

Fig. 2 Functions of IoT.

to the place, "Cognition" in Fig. 1, where useful information are extracted from the transmitted data. Sensing environments and transmitting the sensed data are referred to as IoT or sensor network, depending on where we talk about them. The sensed data are often referred to as big data. Based on the information extracted from the collected sensed data, ambient intelligence adaptively changes the environments and/or presenting the useful information to enhance and/or assist human activities, that is, to realize smart city. As shown in the figure, ambient intelligence consists of a cognitive cycle.

In IEICE the Technical Committee on ASN is actively working on researches about ambient intelligence.

4. IoT

The IoT is essential to realize ambient intelligence in which an environment itself has intelligence. As written in the section of Introduction IoT is the cornerstone of the ambient intelligence. The IoT is the network of physical objects (Things) that contain embedded technology to communicate and sense or interact with their internal states or the external environments. In the IoT various kinds of Things are connected, such as sensors, actuators, computers, homes, buildings, structures, vehicles, energy systems, even lighting, dishes, toothbrushes, glasses, wearable devices, as well. Those Things provide and/or receive sensing data through network, some of them are actuated by cognition based on data collected from the Things. In more detail the Thing has some of but not limited to the following functions, shown in Fig. 2: (1) sensing, (2) actuating, (3) transmitting, (4) receiving, (5) storage, (6) learning, (7) reasoning. Through the exploitation of those functions, the IoT makes full use of Things to offer services to various kinds of applications, whilst ensuring that security and privacy requirements are fulfilled.

ITU-T defined the IoT in a broader sense [19]: The IoT is defined as a global infrastructure for the information society, enabling advanced services by interconnecting (physical and virtual) Things based on existing and evolving interoperable information and communication technologies. In [19] the Things are defined as objects of the physical world (physical things) or the information world (virtual things), which is capable of being identified and integrated into communication networks. From a broader perspective, the IoT
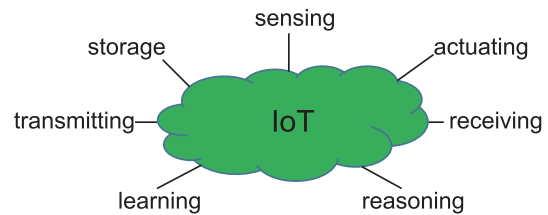
can be perceived as a vision with technological and societal implications.

As the fundamental characteristics of the IoT, the followings are listed in [19]:

- Interconnectivity
- Things-related services
- Heterogeneity
- Dynamic changes
- Enormous scale

In [19] the high-level requirements relevant for the IoT are also listed:

- Identification-based connectivity
- Interoperability
- Autonomic networking
- Autonomic services provisioning
- Location-based capabilities
- Security
- Privacy protection
- High quality and highly secure human body related services
- Plug and play
- Manageability

For the detail of each, readers are encouraged to refer to [19].

5. Some Components of a Smart City

There are many components of a smart city. In [13] nine components are mentioned: infrastructure, buildings, transportation, energy, healthcare, technology, governance, education, and citizens. Some of them are the same as mentioned as the primary indicators or the keywords in [14]. The smart city model in [20] consists of six key components, smart economy, smart people, smart governance, smart mobility, smart environment, smart people, and smart living. As can be seen, many papers have common components of a smart city. In this section some of the components are picked up and explained.

5.1 Smart Energy

Energy is essential for a smart city and is like a blood for a human body. There are various kinds of energy sources, such as electricity, gas, solar, fossil fuels, and so on. What is the smart energy? There are some definitions, however, they have the following concept in common. The smart energy
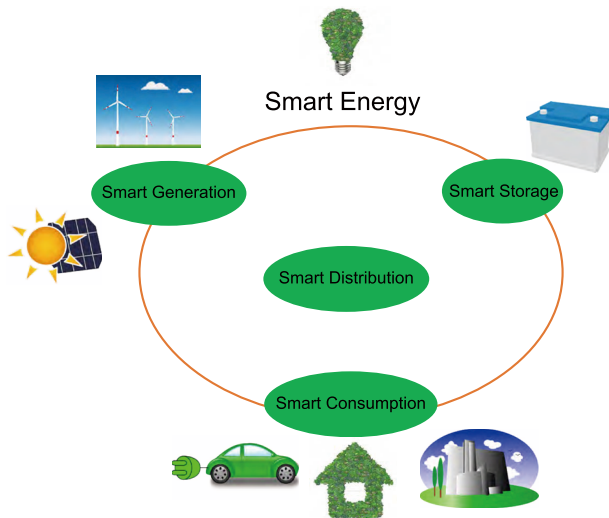
Fig. 3 Smart energy.

is the concept in which energy is produced in smarter ways that put much less burden on the environment. In the smart energy a good balance is provided between energy supply and demand so that the energy can be used very efficiently, which leads to sustainable energy and society. This good balance is supported by ICT based on ambient intelligence.

As the energy source of the smart energy in the smart society, the following new sources can be used in addition to the traditional energy: clean energy, green energy, sustainable energy, renewable energy, and so on. The use of these energies supports the realization of low carbon society. For a smart city, a smart energy system is important where there are four key components, smart generation, smart storage, smart distribution, and smart consumption, as shown in Fig. 3. As shown in Fig. 3, those components compose a cycle. "Smart Generation" refers to smart ways to generate energy, as shown above: clean energy, green energy, sustainable energy, renewable energy, and so on. In "Smart Consumption" the energy generated in smart ways, that is, from "Smart Generation" and that generated by traditional ways, are consumed in smart ways where it consumes the energy efficiently, that is, less energy, with lower emission of carbon dioxide and other unfavorable gasses. "Smart Storage" is also a key component of "Smart Energy." "Smart Storage" enables people to use energy when it is needed, with more stable and cheap prices, because it enables s stable supply of energy. "Smart Distribution" can realize efficient energy distribution from "Smart Generation" to "Smart Consumption" and "Smart Storage", from "Smart Storage" to "Smart Consumption", from "Smart Storage" to "Smart Storage," and so on. "Smart Energy" s the intelligent integration of these components. The similar model can be seen in the smart grid (smart energy grid). "Smart Energy" is expected to improve people's lives.

5.2 Smart Mobility

Smart mobility, also called smart transportation, is also an important component of a smart city. Like other components in a smart city, smart mobility is based on ICT where it exploits the information more than traditional transportation. Exploiting the information obtained by ICT, smart mobility can reduce traffic accidents, use energy more efficiently and thus reduce CO2 emission and noise, reduce traffic congestion, and make it easy for people to utilize it. Thus, we can say that smart mobility is a revolution of intelligent transportation system (ITS). Among smart mobility, traffic control and management is important, because the economical loss of society and the burden on environments by traffic congestion are very large. In [21] it is reported that transport currently accounts for about 23% of global energy-related greenhouse gas emissions of which 75% are derived from land transport. It is also mentioned that due to the increasing motorization and urbanization, greenhouse gas emissions from land transport are set to double by 2050 [21]. It is also reported in [22] that road traffic congestion costs billions to the world economy, such as follows:

- $101 billion in USA
- Aggregate delays of 4.8 billion hours, which causes the waste of 1.9 billion gallons of fuel worldwide.

In ITS the available information is limited, which is not sufficient information about traffic control. In [22] the review of the different technologies used in the different phases involved in traffic management systems (TMS) is given, the data sensing and gathering phase (DSG), the data fusion, processing, and aggregation (DFPA) phase, the data exploitation (DE) phase, and the service delivery phase (SD). As you may notice, these phases are the same as those in ambient intelligence, though the names are different. They also discuss the potential use of smart cars and social media to enable fast and more accurate traffic congestion detection and mitigation. In [23] the authors write that conventional ITS technologies are not as yet fully profiting from user interactions and engagement through smartphones and social networking. Then they suggest the concept of smart social mobility services, in which the basic idea is to dynamically sense specific mobility needs of users and check them not only against the set of currently running mobility services, but also against potential mobility capabilities that could be turned into new mobility services. Like smart social mobility services, exploiting information from citizens and social networking are key idea of fulfillment of smart cities.

5.3 Smart Healthcare

One of the fundamental desires by people is to live healthy and peacefully. Healthcare is very important to realize it. Smart healthcare is a concept for an advanced healthcare. For smart healthcare, we expect improved healthcare services based on ICT, where the information obtained by sensors are

exploited, such as on-body (wearable) sensors, contactless sensors, ambient sensors, and so on. Using these new devices, it becomes possible to always get medical data so that we can know not only physical condition but also mental condition in more detail. As same as other components in smart society, smart healthcare largely depends on ICT and ambient intelligence. There are several definitions for smart healthcare. In [24] smart health is defined as the provision of health services by using the context-aware network and sensing infrastructure of smart cities. It is mentioned in [24] that smart health is a subset of electronic health (e-Health), because smart health is based on the ICT infrastructure of a smart city. In [13] it is mentioned that smart healthcare can be conceptualized as a combination of various entities, including traditional healthcare, smart biosensors, wearable devices, ICTs, and smart ambulance systems. Smart healthcare can remove barriers of costs, distance, and so on, to receive good medical services. Telemedicine is one of the services in smart healthcare that uses ICT to provide clinical health care from a distance, which can remove the barriers. Advanced ICT including haptic makes remote surgery possible, such as the da Vinci surgical system [25].

Smart healthcare is also expected in assisted living for elderly people. For instance, Japan is known as the rapid aging society, "super-aging society". According to the Statics Japan the ratio of people aged 65 years or over to the total population reached 26.7% in 2015. The ratio is expected to rise to about 36.1% by around 2040. Naturally, social costs for nursing care and medical expenses will rise. In fiscal 2016 the budget for nursing care is $10.4 trillion; by fiscal 2025 it is expected to approach $20 trillion [26]. Meanwhile, the size of the average family has continued to shrink: the average number of household members fell from 2.82 in 1995 to 2.39 in 2015. This also results in the increase of elderly people living alone. Smart healthcare is expected to support the super aging society where people can live healthy and peacefully, while reducing the costs for support dramatically. To realize such a society, smart technologies are needed. Smart sensor is one of the smart technologies where it is expected to collect information about people and environments while keeping privacy. For instance, monitoring people living alone is a crucial issue where the use of camera is usually not allowed or preferred. We developed several smart sensors that can monitor people without using camera. Array sensor is one the smart sensors that we developed [27]–[31]. Figure 4 shows a trial product of the array sensor. The array sensor exploits an antenna array on the receiver side and decomposes received signals into eigenvectors and eigenvalues. It uses these components and sometimes received signal strength (RSS) depending on its applications. When an event (e.g. falling down) occurs, the propagation environment changes, and thus the features such as eigenvector related to the propagation also change. Based on the change of the features, we can detect an event without using camera. Using machine learning such as support vector machine (SVM) based on those features obtained by the array sensor, it can classify several more complex states
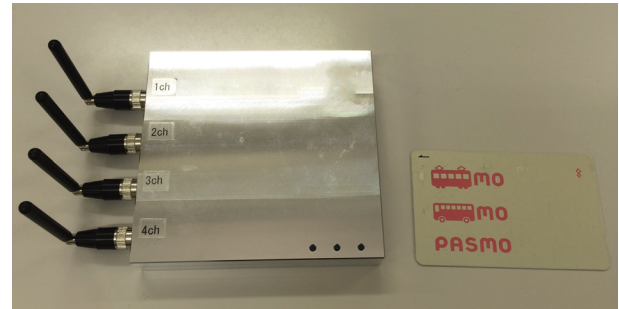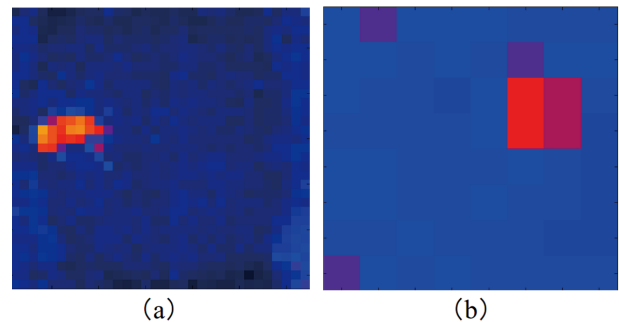

Fig. 4　Array sensor.

(a)　　　　　　　　　(b)

Fig. 5　Temperature distribution images obtained by the infrared array sensor: (a) 32×31 pixels, (b) 8×8 pixels.

and activities, such as sitting in a bathtub and falling in a bathroom. The array sensor can also realize passive localization using SVM based on those features in a fingerprinting manner.

The other smart sensor good for monitoring elderly people while keeping privacy is the activity recognition system using low-resolution thermopile sensor arrays [32]. The low-resolution thermopile sensor arrays has $m \times n$ infrared detectors (or pixels) inside. It obtains the temperature distribution on a two dimensional area. This kind of sensor is typically used for high performance home appliances (microwave oven and air conditioner), digital signage, automatic door, and so on. The activity recognition system using low-resolution thermopile sensor arrays installs the sensor on a ceiling and/or other places. Figure 5 shows the examples of temperature distribution obtained by the infrared array sensor that has $m \times n$ pixels inside. Different from images obtained by cameras, due to the low-resolution of sensor, we cannot distinguish individuals nor get much information about them, thus can keep privacy. The other advantage of the sensor is it can detect a person even in darkness by detecting infrared rays. The system extracts several features from the temperature distribution data and then classifies activities based on those features with high accuracy. It can also localize people easily.

6. Conclusions

A smart city is not an all-around medicine. However, it can overcome the various challenges the city faces. The

ambient intelligence where the environment has intelligence is a key factor to realize it. As mentioned, the ambient intelligence can be realized by ICT including the IoT and BD. This paper introduces several key components of a smart city, smart energy, smart transportation, smart mobility, and smart healthcare. Although this paper does not introduce other components in detail, they are also very important. In particular smart education is important one. A smart city is definitely built upon the education that promotes the growth of people in various senses, sometimes called smart people. The concept of a smart city makes cities global and sustainable. To fully realize a smart city, ICT still needs more development.

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