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NETWORKING TECHNOLOGIES FOR SMART CITIES: AN OVERVIEW

Dalibor Dobrilović*

University of Novi Sad, Technical Faculty "Mihajlo Pupin"
Zrenjanin, Serbia

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ABSTRACT

Considering the complex architecture of Smart City environments it should not be forgotten that their foundation lies in communication technologies that allow connectivity and data transfer between the elements in Smart City environments. Wireless communications with their capabilities represent Smart City enabling technologies that gives the opportunity for their rapid and efficient implementation and expansion as well. In that field the evident trend is appearance of numerous technologies, which can be applied in variety of scenarios. In order to be able to make rapid deployment of the Smart City systems it is necessary to perform good analyses of performances and applicability of those technologies. By knowing the characteristics of particular technologies, the professionals will have the opportunity to develop efficient, cost effective and flexible Smart City systems by implementing the most suitable one. In this article the review and discussion on wireless technologies for enabling Smart City services is presented.

KEY WORDS

smart city services, wireless communications, wireless technologies

CLASSIFICATION

ACM: Networks, Cyber-physical networks, Sensor networks

JEL: O18, R58

*Corresponding author, η: dalibor.dobrilovic@uns.ac.rs; +381 62 801 97 60;
Djure Djakovica bb, 23 000 Zrenjanin, Serbia

INTRODUCTION

The rapid development and deployment of Smart City environments impose challenging tasks to the engineers, developers and researches working in that field. Communication technology play important role in those systems because it allows connectivity and data transfer between the elements in Smart City environments. The advantages of wireless communications are obvious, because the Smart City systems are employed on wider, preferably urban areas, and can face demand for rapid expansion and reconfiguration. The usage of wireless technology is further justified with the extensive use of movable sensor nodes, nodes deployed on various places where it is difficult to install wired infrastructure, and above all, notable decrease in sensor and communication module prices and power consumption. In order to prepare ourselves for effective and rapid deployment of the efficient Smart City systems it is necessary to perform good analyses of performances and applicability of those technologies.

In this article the review and discussion on wireless technologies for enabling Smart Cities is presented. The article is structured as follows: after the introduction, definition of Smart Cities and related trends is given. It is followed by the classification of various well-established and emerging wireless technologies targeting Smart City environments. The discussion of their applicability in accordance with their features and characteristics and author experience is presented in next section. Finally, the conclusion based on analyses and authors experience is presented at the end of the article.

SMART CITIES

In the beginning of these analyses it is important to explain definition of Smart City. Having in mind that this is complex term which demands extensive explanation, for the purpose of this article it will be simplified. A Smart City can be defined as environment that uses currently available technologies to improve living conditions by offering access to information about parameters that enhance lives of its inhabitants. These parameters can range from status of their education and employment possibilities, available utilities for citizens, transportation information, energy consumption information, health-related issues, water and air quality monitoring, waste management and other relevant information that potentially could benefit the community [1].

The term *Smart City* can be considered as the new urban environment, designed for performance through information and communication technologies (ICTs) and other forms of physical capital. Visionaries and planners hope that Smart Cities with the effective management of resources through intelligent management will lead to a higher quality of life for citizens and can improve economic and environmental conditions [1].

Smart Cities should heavily rely on ICT. So it is important to define the main ICT trends who will take the role of enablers of Smart Cities. Those two emerging trends are Machine-to-machine (M2M) and Internet of Things (IoT). Simply said, M2M communication should not be confused with IoT despite their similarity. M2M is used to connect sensors and other devices to ICT systems through wired or wireless networks. On the contrary, IoT represents paradigm including a set of technologies, systems, and design principles associated with the Internet-connected things and larger Internet network. The vision of IoT is to reach a structure similar to today’s Internet, where connections merge things and real world, while the M2M technologies should act as an enabler for that. In that sense, IoT represents an extension to the existing Internet, with an automatic data collection, control, and supervision of physical infrastructure, through a remote monitoring [2].

SMART CITY ENABLING COMMUNICATION TECHNOLOGIES

The rapid development of the wireless technologies is heavily inspired by novel services planned for Smart City environments. E.g., some technologies like IEEE 802.11 (Wi-Fi), in contrast to its high popularity, are not suitable for the IoT and for the Smart Cities as well. The reason is that Wi-Fi is originally designed to offer end users high speed Internet or LAN access from limited number of stations in short distances and indoor environments. The purpose of Wi-Fi technology is to enable high speed access to multimedia data and services. In order to expand the usage of IEEE 802.11 networks to IoT, IEEE 802.11ah Task Group (TGah) is formed with a goal to design energy efficient protocol [3].

In order to realize what wireless technologies are applicable in Smart Cities and to determine their efficient appliance in particular services, the classification of the technologies should be made. Smart City wireless technologies can be categorized, according traditional classification based on range, into three classes: Wireless Personal Area Networks (WPAN), Wireless Local Area Networks (WLAN), and Wireless Metropolitan Area Networks (WMAN) [4]. The classification nowadays can be expanded with new terms such as Home Area Networks (HAN), Neighborhood Area Networks (NAN) [5], Field Area Networks (FAN) and Body Area Networks (BAN). The classification of Smart City communication technologies can also be made according to [6] where there are three groups: (i) *Cellular Mobile Networks*, (ii) *IoT-Dedicated Cellular Networks*, (iii) *Multi-Tier Networks*.

Cellular Mobile Networks are planned for new communication paradigm with little or no human interaction, e.g. for Machine-To-Machine (M2M) or Machine-Type communications (MTCs). Those networks should be implemented in Smart City applications designed for high coverage and flexibility of supported data rate. *IoT-dedicated cellular networks* are intended to answer the need for design of low-cost, low-energy M2M applications with limited traffic requirements. Those technologies have advantage comparing to cellular operators, lower costs of network equipment and network devices and include technologies such as: SigFox, LoRaWAN, Weightless, Ingenu, etc. *Multi-tier Architectures* cover variety of solutions like following: IEEE 802.15.4. ZigBee, WI-SUN (802.15.4g), ULP (802.15.4q), Wireless M-Bus, Z-Wave, Bluetooth Low Energy (BLE), WiFi Low Power (802.11ah), etc. These technologies are targeted to applications with limited number of nodes and low communication range, allowing flexible setups and easy customization.

The comparison of main characteristics of technologies is given in Table 1. In the table, related standards and governing bodies, operating frequencies, data rates, range and typical topologies are given for each technology. The technology characteristics are extracted and compiled from following sources [2, 4-12].

The model of usage of presented wireless technologies in Smart City environment is shown in Fig. 1 where technologies and possible areas of application are given according to [4, 13].

DISCUSSION ON TECHNOLOGY APPLICABILITY

In general, application for smart cities can be classified in the following groups: Smart Health, Smart office, home and residential buildings, Smart Energy (including Smart Grid and Smart Lightning), Smart Environment (Water Management, Smart Waste, Weather, Noise and Air pollution monitoring), Smart Physical safety /security, Smart Education, Smart Administration, Smart Industries and Smart Transportation (Traffic monitoring, Smart traffic lights, Smart Parking) [2, 4, 6, 13-17]. All these applications have different requirements. Two important features of the technologies related to requirements are listed in Table 1 and those features are range and data rates. Those two features have major impact on the possibility of

Table 1. Comparison of Smart City technologies (continued on p.412).

Communi-cation Technology	Standard/ governing bodies	Frequency	Range (app.)	Data rates	Topology
NFC	ISO/IEC – ISO 13157 etc.	(HF) 13,56 MHz	10 cm	106, 212, 424 Kbps	Point-to-point
RFID	ISO/IEC - ISO/IEC 18000	(LF) 125 -134 kHz (HF)13.56 MHz (UHF) 856 - 960 MHz	3-10 m (active up to 100 m)	40 Kbps-640 K	Point-to-point
Bluetooth/ Bluetooth Low Energy (BLE)	IEEE 802.15.1/ Bluetooth SIG	2.4 GHz	10 m typical 30-50m (BLE)	1-3 Mbps 1 Mbps (BLE)	Point-to-point, Piconet, Scatternet, Star-bus (BLE)
Z-Wave	Z-Wave Alliance	900 MHz	30 m (ind.) 100 m	9,6-100 kbps	Star, cluster, mesh
ZigBee	ZigBee Alliance	2,4 GHz	10-100 m	250 kb/s	Mesh
WiFi	IEEE 802.11 (a/b/g/n)	2,4/3,6/4,9/5/5,9 GHz	100 m	1-54Mbps	Star
ULP (802.15.4q)	IEEE Std 802.15.4q	868/915/2450 MHz	100 m	100 kbps	Star
WI-SUN 1606 (802.15.4g)	Wi-SUN Alliance	sub-1 GHz, 2,4 GHz	200 m	1 Mpbs	Star, Mesh, Peer-to-peer
6LoWPAN	Internet Engineering Task Force (IETF) IETF RFC4944	868MHz/ 915MHz/ 2,4GHz	200 m	250 kbps (2,4GHz) 40 kbps (915MHz) 20 kbps (868MHz)	Node-to-node, Star, Tree, Mesh
Wireless M-BUS	EN 13757-4	169/433/868 MHz	300 m	2,4 kbps-100 kbps	Star
WiFi Low Power (802.11ah)	IEEE 802.11 working group	Sub-1 GHz	1 km	150kbps ~ 346,666Mbps	Star, Tree
Weightless-W	Weightless Special Interest Group (SIG)	470-790 MHz TV white spaces	5 km	250 b/s-50 kb/s (UL) 2.5 kb/s-16 Mb/s (DL)	Star
Weightless-N	Weightless Special Interest Group (SIG)	Sub GHz (ISM)	3 km	250 b/s (UL) None (DL)	Star
Weightless-P	Weightless Special Interest Group (SIG)	Sub GHz (ISM)	2 km	200 bps-100 kbps (UL) 200 bps-100 kbps (DL)	Star

Table 1. Comparison of Smart City technologies (continued from p.411).

Communi-cation Technology	Standard/ governing bodies	Frequency	Range (app.)	Data rates	Topology
LTE-M Release 12/13	3GPP Release 12	700-900 MHz	2,5-5 km	200 kbps (DL) 200 kbps (UL)	Star
DASH7 1606	DASH7 Alliance	SUB-GHz 433/868/915 MHz	5 km	9.6,55.6,166.7 kbps	Node-to-node, Star, Tree, Mesh
LoRaWAN	LoRa Alliance	433, 863-870 MHz (EU) 902-928MHz (US)	2-15 km	250 bps-50 bps (UL EU) 250 bps-50 kb/s (DL EU)	Star
SigFox	SigFOX	868-902MHz	10-50 km	256 b/day (DL), ≤100 bps (UL)	Star
LTE	3GPP	2,5/5/10 GHz	30 km	300Mbps(DL), 75 Mbps(UL)	Star
LTE-A	3GPP	2,5/5/10/15/20 GHz	30 km	1Gbps(DL),500Mbps(UL)	Point-to-point
WiMAX	3GPP	3,5 GHz	50 km	75 Mbps	Point-to-multipoint, mesh
Ingenu	Ingenu	2450 MHz (ISM)	100 km	624 kbps (UL) 156 kbps (DL)	Star. Tree
NB-IoT	3GPP Release 13	Can be deployed in 2G/3G/4G spectrum (e.g. 450 MHz to 3.5GHz),	1 km (urb.) 10 km (rur.)	234,7 kbps (DL) 204,8 kbps (UL)	–
EC-GSM	3GPP Release 13	800-900 MHz	15 km	~300 kbps (DL) 10 kbps (UL)	–
CS IoT	–	700-900 MHz	–	200 kbps (DL) ~48 kbps (UL)	–

possibility of appliance of particular technology for particular Smart City service or application. E.g. Home automation requires short range and low data rates and Smart traffic lights service require short range, but medium to high data rate. Traffic, Air quality and noise monitoring, smart lightning and waste management applications require long range and low data rate communications [6]. Smart health requires short ranges and high data rates [18].

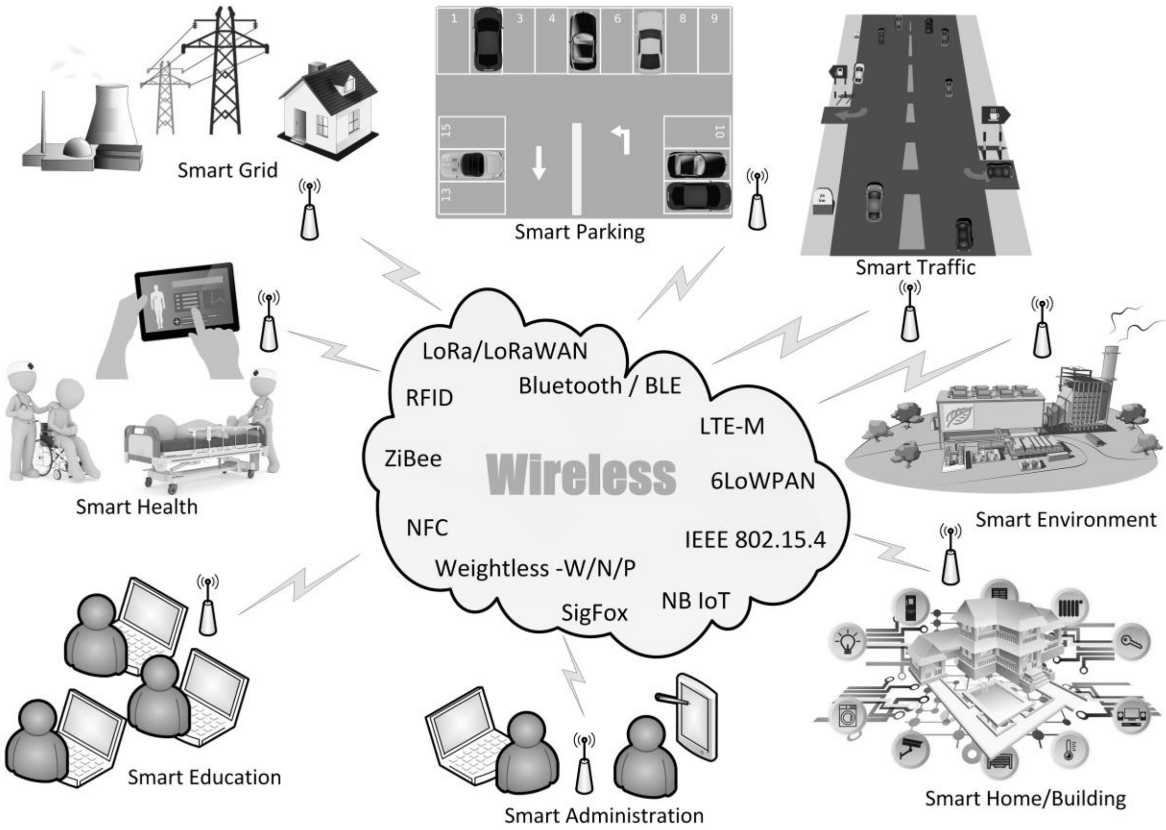

Figure 1. The usage of Wireless Technologies in Smart Cities.

Considering the range, three following categories listed in the beginning of the article can be used: WPAN, WLAN and WMAN. Despite this, some technologies like 6LoWPAN have range of 200m and are still classified like WPANs, while WI-SUN (802.15.4g) is classified as Field Area Network (FAN) by WiSUN Alliance. In order to avoid confusion, terms like short, medium and long range are used for classification in this article. Short range technologies with range from 10 cm to 3 m (see Table 1) are NFC and RFID. There is many more technologies (which can be still classified as short range) with longer range (10m-50m) such as: Bluetooth, Blue Low Energy (BLE), Z-Wave and ZigBee. Medium range technologies have extended coverage and usually have range from 100 m to 300 m. This group includes WiFi, ULP (802.15.4q), WI-SUN (802.15.4g), 6LoWPAN and Wireless M-BUS. The third group includes longer range technologies with range from 1 km to 15, 30, 50 or more kilometers. The group includes/consists of: WiFi Low Power (802.11ah), Weightless–W, Weightless–N, Weightless–P, LTE-M Release 12/13, DASH7, LoRa, LoRaWAN, SigFox, LTE, LTE-A, WiMAX and Ingenu. It should be noted that: Weightless, LoRa, LoRaWAN, SigFox and NB-IoT can be called Low-Power Wide-Area Network (LPWAN) [11, 16, 17]. Considering the data rate the networks can be also divided in three categories [6]: low, medium and high data rate technologies.

According to the presented literature and findings following conclusion can be made. Standards such as Bluetooth/Bluetooth Low Energy, IEEE 802.15.4 and ZigBee are considered as WPAN networks and are indented to be used for interconnecting the individual's workplace devices [4]. These standards are suitable for smart health monitoring and smart lighting applications as well as for other short range applications such as: Smart Home, and Smart parking and Smart traffic lights. 6LoWPAN can be used for Smart lighting [20]. WMAN or long range technologies are designed for covering large areas approximately the size of a city (with or without suburban and rural surrounding region) as point-to-point or point-to-multipoint networks. Those networks can are usually owned by an entity, such as an Internet service provider (ISP), government, or an enterprise. [4] Low-Power WANs (LoRa, LoRaWAN, SigFox, etc) with features suitable for low-cost mobile and secure bidirectional communication can be used in most smart cities applications, such as Smart grids and metering, Smart street lighting, Smart homes, Smart health monitoring, and Smart transportation. According to authors [16] NB-IoT is a better fit for electric metering applications than SigFox and LoRa because of the required high data rate and frequent communication, while in Smart building applications LoRa and SigFox have advantage over NB-IoT.

The author of this article has experience with LoRa [20-22], ZigBee [23-25] and proprietary sub-1 GHz [26, 27] technologies. The experiments related to ZigBee technology are connected to testing its performance in indoor environments as well as for usage in wireless temperature monitoring systems. Experiments made with sub 1 GHz technology are connected to indoor propagation. Experiments with LoRa technologies are made for coverage testing, tuning outdoor propagation models and testing LoRa applicability for moving stations. ZigBee and sub 1 GHz experiments justify usage of these technologies for Smart home and building systems. Experiments with LoRa technology justify its usage for any Smart City service requiring long range (up to 5 km in urban area for stationary sensor nodes and up to 3 for movable stations) and medium to low data rates.

CONSLUSION

This article indicates one of the major challenges in designing and planning Smart City applications and services – the choice of suitable technology to be implemented. The complexity of this task is caused by variety of technologies applicable to these environments, and frequent appearance of new technologies as well. Significant difference in technology features makes this task more complex. In this article, the effort to classify available and most applicable wireless technologies for smart cities is made. The additional effort is made towards brief systematization on applicability of particular technologies for particular smart city application.

The future research in this area should be pointed in two directions. One is to determine the technology that is applicable in greater number of Smart City applications. The other one is to make more experiments in order to test these technologies in variety of scenarios.

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