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Chapter 4

# The Role of Communication Technologies in Building Future Smart Cities

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Additional information is available at the end of the chapter

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**Abstract**

The world population is continuously growing and reached a significant evolution of the society, where the number of people living in cities surpassed the number of people in rural areas. This puts national and local governments under pressure because the limited resources, such as water, electricity, and transports, must thus be optimized to cover the needs of the citizens. Therefore, different tools, from sensors to processes, service, and artificial intelligence, are used to coordinate the usage of infrastructures and assets of the cities to build the so called *smart cities*. Different definitions and theoretical models of smart cities are given in literature. However, smart city can usually be modelled by a layered architecture, where communication and networking layer plays a central role. In fact, smart city applications lay on collecting field data from different infrastructures and assets, processing these data, taking some intelligent control actions, and sharing information in a secure way. Thus, a two way reliable communications layer is the basis of smart cities. This chapter introduces the basic concepts of this field and focuses on the role of communication technologies in smart cities. Potential technologies for smart cities are discussed, especially the recent wireless technologies adapted to smart city requirements.

**Keywords:** ICT, smart cities layered model, quality of service, communication requirements, low-power wireless area network, power line communication, machine-to-machine communication, Internet of things

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## 1. Introduction

The world population has grown exponentially at an average rate of 1.2% per year in the last 50 years. In 2007, for the first time ever, the number of people living in cities surpassed the number of people living in rural areas. Furthermore, it is estimated that the proportion will exceed 70% by 2050. According to the UN World Economic and Social Survey for 2013, Africa, Asia, and other developing regions will be housing an estimate of 80% of the world's urban population in the coming years [1]. While urbanization has advantages, it also brings challenges. Rapid urbanization adds pressure to the resource base and increases demand for energy, water, and sanitation, as well as for public services, education, and health care. Consequently, social, economic, and environmental issues have become tightly interconnected. Cities greatly contribute to environmental degradation on local, regional, and global scales. Studies have demonstrated that they are accountable for 70% of global greenhouse gas emissions as well as 60–80% of global energy consumption [2]. Thus, the challenge for the humanity is that the governments and any decision-maker is to find solutions and means to make roadmaps into execution to answer the question: how can cities be made smart and sustainable under such underlying conditions?

The answer lies in making cities "smarter" by efficient management of resources and infrastructure, greener environment, and smart governance resulting in a better quality of living of its citizens. This can be enabled by the effective use of information and communication technologies (ICTs) tools, which have the ability to provide eco-friendly and economically viable solutions for cities. Potential advancements could be made, among others, through efficient water management based on real-time information exchange, public transport systems organized through information from satellites, air quality, and electromagnetic field monitoring. This is where the concept of smart sustainable city comes into play [3].

Decades ago, cities started to use ICT to provide better services and quality of life to citizens. The evolution of the cities begun from "wired Cities," going through "virtual cities," to "intelligent cities," "information cities," "digital cities," "sustainable green cities," and then "smart cities." Currently, specialists are talking about smart sustainable cities (SSCs). Historical details of the evolution of cities from classic to smart can be found in [4].

There are several definitions of smart cities depending on the research field. In this chapter, only definitions from bodies and organization related to ICT are taken into consideration, namely the ITU and IEEE. The ITU—Telecommunication Standardization Sector (ITU-T), through its ITU-T's Focus Group on SSC, adopts the following definition of a smart sustainable city as "*A Smart Sustainable City 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*" [3]. The IEEE, in the context of Internet computing, states that a smart city can effectively process networked information to improve outcomes on any aspect of city operations. Such operations cover a very broad domain: surfacing information to authorities, businesses and citizens, and optimizing energy and water production or consumption, traffic management, public safety, and emergency response [5]. To address smart cities' multifaceted and cross-domain challenges, the Internet plays a fundamental role in communication, information sharing and processing, data transfer and analysis, and distributed computing. The rise of the Internet of things (IoT) and the large-scale adoption of Web technologies in urban environments have proven that Internet-based solutions can successfully address societal challenges.

For the elaboration of roadmaps to design and deploy smart cities, a layered architecture is used to model the smart city with its different application fields and infrastructures. Communication and networking layer as the middle of this layered architecture plays a very important role in building smart cities. This is why we focus on this central layer by discussing in this chapter the related requirements and communication technologies. The discussion is illustrated by the layered model of smart grid, as it is one the most critical national infrastructures (CNIs), since all industries, administration, and citizen's life are strongly depending on it. The chapter is closed by an overview on the most recent advances in wireless communications, which adapted to build the backbone of the smart cities.

## 2. Applications of smart cities and the enabling ICT

### 2.1. Overview of smart cities applications and features

Nowadays, there are more sources of innovation available in the world than ever before. By using the accumulated progress and improvements in ICT during the last decades, the smart city will provide relevant scenarios of livability for citizens with the necessary quality and simplicity in urban areas. A further purpose of the smart cities could be also to drive economic growth and area-based development in order to build a clean and sustainable environment, enhance incomes for all, support disadvantaged persons, or to make the governance of the city more transparent. If so, smart cities' paradigms should extend and/or radically transform our traditional infrastructure by bringing together innovation, reliability, mobility across the city, and easiness of daily services in the urban spaces. As depicted in **Table 1**, smart city applications are then a mesh of technologies services and a combination of many vertical smart solutions deployment in different locations and over many domains, such as health care, logistics, commercial and industrial networking, security and surveillance, transportation and mobility, education.

### 2.2. Smart cities infrastructures and role of ICT

Setting up a smart city is more than improving the old system with technology by simply adding sensors, remote supervision, and control to essential city services. It should be a complete shift of a paradigm in daily life when using new technologies, especially new ICT leading to smart outcomes. If that is the case, some major questions must be asked about the adoption of any transformation strategy to retrofit smart city ideas into the existing city: What are particular opportunities and threats on the existing infrastructure and services? How to redesign and integrate ICT in a smart way? How to manage the risk of growing volumes of all the gathered information? How could that transform and automate information usage in business processes? How to use ICT to enhance the quality of life and to better engage residents to such integrated vision for the improvement?

| **Smart energy** | **Smart buildings** | **Smart transportation** | **Smart water** |
|---|---|---|---|
| - Smart metering<br>- Demand response and demand-side management<br>- Distribution automation<br>- Distributed generation<br>- Integration of renewables and decentralised energy<br>- Network monitoring and control | - Light control<br>- Heating control<br>- Energy efficiency<br>- Local energy generation<br>- Security, occupancy control<br>- Synergies between energy efficiency, comfort and safety and security<br>- Building as a network: Integration of multiple technologies (HVAC, lighting, plug loads, fire, safety, mobility, renewable, storage, materials, IAQ, etc.)<br>- Software: Efficiency, automation and control, analytics and big data management | - Vehicle-to-everything (V2X)<br>- Driver behaviour management<br>- Mobile applications based on open data<br>- Traffic and fleet monitoring and control<br>- Services for drivers and passengers based on real- or near-real-time information<br>- Integrated public transportation | - Pressure management<br>- Remote control and predictive maintenance<br>- Integrated platforms for water management<br>- Smart metering<br>- water conservation and efficiency |
| **Smart waste** | **Smart physical Safety/security** | **Smart health care** | **Smart education** |
| - Waste Management<br>- Wastewater treatment<br>- City cleaning<br>- Sorting of waste<br>- Waste tracking | - Video surveillance and video analytics<br>- Seamless communication during natural and man-made disasters | - Adequate sanitation<br>- Disease control and mitigation<br>- Smart hospitals<br>- Real-time health care including analytics<br>- Home and remote health care including monitoring<br>- Electronic records management | - Flexible learning in an interactive learning environment<br>- Accessing world class digital content online using collaborative technologies<br>- Massive open online course (MOOC) |

**Table 1.** Main applications related to infrastructures of smart cities.

Certainly, answers will be different in every case as there is no unique and generic approach for a simple step-by-step procedure in building smart cities using ICT. As a result, we typically start by the modeling of the smart cities. Since many possible solutions exist, there are discussions about the main pillars building the city, after that the smartness may be checked in each pillar of the city. Without loss of generality, the main common four pillars building the city in the literature are economy, governance, environment, and society, according to [3]. These are reflected via three overarching dimensions of a city: environment and sustainability, city level services, and quality of life. Each of these dimensions has multiple characterizing attributes, sometimes overlapping. Sustainability and environment are critical to the urban landscape since cities represent 75% of energy consumption and 80% of $CO_2$ emissions on a global basis. The primary attributes in this dimension include infrastructure and governance, energy and climate change, pollution, waste, social, economic, and health aspects. As for city level services, the key attributes include technology and infrastructure (e.g., transportation, buildings, health care), sustainability (e.g., water, air, waste), governance (e.g., organization, administration, and leadership) and economy (e.g., financial, human capital, economic strength). The final dimension is the quality of life of the citizens. This reflects how the inhabitants of a city perceive their own sense of well-being and the fact that they are constantly striving to better themselves—for example, in terms of wealth, health, and education. All of the above need to be balanced for a successful smart sustainable city [3].

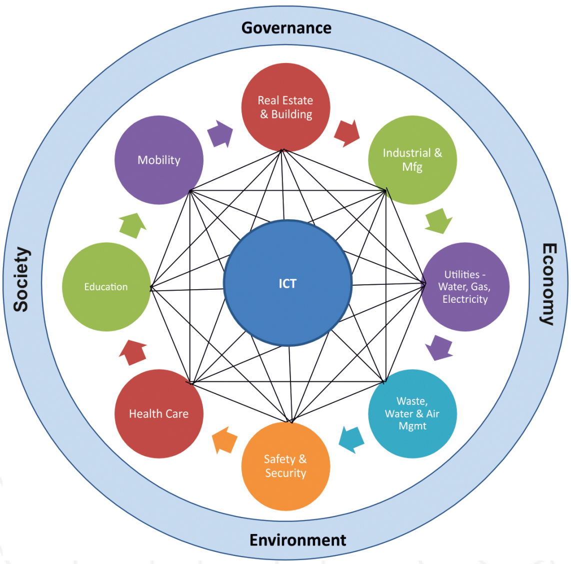


**Figure 1.** Core field components of sustainable smart cities and position of ICTs.

Infrastructure is a pivotal aspect of a smart sustainable city. Traditionally, there have been two types of infrastructure: physical (e.g., buildings, roads, transportation, and power plants) and digital (information technology (IT) and communications infrastructure). There is also a service infrastructure, providing services run on top of the physical infrastructure (e.g., education, health care, e-government). The digital infrastructure provides the glue enabling the smart sustainable city to operate efficiently in an optimal way.

ICT has a crucial role in SSC since it acts as the platform to collect and aggregate information and data from the field to help enabling an improved understanding on how the city is functioning in terms of resources consumption, services, and lifestyles, as illustrated in **Figure 1**. ICT also enable the following functions, which are keys to achieving the goals and maximizing the performance of smart city [3]:

- ICT-enabled information and knowledge sharing: Traditionally, due to inefficiency on information sharing, a city may not be ready to solve a problem even if it is well equipped to respond. With immediate and accurate information, cities can gain an insight on the problem and take actions before it escalates.
- ICT-enabled forecasts: Preparing for stressors like natural disasters requires a considerable amount of data dedicated to study patterns, identify trends, recognize risk areas, and predict potential problems. ICT provides and manages this information more efficiently, so that the city can improve its preparedness and response capability.
- ICT-enabled integration: Access to timely and relevant information (e.g., ICT-based early warning systems) need to be ensured in order to better understand the city's vulnerabilities and strengths.

## 3. The smart city architecture: a multilevel model and a use case

### 3.1. Layered architecture of smart cities model

The realization of smart cities involves different components and players: sensors vendors, equipment vendors, communication providers, services providers, business innovation. Users of smart cities belong to different domains, such as industry, utilities, transport/logistic, health care. These different components can be organized in a layered architecture, as illustrated in **Figure 2**, which shows the importance of ICT in building smart cities by connecting the applications/services and the city infrastructures, such as electricity grid, roads, parking. Much of the current debate about smart cities concerns the data layer, and some of the most important smart city work currently being explored in trials, demonstrations, and projects is to solve issues of data security, privacy, trust, sharing, standardization, APIs, and commercialization. There are opportunities for multiple players here to help cities to understand what data they have and how they can accomplish collection, enrichment, analysis, and use of their data effectively in practice. However, while recognizing the significance of data, the main focus of this chapter is the communication networks layer.

Basically, communication networks are hardware and software entities that could support and facilitate communication of any form (video, text, data, or any other digital objects) from a local area network (LAN) to wide area network (WAN).

Thus, why is the focus on communication networks so important in the case of a smart city? What, exactly is ICT supposed to do in this case? In fact, the layer of communication networks is the midpoint, the main vehicle of information and the core framework to model how applications and services can communicate over one or multiple networks and to set how data communication should take place when using applications of smart city. It defines and describes the way in which interrelated entities communicate more effectively between each other; systems arranged and connected to emerge smartness in use and provide higher quality services. In other words, effective deployment of ICT, if possible, may be a good factor of making easy modular engineering in building smart cities and understanding relationships of all the information we are gathering. However, it is important to notice that we cannot simply dump these ICT opportunities and city cases into the hands of the network operators and expect them to rush off to develop a system that really satisfies all the needs and technical specifications. We will probably need to be a lot more definitive about what we want the communication networks to do. Of course, ICT do not define itself a solution, but it provides the first perspective on what any viable solution would need to accomplish a move to a smart application using the latest tools and technology.

Therefore, an attempt should be made to deeply understand the role of such communication networks in the support of smart city applications. As sometimes the concepts of smart cities are too large with regard to communication networks scenarios, we should keep things simple. We might find it beneficial to make our explanation more concrete through an illustrative use case as a part of the overall process. The smart grid is examined in the following as a use case.

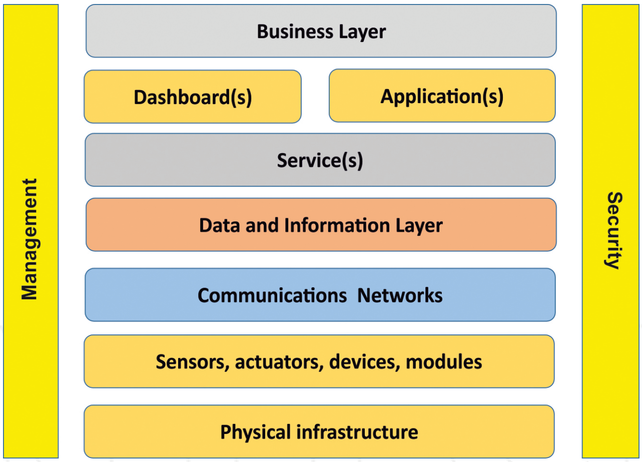


**Figure 2.** Functional layers and of smart cities.

### 3.2. Smart grid as an illustrative use case of smart cities

The energy infrastructure is considered to be the single most important part in any city. Therefore, electricity grids are set as *critical national infrastructure* (CNI). If unavailable for a significant enough period of time, all other and also critical organizations/functions are affected, such as security, police, telecoms. Smart grid includes intelligence in control and monitoring of the electricity and water infrastructure in all levels, from the generation plant to the consumer premises through transmission and distribution. Smart grid is defined by IEEE as "*An automated, widely distributed energy delivery network characterized by a two-way flow of electricity and information, capable of monitoring and responding to changes in everything from power plants to customer preferences to individual appliances*." A smart grid covers three major classes of functions: (a) It modernizes power systems through self-healing designs, automation, remote monitoring and control, and establishment of microgrids; (b) it informs and educates consumers about their energy usage, costs, and alternative options, to enable them to make decisions autonomously about how and when to use electricity and fuels; and (c) it provides efficiently safe, secure, and reliable integration of distributed and renewable energy resources, where consumers are also participating actively in the energy market. A global, but not complete, picture of smart grid applications is illustrated in **Figure 3**. All these add up to an energy infrastructure that is more reliable, more sustainable, and more resilient. Thus, a smart grid sits at the heart of the smart city, which cannot fully exist without it [6]. Therefore, the example from the practice given in this chapter are from smart grid field, especially from smart metering that is the corner stone of smart grid.

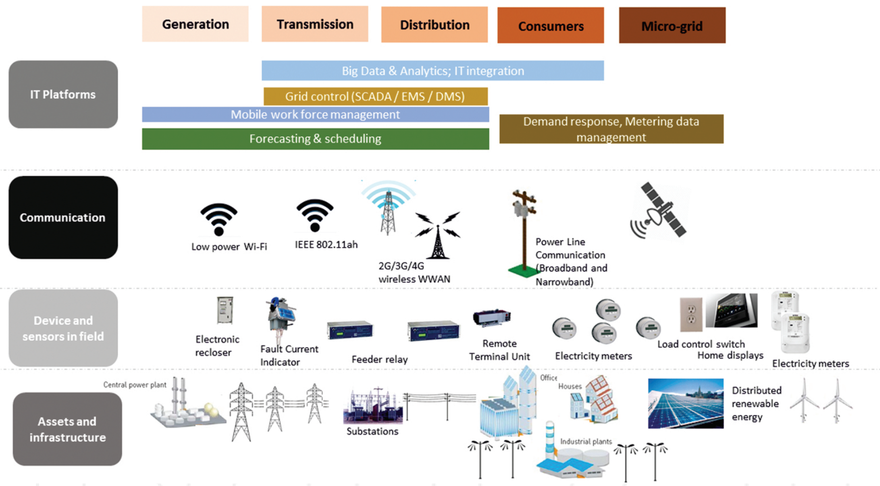


**Figure 3.** Different levels of smart grid model.

## 4. A roadmap of using ICT towards smart cities

### 4.1. ICT requirements in smart cities

As stated before, the ICT infrastructure plays a critical role as the central nerve of the smart city, by connecting and coordinating all the different interactions between the pillars and the infrastructure elements. It is an essential ingredient, since it acts as the "glue" that integrates

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all the other elements of the smart city in the form of a foundational platform that is present in all interactions of smart city components, either in form of human-to-human, human-to-machine, or machine-to-machine communication. Therefore, the ICT platform must respect a set of requirements in order to accomplish the desired tasks without becoming a cause of malfunctions and constraints of daily activities in the city. The most important requirements are the following:

- Cost-effectiveness: Sensors or metering points, like smart metering communications technologies that will be deployed on a massive scale must be designed to minimize those costs and provide excellent value. The costs-effectiveness of the communication infrastructure should cover all three aspects: capital expenditures (CAPEX) and operations expenditures (OPEX), such as low energy consumption and long battery lifetime, minimal infrastructure, low HW/SW equipment costs and low installation costs and low maintenance.

- High reliability and long lifetime: Communications equipment and modules could be placed in different environment depending on the application. By taking the example of smart grid, smart meters and the communications technologies supporting them should be able to stay online for 10, 15, or even 20 years without requiring the components to be replaced or directly maintained. Therefore, metering communications technologies must be highly reliable and designed with industrial-grade specifications to meet extreme environmental conditions of shock, corrosion, temperature, vibration, humidity, and interferences with other equipment and machines in the deployment environment. A negative example of low-reliable communication solution is power line communications (PLCs), which performances are fluctuating according to activities and machines connected to the electricity installations. Generally, business cases for utility solutions are often based with a 20 years life span for meters, while telecommunication solutions are moving every 2 years. So utilities have a challenge to operate, maintain, and manage the communication infrastructure over a so long time span.

- Network security: When two-way command and control systems are embedded into energy management systems, several security threats must be addressed. Generally, security needs to be guaranteed: confidentiality of data, which only allows authorized entities to access the data; integrity of data, which assures that data are not manipulated; authenticity of data, which guarantees that the data are sent by a dedicated entity; and availability of data, guaranteeing that data are available when needed.

- Interoperability and open standards/SW: Communication systems should be based on standard metering protocols to assure interoperability with changing energy supplier equipment and/or consumer equipment over the life of the sensing end-device. True efficiency is the result of interoperability that allows data to flow freely across various technologies within city functions such as lighting, transportation, and infrastructure—enabling intelligent communication, while maintaining security protocols.

- Quality of service (QoS): The term of QoS covers several criteria used to evaluate and select the communication technologies. The most important of them are as follows: Throughput or bit rate, network capacity in terms of number of connected devices at the same time, delay, jitter.

### 4.2. Process to select optimal communication technologies

Even with a good communication networks in a city, as when it has built its own fiber network or when it counts multiple mobile network operators (MNOs), or puts in place dense networks of sensors—connectivity is still seen by cities as a challenge. This challenge has different aspects, such as the deployment costs, the costs for operation and maintenance, the diversity of required services and generated traffic. For instance, the last mile connection between sensors and the core communications infrastructure can be made either on an application-specific basis, or in a way that supports multiple applications. Therefore, multiple networks and technologies are required to connect the smart city components as it comprises a collection of Internet of things (IoT) applications, having each their own specific communication and data requirements. For example, the mobile cellular network offers currently over 90% of coverage in cities, but a cellular network is highly unlikely to be able to deliver appropriate connectivity for every smart city application, even if it is able to satisfy many requirements. Examples of challenges for the traditional cellular networks (GSM/GPRS/UMTS/LTE) are the absence of service level agreement (SLA), deep indoor coverage and signal building penetration, high battery power consumption. Despite the emerging narrowband IoT (NB-IoT) networks and partnerships with competing IoT low-power wireless area networks (LPWANs) providers, for the foreseeable future, a smart city will use multiple network technologies.

Different factors must be taken into consideration during the selection of the adequate communications technology for the smart city applications. Therefore, the selection process is complex and difficult to model. However, the main influencing factors can be categorized in three principal axes as illustrated in **Figure 4**:

- **Regulatory and standards**: The international standardization bodies define the technological standards for the design and manufacturing of the technologies equipment and devices. However, the national regulatory has the full control on the use of the infrastructure and the standards allowed to be used in its territory. For example, when designing a wireless networks, only a very limited spectrum of slots are available. Furthermore, the use of available frequencies will be allowed only after purchasing a license from the regulatory authorities. A more concrete example is the 2G/GSM where we can use according to the standard a very large spectrum range going from low frequencies around 400 MHz until 1.9 GHz. However, in each country only very limited frequencies are used, because each country has its own spectrum occupancy and allocation policy as well as the historic.

- **Technical criteria**: This covers all QoS parameters discussed earlier, going from throughput to jitter. The choice of the technology to be used depends on the end application and its requirements in terms of offered throughput and QoS.

- **Strategic decisions**: This helps to check whether the resulting investment will enforce the position of the network owner/operator in the economy landscape of the country, or revenues will be generated to covers the invested money (known as return-on-investment).

The communication network to be built should fulfill the requirement for the applications with minimum costs, considering CAPEX as well as OPEX.

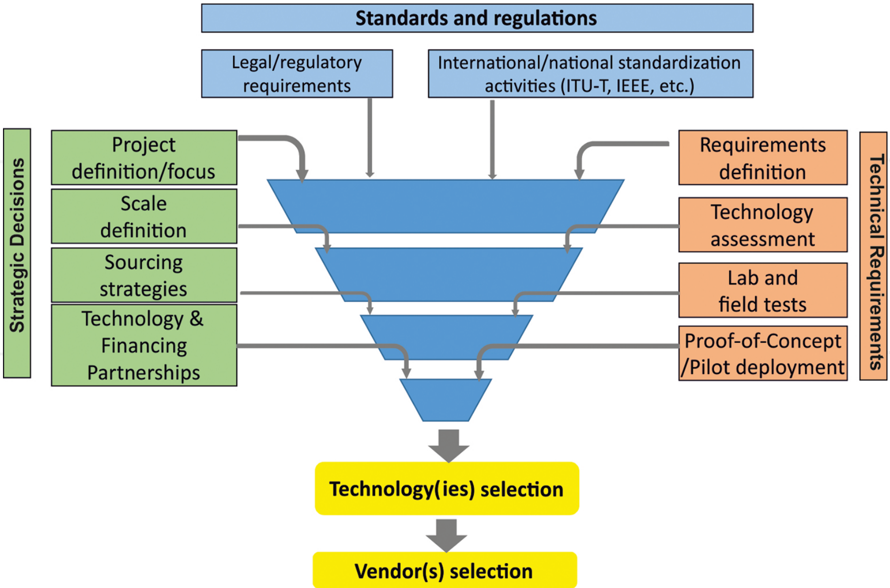


**Figure 4.** Selection process of communication technologies for smart city applications.

In the next sections, the most adequate technology candidates will be discussed by underlining their advantages, drawbacks, and the smart city applications to which they match optimally.

## 5. ICT enablers for smart cities

### 5.1. Machine-to-machine (M2M) and Internet of things (IoT)

M2M communication is sometimes confused with IoT as it is similarly meant to connect sensors and other devices to ICT systems through wired or wireless networks. However, IoT stands for a whole paradigm including a set of technologies, systems, and design principles associated with the emergence of general Internet-connected things, as well as a broader "Internet" network, based on a specific physical environment. IoT ecosystem is expected to reach a structure similar to today's Internet, where content can also include things and real world, with the M2M acting as an enabler. IoT is expected thus, in addition to connecting people, media, and content, to connect all real-world assets, equipped with a variable intelligence enabling information exchange, interaction with people, enterprises business process support, and creativity. Therefore, IoT is an extension to the existing Internet, with an automatic data collection, control, and supervision of physical infrastructure, through a remote monitoring and control, as illustrated in **Figure 5**. A detailed analysis of differentiating characteristics between M2M and IoT is developed in [7]. On the long term, the adoption and deployment of IoT solutions in a wide scale will have to go through a deep understanding of the targeted systems, the economies of scale, and interoperability methods, in addition to key business drivers and governance structures across value chains.

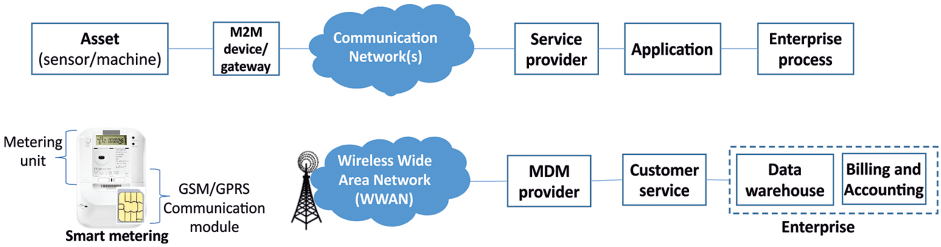


**Figure 5.** Generic M2M system (top) and corresponding system in smart metering (bottom).

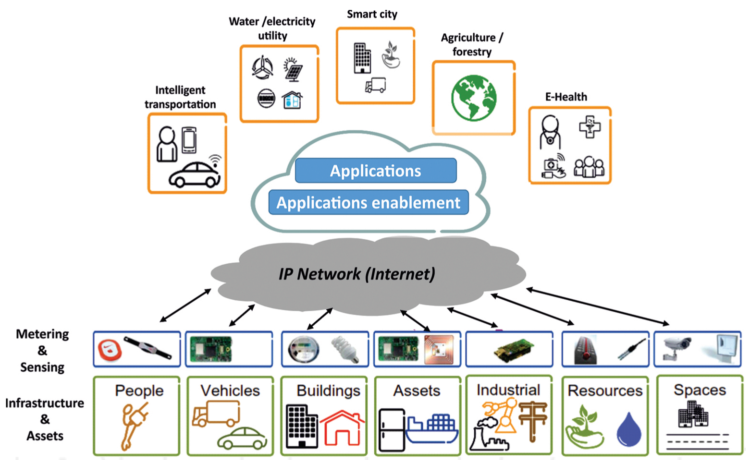


**Figure 6.** Overview on IoT architecture including different application areas.

The Internet of things (IoT) is a recent paradigm and widely used term for a set of technologies, systems, and design principles associated with the emerging wave of Internet-connected things that are based on the physical environment. In many respects, it can initially look the same as M2M communication, connecting sensors and other devices to ICT systems via wired or wireless networks. In contrast to M2M, however, IoT also refers to the connection of such systems and sensors trough Internet-protocol (IP) networks. This will guarantee a high interoperability and connectivity of devices from different manufacturers. This will increase the mass production and deployment, and hence the price reduction in innovative products, by an IoT ecosystem that will emerge not dissimilar to today's Internet, allowing things and real-world objects to connect, communicate, and interact with one another in the same way humans do via the web today.

In the future, the Internet will not be only about people, media, and content, but it will also include all real-world assets as intelligent creatures exchanging information, interacting with people, supporting business processes of enterprises, and creating. The IoT is not a new Internet, and it is an extension to the existing Internet, where the technology, the remote monitoring, and control are applied to automatic data collection and control and supervision of physical infrastructure, as illustrated in **Figure 6**. A detailed analysis of differentiating characteristics between M2M and IoT is developed in [7].

### 5.2. Technologies landscape for communication in smart cities

Smart cities deal with large number of population and infrastructures distributed unequally in the city area. This will result in a large number of applications end-points. Therefore, it is normal that different communication technologies will be in use. The common technologies that are currently widely used and will have an important impact in the ICT landscape are presented in **Figure 7**. They are classified into indoor solutions, where sender and receiver are in a relatively small area like room/home/building, and outdoor solutions where the communicating systems are far from each other. It is clear that wireless communications is the mostly used technology, and even Internet is nowadays mostly accessed either via Wi-Fi or 3G/4G. The wireless connectivity offers the advantage of mobility and ease to deploy. However, wired communications will also be present in the communications landscape for smart cities, especially where the very high speeds are required.

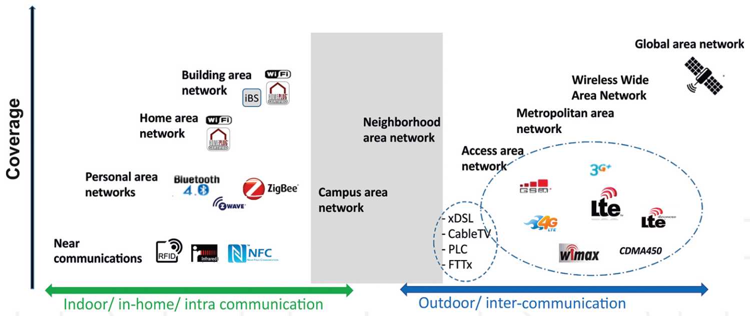


**Figure 7.** Main technologies to play a role in smart cities communications.

### 5.3. Wired technologies

As stated above, wired communication is a part of the smart city communication platform. Generally, it offers a high bit rate, immunity against interferences, performance stability in terms of achieved bit rates and Bit Error Rate (BER), unlike wireless communications that suffer from wireless channel impairments and the physical phenomena weakening the electromagnetic wave during the radio-wave propagation, such as reflexions, refractions, path loss, and fading. However, its main drawback is the necessary civil engineering works to lay cables, which generates higher investments and longer deployment time. This was and will be the main obstacle for deploying fiber-to-the-home (FTTH). Therefore, there is a big interest to make reuse of existing cables in the field, like in digital subscriber line (DSL), cable TV (CATV), and power line communications (PLCs). In the normal telecom services for voice and Internet, the DSL solutions have the largest part of the market for the access area networks. However, with the apparition of smart cities and some of its special applications, new technologies have emerged to fulfill some special requirements. For example, PLC is widely used in Europe for the automated metering infrastructure (AMI) that builds the core of the smart grid, because utilities want to use their own infrastructure, in this case the low-voltage power cables, to build their communication platform. By avoiding infrastructure from third parties, utilities aim to have a full control on the communication infrastructure, or at least a part of it. For this purpose, new standards have been developed and new spectrum has been explored, like the standards meters and more deployed for more than 30 million of smart meters by ENEL in Italy [8], which reference architecture is presented in **Figure 8**, the standard PRIME developed by the Spanish utility IBERDROLA [9] and the G3-PLC developed in France by ERDF [10]. Cable TV is also used for smart metering, but the communication between the meter and the cable modem occurs over a wireless local area network (WLAN) through IEEE802.11 technology (Wi-Fi).

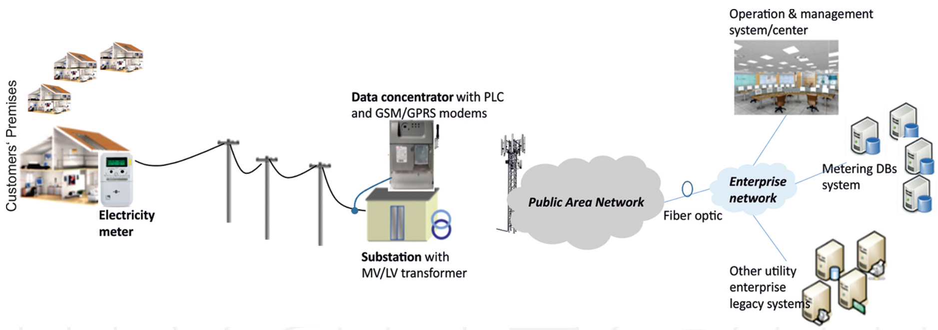


**Figure 8.** Reference architecture smart metering using PLC.

## 5.4. Wireless technologies

### *5.4.1. Overview*

Wireless technologies are living prospectus era, where new standards and releases are developed and issued each year. This new era has been intensified since the apparition of the first standard (Release 8) of long-term evolution (LTE), which was handled as fourth mobile generation (4G), as illustrated in **Figure 9**. Since then, the bit rates of mobile communications did not cease in evolving drastically, so that currently 4G are reaching easily 600 Mbps in cities, and even 1 Gbps has been measured in field trials of 5G (**Figure 10**). These explosive throughputs are becoming possible by adopting advanced techniques, like advanced multi-carrier modulations, multi-input-multi-output (MIMO), adaptive coding and modulation (ACM) [11].

In spite of these advantages, some critical points are still challenging the use of commercial mobile services in some smart cities applications. By taking the example of smart grid, the utilities are still seeing the following critical challenges:

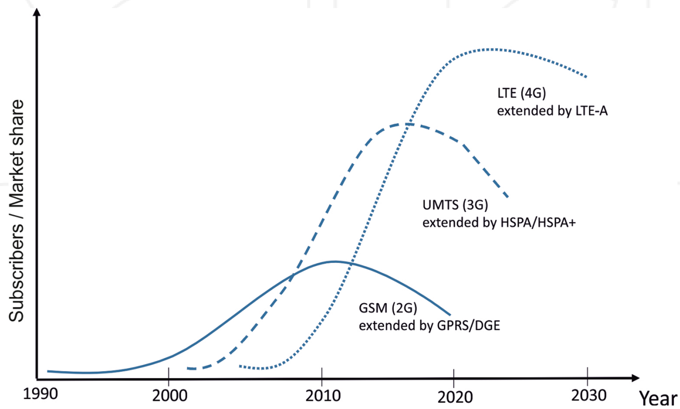


**Figure 9.** Relative adoption and life cycle of wireless technologies in the last three decades.

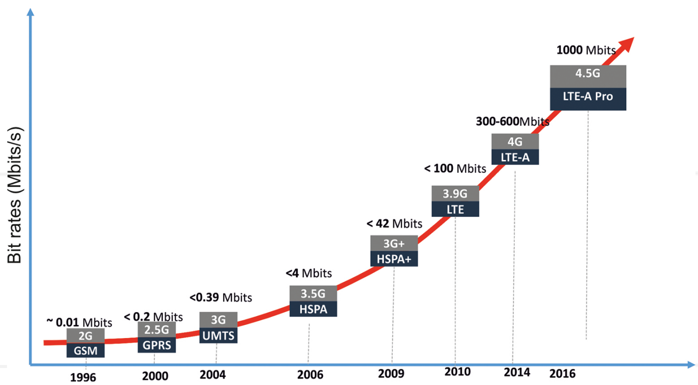


**Figure 10.** Throughput evolution of wireless technologies for access networks and WWAN.

- **The high number of users and no service guarantees in critical situations**: For some high priority smart cities applications, such as disaster and public safety management, the share of the same infrastructure with lower priority uses can compromise high priority applications requirements, thus making it ineffective.

- **Short wireless technologies life cycle**: Utilities are running their business models by considering equipments that last for more than 20 years. However, the modern mobile communications has a short life cycle, as depicted in **Figure 9**. In fact, Global System for Mobile Communications/General Packet Radio Service (GSM/GPRS, i.e. 2G/2.5G) networks is at the end of life, so that AT&T in the United States already started to switch off their GSM/GRPS infrastructure, as mobile network operators (MNOs) consider it wastes OPEX and spectrum efficiency [12]. This issue is also discussed for the old version of the Universal Mobile Telecommunications System (UMTS, i.e. 3G).
- **Short life cycle of electronics**: The traditional mechanical electricity meters, called also Ferrari meters, have a life cycle of about 25 years and more. The modern intelligent smart meters with all types of electronic components inside and its communication module will rarely reach this age of life cycle. As an example, the power utility in Italy ENEL has a total of more than 32 million of metering points and ERDF in France has more than 36 million meters. Considering this large number of end-devices, utilities must adjust their business models based on an intensive benefit–cost analysis.
- **Low battery**: Modern mobile networks are strongly consuming the power of the battery.
- **Indoor coverage and building penetration**: Most of the smart meters are placed in building basements, which are very rarely reached by the GSM coverage signal, especially in European cities. In this case, utilities must use a first level of communication, home area network (HAN) or building area network (BAN). This is also the problem for the communication in smart parking in the underground.

The above-cited challenges have pushed MNOs and equipment manufacturers to build associations, in order to unify their points of view together with industrials and to define the requirement of the next generation of wireless and mobile networks. The most known international association is the next-generation mobile network (NGMN) Alliance [13]. Their activities have resulted in new standards and new product and technologies of wireless networks, mostly known as low-power wireless area networks (LPWANs). These new generations and technologies build the focus of the next session.

#### *5.4.2. New wave of communication technologies*

As already stated in section 2.1, smart applications are already deployed using current technologies, and standards are forecasting more smartness in current deployment enabled by technologies and features to be proposed. As an example, LTE and LTE-A can give usable characteristics for smart city applications, in addition to LPWAN. IoT is tightly related to smart city applications as these applications rely for the most on a smart metering coupled with a pre- and/or post-intelligence. Thus, smart city LTE-enabled applications focus on IoT requirements. **Table 2** shows some LPWAN IoT characteristics, sufficient enough today for low rate applications.

Note that there exist wireless networks already used for low-power applications, such as bluetooth, Wi-Fi, and ZigBee. However, long-range performance and cellular M2M networks, on which smart cities are mostly based, would be costly and energy consuming, besides being expensive as far as hardware and services are concerned, while many connection devices are massively deployed in a smart city but need to send only small amounts of data over a long range when maintaining long battery life. In comparison with other technologies, LPWAN seat at the range shown in **Figure 11**. Following the use cases, other technologies can be used to the deployments of IoT.

| Technology | SIGFOX | LoRa | NB LTE-M Rel. 13 | LTE-M Rel. 12/13 | EC-GSM Rel. 13 | 5G (under development) |
|---|---|---|---|---|---|---|
| Range (outdoor) (km) | <13 | <11 | <15 | <11 | <15 | <15 |
| MCL (dB) | 160 | 157 | 164 | 156 | 164 | 164 |
| Spectrum Bandwidth | Unlicensed 900 MHz 100 Hz | Unlicensed 900 MHz <500 kHz | Licensed 7–900 MHz 200 kHz or Shared | Licensed 7–900 MHz 1.4 MHz or Shared | Licensed 8–900 MHz 2.4 MHz or Shared | Licensed 7–900 MHz Shared |
| Data rate | <100 bps | <10 kbps | <150 kbps | <1 Mbps | 10 kbps | <1 Mbps |
| Battery life (years) | >10 | >10 | >10 | >10 | >10 | >10 |
| Availability | Today | Today | By end of 2016 | By end of 2016 | By end of 2016 | By 2020 |

**Table 2.** Wireless technologies to build LPWAN for IoT connectivity.

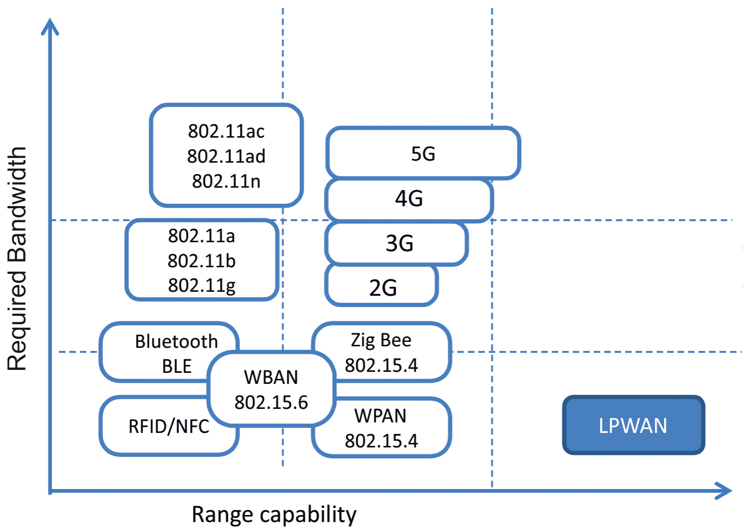


**Figure 11.** LPWAN range vs bandwidth in comparison with other technologies.

*5.4.3. LPWAN*

One of the major issues for M2M communications is the low-power long-range communication. LPWAN technologies, in order to achieve a long range capability, need to use high receiver sensitivities, up to -130 dBm compared with the -90 to -110 dBm in many traditional wireless technologies. This implies a higher energy per bit and thus a slower modulation rate. An example here is SigFox, which uses the extremely slow BPSK modulation. Some existing LPWAN platforms are described in the following:

- **LoRaWAN** is an LPWAN specification for wireless battery operated things with low data rate communicating over long distances, typically 15–20 km, promoted by LoRa Alliance12. It can be arranged to provide coverage similar to that of a cellular network, with millions of nodes and a battery life in excess of 10 years. In practice, LoRa networks are already deployed by cellular network operators who use existing masts to mount LoRa antennas, with possibility of combining antennas in some cases. Requirements for LoRAWAN meet target key requirements of IoT such as secure bidirectional communication, mobility, and localization services. The main advantage of this standard is the simplicity of local installation with an easiness of use for the end user and developer. Supported data rates range from 0.3 to 50 kbps, and the selection of the data rate is a trade-off between communication range and message duration.
- **SigFox** is a global IoT network designed exclusively for long range, small-message device communication with a low deployment cost. Historically, it is the first to have been developed. SigFox is a narrowband technology using BPSK modulation. It has thus the advantage of allowing the receiver to only listen in a tiny slice of spectrum, which mitigates the effect of noise. It has bidirectional functionality, but its capacity going from the base station back to the endpoint is constrained. Sigfox is currently deploying in many areas, even though it requires a new architecture because of the slow transmission.
- Other solutions existing in the market, such as *Weightless*, *Symphony Link*, *Nwave*, or *Ingenu*.

Note that most LPWAN solutions are addressing similar use cases identified within the 5G Umbrella, with the name of "Massive IoT". Complementarity with cellular can provide new opportunities to both technologies. However, some of previous solutions may be an alternative solution for smart cities while waiting for 5G standardization [14].

*5.4.4. The 4.5 and 5G wireless shaped for smart cities applications*

*5.4.4.1. LTE and LTE-A*

Following the requirements for smart cities applications, stated in section 4, these requirements meet for many applications the requirements of IMT-Advanced. LTE-A surpasses requirements of IMT advances. Actually, new users categories (cat1–6) are introduced starting from LTE release 8, with up to 20 MHz possible. LTE-A (Release 10) defines further categories, 6–8 and Release 12 defines LTE Cat-0 with a speed of 1 Mbps, and LTE-M defined in Release 13 with an even lower speed (kbps) are categories for machine type capabilities. LTE Cat-0 has been defined to suit needs of IoT applications and general M2M applications with much lower data rates, usually in short bursts, and treating only low levels. This new category has a reduced performance requirement, reduced complexity, and current consumption, while still with the LTE system requirements. In particular, peak downlink and uplink rate for Cat-0 is 1 Mbps, while Cat1–8 range from 10 to 1200 Mbps for downlink and from 5 to 600 Mbps for uplink. **Figure 12** illustrates the performance and complexity scaling in LTE releases in terms of data rates and bandwidth requirements.

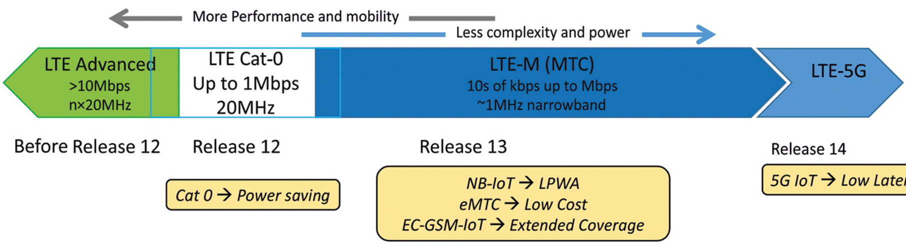


**Figure 12.** Scaling LTE-A following the requirements.

Note that Cat-1 chips are already suitable for many industrial applications including telematics, digital signage, and security systems. Nevertheless, Cat-0 chips, demonstrated, for example, by Sequans at CTIA's Super Mobility Week in Las Vegas, September 2015, are suitable for lower-speed applications. Similarly, Cat-M, already announced by Verizon, requires a new generation of highly optimized chipset design to reach the cost and market objectives [15]. The chipset makers are building dual mode chips supporting Cat-1 and Cat-M protocols at once, in order to allow the device to switch between modes following the conditions. In addition to UE categories, LTE/SAE (system architecture evolution) offers new solutions compared with earlier systems. In particular, the bandwidth in SAE can vary from 1.4 MHz up to 20 MHz, so the LTE/SAE can be used in various scenarios including IoT, LTE-A, and IEEE 802.16m (WiMAX 2).

*5.4.4.2. 5G Enabling capabilities*

Smart cities use distributed intelligence at different levels. Hopefully, IoT is a central part of 5G objectives. Compared with 4G, an increasing by a factor 1000 for mobile data volume is expected for 5G, the number of connected devices by a factor 100, guaranteed user data rate >50 Mbit/s, and a reduction by a factor 5 for the latency. The emerging technologies driving the 5G include, among others, device-to-device (D2D) technologies, software-defined networking (SDN), network functions virtualization (NFV), mobile edge computing (MEC), fixed mobile convergence (FMC). Below are some of the expected of enabling capabilities in 5G:

- **D2D**: Proximity-based device-to-device communications are an important 5G capacity enhancing technology. D2D UEs (DUEs) can act as transmission relays and set up multihop communication links, thus improving and extending network coverage. As for smart city applications, D2D communications will play an important role.

- **Fog Networking**: The large deployment in IoT applications implies a huge amount of data collected which, for some applications, needs to be centralized, and may use a cloud computing. This "cloud model" can be extended to the edge fog networking, which is a system-level horizontal architecture that distributes resources and services of computing, storage, control, and networking anywhere along the continuum from cloud to things. Ideally, IoT platform should fuse fog and cloud to have a device and service consolidation in addition to an optimization of lifecycle management of tenants and virtualized services, enhancement of data policy management, and integration of application and data management. A unified orchestration for fog and cloud can enforce service and security and integrate the entire IoT verticals. It is important to emphasize that the use of resource-rich fog servers running at the edge of mobile networks, known as mobile edge computing (MEC), as a part of the fog networking paradigm, and in conjunction with SDN and NFV, will be crucial in effecting low latency, high bandwidth and agility that will be able to connect trillions of devices.
- **C-RAN (Cloud RAN)**: This architecture promises the reduction in the cost of ultra-dense networks, expected especially with IoT deployments, through the simplification of the small base stations to remote antennas, possibly using a massive MIMO technology, and moving all the baseband processing to the cloud. This will improve the capacity by a joint processing of several signals from several remote antennas and can offer more optimization possibilities for coordinate multipoint (CoMP) and resource allocation. Networks can thus be flexibly and adaptively deployed to manage contents in a content centric way rather than the connection centric mindset currently adopted. The evolution toward C-RAN/ virtualized RAN (vRAN) architecture and interworking with mobile edge computing, the use of flexible, efficient, and reconfigurable hardware/software platforms, and data gathering and context information are key enablers for future IoT, leading to an evolution towards the "software defined everything."

## 6. Conclusions

The notion of smart city appeared in order to build future sustainable cities that benefit their inhabitants in a context of exponential urban growth, resource scarcity, demographic explosion, and strong environmental constraints. The smart cities is a set of applications, processes, and services that make use of engineering advancement to make an optimal use of the available infrastructures and foreseen the need in the future. The applications and processes of smart cities make use of massive data and information collecting, processing, and sharing. Therefore, a reliable communication and networking infrastructure should build the backbone of the smart cities, in order to make the data transmission possible. A large number of applications build the application layer of the smart city architecture, where each application has its own ICT requirement and expectation. Therefore, building such ICT infrastructure will involve different technologies depending on the application and the deployment environment. Wireless technologies are the most desired solution, because of all the economic and societal benefits they promise, particularly flexibility and ease of deployment. However, there are still challenges that wireless communication has to cope with, like power consumption, ease of installation, great indoor coverage. To overcome these challenges, equipment manufacturers and mobile network operators have unified their activities to develop and deploy a new wave of wireless technologies, named low-power wireless area network.

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