Smart Cities: Potential and Challenges

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***Abstract*—This paper aims to discuss a few fundamental questions related to the smart city paradigm, such as "what actually is a smart city? What can we expect from a smart city? and which problems have to be addressed and solved in order to turn a standard (dumb) city into a smart one?"**

Starting from a discussion of the Smart City concept, we will then illustrate some of the most popular smart services, also using the results of proof-of-concept experiments carried out in different cities around the world. Successively, we will describe the fundamental functions required to build a smart service, and the corresponding enabling technologies. We then describe the main research challenges that need to be addressed in order to fulfill the Smart City vision, and we conclude with some final remarks and some considerations about possible evolution of the Smart City concept.

I. Introduction

We are undoubtedly entering into a "smart" era: we own smart phones, wear smart watches, watch smart TVs, use smart appliances, and dream to live in Smart Cities.

As a matter of fact, an increasing number of cities around the world [1], including global capitals such as Barcelona [2], New York City, Amsterdam, and Singapore, as well as smaller towns, like Padova (Italy) [3], have initiated what we can define as a "smartening" process. However, despite the steady stream of scientific and technical publications, articles on magazine, and web pages dedicated to the Smart City idea, we still lack a formal and universally accepted definition of this paradigm. For example, Hall *et. al* in [4], offers a rather broad interpretation of the Smart City concept, which embraces services, technologies, and processes:

> The vision of Smart Cities is the urban center of the future, made safe, secure, environmentally green, and efficient because all structures - whether for power, water, transportation, etc., are designed, constructed, and maintained making use of advanced, integrated materials, sensors, electronics, and networks which are interfaced with computerized systems comprised of databases, tracking, and decision-making algorithms.

A more technical-centered vision is offered by Daniel and Doren in [5], where they associate the smartness of a city to the existence of a city-wide communication infrastructure, and the existence of software and sensors that can improve the quality of life of the citizens:

> A city that has deployed and integrated on a large scale advanced information and communications technology (ICT), including wireless and broadband connections, advanced analytic software and intelligent sensors to achieve significant improvements in efficiency and in the quality of life, and to help change behavior among residents, businesses and government so cities can grow in a more sustainable way.

A similar vision is proposed by IBM, which suggests a holistic approach, focused on integrated technologies. Again, the objectives are related to quality of life in general:[1]

> Cities must take greater advantage of the most advanced technologies to update service delivery. Cognitive computing [...] introduces fresh opportunities for government organizations to improve citizens' lives and the business environment, deliver personalized experiences, and optimize program and service outcomes.

In [6], the authors stress the relation between citizens and system administration, a point of view shared by Toppeta that, in [7], states the following:

> A city combining ICT and Web 2.0 technology with other organizational, design and planning efforts to dematerialize and speed up bureaucratic process and help to identify new, innovative solutions to city management complexities in order to improve sustainability and livability.

Also Giffinger *et al.* in [8] stress the role of citizens in the Smart City ecosystem, remarking their ability of being self-decisive, independent, and aware.

By making an abstraction effort, we can identify three main aspects that are in common to most of the definitions and visions of Smart City proposed in the literature, and which can hence be assumed as the actions that may turn a dumb city into a smart one, namely:

- improving the quality of public services and of the urban environment;
- reducing the Operational Expenditure (OPEX) of such services or, at least, improving the quality/OPEX ratio;
- closing the gap between citizens and public administration.

We can hence state that *the ultimate objective of a Smart City is to make a more efficient use of public resources, whether they are materials or humans.*

The information and communication technologies (ICT) are definitely instrumental to achieve such an ambitious objective, but are not the only enabler. Citizens indeed play as much an important role, as it will be discussed in the next sections.

In the rest of this paper, we illustrate the potential of the Smart City concept by briefly describing some notable Smart City services and applications, some of which have already been deployed in practice. We then describe the enabling

[1] IBM, Smarter Cities – Overview, OnLine Available: http://www.ibm.com/smarterplanet/us/en/smarter_cities/overview. Last visited on: 20 Sept. 2018.

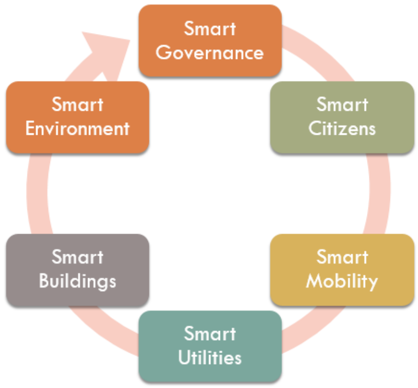

Figure 1. Smart City thrusts.

technologies, with particular attention to the communication systems, and we finally conclude the paper with a discussion of the still open challenges that need to be addressed in order to fully unleash the potential of the Smart City paradigm, and of the emerging trends.

II. The potential of the smart city concept

A modern city can be seen as a complex ecosystem consisting in infrastructures, processes, and citizens. The city administration is in charge to design, develop, and manage the infrastructures and the processes of the city to guarantee sustainability, while providing for the needs of the citizens in a way that accounts for their traditions, habits, lifestyles, and expectations. Therefore, the citizen should be at the center of the design of a Smart City and, indeed, most of the smart services proposed so far are intended to improve the quality of life in the city, with a double return in terms of satisfaction of the citizens and reduction of the OPEX.

By considering the solutions proposed in the literature, and the services already implemented by some important cities in the world, we can identify six thrusts that should be addressed in the design of a Smart City: namely Governance, Citizens, Mobility, Utilities, Buildings, and Environment (see Fig. 1).

In the guise to exemplify and discuss the potential of the Smart City concept, here next we will briefly illustrate how each of the above thrusts can take form into practical services and applications.

A. Smart Governance

The ultimate goal of smart governance is to (dramatically) improve the governance processes of the city by favoring the coordination of the different involved agencies, reducing the complexity of the administrative mechanisms, and improving transparency towards the citizens.

A first necessary (though not sufficient) step to achieve this ambitious goal is the harmonization and consolidation of the digital systems used by the different governance agencies into a single digital platform.

Such a solution would provide dramatic advantages to both the citizens and the city administration. The citizens would indeed have one single point of access to the public administration, whether it is for residential, fiscal, education, medical, or any other matter, greatly reducing the waste of time (and frustration) of interacting with many different public offices. At the same time, the public administration would have a simple and effective way to access demographic, corporate, and other types of data, with the possibility to draw demographic maps of the city, identifying spontaneous communities, revealing the risks of segregation of part of the population and the creation of ghettos, tracking the demographic flows, and so on. In addition, using one single platform in place of many (heterogeneous) systems would translate in a reduction of the costs to acquire, deploy, and maintain the information infrastructure, which can then be realized by leveraging the Infrastructure/Platform/Software-as-a-Service (IaaS, PaaS, SaaS) paradigms.

Therefore, from a technical point of view, enabling the Smart Government vision will require access to cloud services, which can either be provided autonomously by a central public office, or rented from an external service provider. The peripheral offices, in turn, will only need a good broadband connection to the governmental cloud, in order to enable the PaaS and SaaS solutions.

B. Smart Citizens

As mentioned, Smart Cities should be built around their citizens, not only for philosophical or social motivations, but also for a very pragmatic reason: the public administrators need to build consensus about their policy among the citizens, and the investments in Smart City services may have an economical return only in the long term (likely longer than their public mandate). Therefore, in order to accept the expenses in Smart City services, the citizens must be informed and involved in the creation of their own Smart City.

This engagement can be pursued in different ways. One possibility is to increase transparency of the administration processes by giving public access to a number of information regarding the current urban scenario as, for example, real-time maps of traffic, pollution, schools population, criminality, and so on. A second action may consist in providing tools to collect feedback from the citizens, in order to realize a two-way communication channel between citizens and administrators. Although today many administrations have citizen offices to listen to the people needs, the process will be greatly improved by dematerializing it by means of a digital platform that allows the citizen to express their opinions, suggestions, and requests, in a simple and convenient manner. Such a platform may also be used to improve some public services with the help of the citizens that, for example, may indicate malfunctioning of the public illumination system, broken/full trash bins, holes in streets or sideways, dangerous situations, and so on.[2]

Along the same line of thinking, the citizens can be deeply involved in the creation of new Smart City services. An example of this type of action is provided by the annual *Amsterdam Smart City Challenge,* an yearly event that is aimed at collecting ideas for new services directly from the citizens. One such challenges has led to the development of

[2]See, e.g., http://www.decorourbano.org .

the Mobypark app,[3] which allows owners of parking spaces to rent them out to people for a fee, while the data generated from this app can be used by the city administration to determine parking demands and traffic flows in Amsterdam.

Note that, all of this would be easily realizable within the Smart Government framework described before, which remarks the potential synergy among the many facets of the Smart City ecosystem.

C. Smart Mobility

Mobility is a major issue in most of modern cities, with a huge impact on the life quality of citizens and the healthiness of the environment, not mentioning the economic impact that slow urban mobility can have on basically all business sectors.

Many metropolises today discourage the urban use of private motor vehicles, e.g., by applying fees to enter the city, or limiting the access to most critical areas, or even increases the taxes for cars' owners. At the same time, they promote alternative mobility through the realization of pedestrian areas and bike lanes, and offer bike sharing and car sharing services. These initiatives are complemented by efficient and capillary public mobility services, which include buses and (subway) trains, whose routes and time schedules are designed to best suite the mobility flows in town.

Knowing such mobility flows is hence pivotal to realize smart mobility plans. For this reason, traffic monitoring systems have been widely deployed in many cities. In particular, the last generations of traffic monitoring cameras can provide a number of useful information, such as real time traffic maps, detection of congestion and accidents, but also recognition of speed and traffic light violations and even checking each single vehicle's condition (revision, insurance, taxes) by means of real-time plate identification and access to the motorists databases.

Besides driving the public administration decisions regarding the discipline of traffic and the planning of public transportation, the data collected by the traffic monitoring services can also be used to display real-time maps of roads congestion in the city, thus making it possible for citizens to better plan their trip to office, or decide which means to take. By combining this information with a smart traffic lighting system, furthermore, it is possible to realize advanced services, as done in Barcelona where a traffic management system can track the position and direction of the public transportation and emergency vehicles and make them find green traffic lights at intersections.[4]

Smart parking is another very useful service that can contribute to the reduction of the traffic and pollution in the city. Its realization requires the deployment of a grid of sensors to monitor the occupancy of the different parking spaces. The information is usually delivered to a central control station that makes it available in real-time to the drivers, through digital roadside panels, or web apps. The sensing can either be realized by equipping each parking slot with a very simple sensor that can detect the presence of a vehicle, or by means of cameras that, using advanced signal processing techniques, can recognize which parking places are available, and which are occupied. The data collected by these sensors are then sent to the control station by means of different transmission technologies, which will be described in Sec. III-B.

[3] https://www.mobypark.com/en

[4] https://www.barcelona-metropolitan.com/features/smart-city-Barcelona/

D. Smart Utilities

A city is expected to provide a number of utilities to its citizens, such as electric power, water, gas, waste collection. These services are generally offered by a number of different private or public companies that often operate in a competitive market, though in certain cases they basically hold a monopolistic position. Clearly, the costs to realize and maintain the infrastructures required to deliver such services is reflected into the bills payed by the citizens, though sometimes the municipality covers part of such costs. Therefore, improving such services and reducing the OPEX can provide substantial advantages to both citizens and public administration.

Once again, the information and communication technologies can play an important role in this context. An example is the smart power grid, which enhances the current power grid with monitoring stations that can instantaneously measure the values of active and reactive power along the lines, thus making it possible to identify the lines with a higher power dispersion due to unbalance between the different current phases. The smart grid can also include equalization elements to counteract the fluctuations in the voltage levels due to the injection of power into the network by secondary power sources (such as, small/domestic energy solar implants). In addition, it may be possible to deploy power storage units that can store the excess of power generated by such energy sources and release it when demanded by the consumers, in order to minimize the costs (see, e.g., [9]). In 2005, one of the main Italian power suppliers, ENEL, started deploying the first national smart grid, with a cost of 2.1 billion euros. However, the investment returned 500 millions per year in OPEX reduction. Furthermore, smart grids are expected to be able to decrease CO_2 emissions of 12% in USA and 15% in India [10]–[12].

Similarly, sensors can be deployed to monitor the provisioning of water and gas, thus making it possible not only to obtain a real-time view of the service demand, but also to rapidly detect problems such as leakages or pipe obstructions, dramatically reducing the time and cost of repairing.

E. Smart Buildings

Many cities around the world dedicate an important budget to the preservation of their historical heritage. For example, the Scrovegni Chapel, in the city of Padova (Italy), contains some fragile frescoes, painted by Giotto in the fourteenth century, that need to be protected from the risk of degradation due to air pollution and humidity, as well as the high levels of CO_2 that may be generated by letting many tourists in the small chapel for long periods. To this end, the chapel has been equipped with an advanced Heating Ventilation Air Conditioning (HVAC) and air cleaning system, and with some sensors that monitor the quality of the air in the chapel. An algorithm than control the HVAC system in order to constantly maintain ideal environmental conditions within the chapel, irrespective of the external weather conditions and the number of visitors (whose access rate is, anyway, limited and controlled). Similar monitoring systems are deployed in many historical buildings and museums with the main objective of preserving the artworks. The more advanced of systems can provide a plethora of additional services, including information to the visitors (smart museum), monitoring of the affluence and permanence time of visitors in the different rooms of an exhibition center, theft prevention, and so on.

Note that, the inertia of environmental conditions (temperature, humidity), in particular in large buildings, may delay the detection of variations of the comfort levels, which may result in an late over reaction of the HVAC control system. This generates the typical oscillations in the comfort level of public environments (in particular when occupied by a variable number of people during the day, as for school classrooms, museums, or conference rooms), with an important power consumption. By deploying a large number of (simple) environmental monitoring devices, which can provide an almost real-time map of the comfort levels in a buildings, and exploiting sophisticated models to predict the dynamic of the environmental conditions (possibly based on historical data through machine learning techniques) would make it possible to realize real-time control systems that perform fine-grain proactive control of the HVAC system in order to stabilize the comfort level while reducing the power consumption of the system.

F. Smart Environment

The preservation of the environment is another key aspect of the Smart City vision. Many metropolitan areas in the world live under a dome of pollution generated by vehicle emissions, building heating/cooling systems, and industrial activities. Furthermore, the waste management is another factor with a significant impact in the urban ecosystem, both in environmental and economic terms.

The deployment of smart mobility, smart utilities, and smart building solutions can significantly contribute to alleviate the environmental footprint of cities, in particular in terms of air quality. In addition, the adoption of intelligent waste management systems can contribute to increase the amount and quality of recyclable garbage, with a positive effect on both the environment and the service costs. For example, sensors can be applied to waste bins to periodically check their filling level and report this value to a control station, which can then optimize the route of the collector truck, increasing the efficiency and improving the quality of the service offered to the citizens.

G. The power of integration

Clearly, the service taxonomy that we used to illustrate the different lines of action that can be followed to realize a Smart City is rather artificial. In practice, a service may impact the urban tissue in many different ways. For example, a bike sharing system can help to reduce the traffic congestion (smart mobility) and air pollution (smart environment). Furthermore, the data generated by the bike sharing service can provide useful information to the city administration regarding the citizens habits (smart government). As an example, in [13] the data regarding the use of bikes provided by the New York City bike sharing service[5] have been used to track the main flows in the city, revealing the most "critical" bike stations. In addition, the access to such open data has made it possible to develop a mathematical model of the bike sharing system and propose a methodology to improve the quality of the service offered to the citizens, while reducing the OPEX. As a further example, the access to the data regarding the utilization of the bike sharing service provided by the municipality of Padova (Italy) has enabled the identification of clear usage patterns, namely from the train station to the university departments and back, which has permitted to (i) propose some improvements in the bike redistribution policy and (ii) design a system to help the redistribution of the bikes by the same users, by means of a gamification approach (smart citizens).

A few regions in Italy have understood the potential of service integration and have centralized all information technology services into a single agency. In this way, it has been possible to reduce the costs to develop new infrastructures, thanks to the economy of scale, and promote the development of cross-sector applications thanks to the use of a common software platform (smart government). One such applications crosses road accidents with the medical reports of the involved people, in order to identify the most dangerous roads and plan targeted road interventions (smart mobility).

Therefore, we can conclude that the full power of the smart city vision can be expressed only by crossing the boundary of isolated services and merging multiple services and technologies together.

In the following section, we will describe which technologies can be used to support such a vision.

III. Enabling Technologies

The previous section described some of the possible advanced services that collectively contribute to make a city smarter. Although the list is far from being exhaustive, still it is apparent that the support of such services will require different technologies at all levels of the protocol stack. Nonetheless, most of such services share a common (though rather abstract) logical structure, which consists in the following five phases:

1) Create data
2) Collect data
3) Share data
4) Extract information
5) Build services

In the rest of this section, we will briefly describe the purpose and technical requirements of each such phases.

A. Create data

Most smart city services need to collect data from the environment as, e.g., light, temperature, humidity, pollution, proximity of people/vehicle, pressure, and so on. These data are generated by sensing devices that, to simplify the deployment of the services, should ideally be low cost, easy to configure and connect to the Internet, and self-sustainable without need for maintenance. Such requirements are actually demanding and not easy to be satisfied.

[5] https://www.citibikenyc.com/system-data

To enable the so-called *place-&-play* functionality, i.e., the possibility to set up the system with little (if not zero) configuration [14], the devices need to be able to connect to the Internet (as for the Internet-of-Things paradigm) and to self-configure (authenticate itself to the server, configure the transmission parameters, etc.), which requires some computation, storage, and communication capabilities. Furthermore, in many cases it may not be practical, or even feasible, to connect the peripheral devices to the power grid, so that sensor nodes may have to be battery powered. In order to minimize the need for maintenance, such devices must be extremely energy efficient, reaching a lifetime of ten to twenty years without the need for battery replacement, which can represent an important cost and be even infeasible in certain scenarios. Ideally, sensor nodes should be *energy neutral*, i.e., capable of scavenging the required energy from renewable environmental sources (typically, using small solar panels). Unfortunately, these requirements contrast with the need to reduce the manufacturing costs, which increase with the complexity of the hardware. To overcome this roadblock, it is hence necessary to work on the software components of the system, trying to engineering all the processes (environmental sensing, data storing, data processing, and data transmission) in order to provide the required service level while minimizing the energy expenditure [15].

B. Collect data

Once data are generated by the so-called "data producers" (i.e., the sensor nodes), they need to be made available to the services that need to use them, generally referred to as "data consumers." To this end, the first step consists in providing digital connectivity to the end devices, i.e., supporting what in the literature is often referred to as *Machine Type Communication* (MTC). Although the IoT paradigm would require that each single node supports the TCP/IP protocol stack, thus being able to talk to any other node in the Internet, in practice the limitations of the end-devices make it preferable to connect them to the Internet through an intermediate node, called *gateway*, which acts as proxy between the end-devices and the IP world. The connection between sensor nodes and gateway, then, can be realized using dedicated transmission technologies, in many cases wireless, specifically designed to support MTC.

Today, there is a plethora of such technologies, with different capabilities and characteristics. A possible classification is depicted in Fig. 2 and described in the following.

a) Short-range multi-hop: the short-range wireless technologies were originally designed to interconnect electronic devices in close proximity, such as headsets and phones, or laptops and printers, as in the case of Bluetooth. Successively, they have been considered to interconnect electronic devices in office or home environments, realizing the so-called domotic scenario. They are characterized by low cost, low energy consumption, and medium bitrates (from hundred of kbit/s to few Mbit/s). However, the coverage range is typically limited to few meters, and the coverage of large areas requires the adoption of multi-hop transmissions, i.e., node-to-node packet relaying, until the gateway is reached. The management of a multi-hop network, however, is complex, since it requires nodes discovery, network establishment, routing, and so on. Considering the variability of the wireless medium, furthermore, the connectivity of the network can vary in time, making the multi-hop packet delivery even more challenging, and increasing the energy consumption of the nodes.

Among the most popular technologies in this class we can mention Bluetooth, in particular in its Low Energy version (BLE), ZigBee, Z-Wave, IEEE 802.15.4, and others.

b) Cellular: contrarily to the short-range multi-hop class, the cellular technologies offer very large coverage ranges, with single-hop communication between peripheral nodes and gateway (which is called Base Station, or eNB, in the cellular system terminology). Furthermore, the cellular networks of the main operators offer almost ubiquitous coverage, without the need to deploy new infrastructure. On the other hand, the cost of cellular radio transceivers is still significantly high for MTC applications, as it is the energy consumption. The most common cellular technologies that are today used for MTC are GSM (in particular, GPRS), and LTE-A. However, both these systems have been designed to support broadband data transmissions, characterized by few devices per cell that generate significant data traffic. MTC has almost dual characteristics, since it is typically generated by a massive amount of devices, densely deployed in the coverage range of a cell, each of which generates a tiny amount of traffic (order of packets per minute, or less). Therefore, traditional cellular technologies can be unsuitable to support MTC, being affected by the so-called *massive access problem* [14], [16], [17].

Recently, the 3GPP standardization organization has released the specifications for the long-waited Narrow Band IoT (NB-IoT), an amendment to the LTE standard that has been explicitly designed to support MTC, and that greatly alleviates the massive access problem. Although the standard promises very low energy consumption and good bitrates, some preliminary studies reveal that the power consumption and the cost of the devices can still be too high for some applications, thus limiting the range of applicability of this technology [18].

c) Low Power Wide Area Networks (LPWAN): the design of this family of technologies has been explicitly targeted to MTC. These systems are indeed characterized by extremely long coverage range (from few kilometers in urban area to tens of kilometers in rural areas), and very low power consumption. Such nice features have been obtained by compromising with the bitrate, which is usually very low (order of hundred of bit/s), and the delay, which is instead quite long (order of seconds). However, many services that require MTC do not have strict requirements in terms of bitrate and delay and can therefore fruitfully adopt LPWAN solutions.

Although there has been a proliferation of LPWAN technologies in the last years [19], today the most popular ones are SigFox and LoRaWAN. SigFox adopts a cellular-like business paradigm, where the infrastructure (gateways) are deployed by the SigFox providers, and the customers just buy the service, i.e., the connectivity and data collection from their end-devices. LoRaWAN, instead, offers the possibility to build and manage private networks, by buying end devices, gateways, and management software (NetServer), which can run in any node connected to the gateways through standard

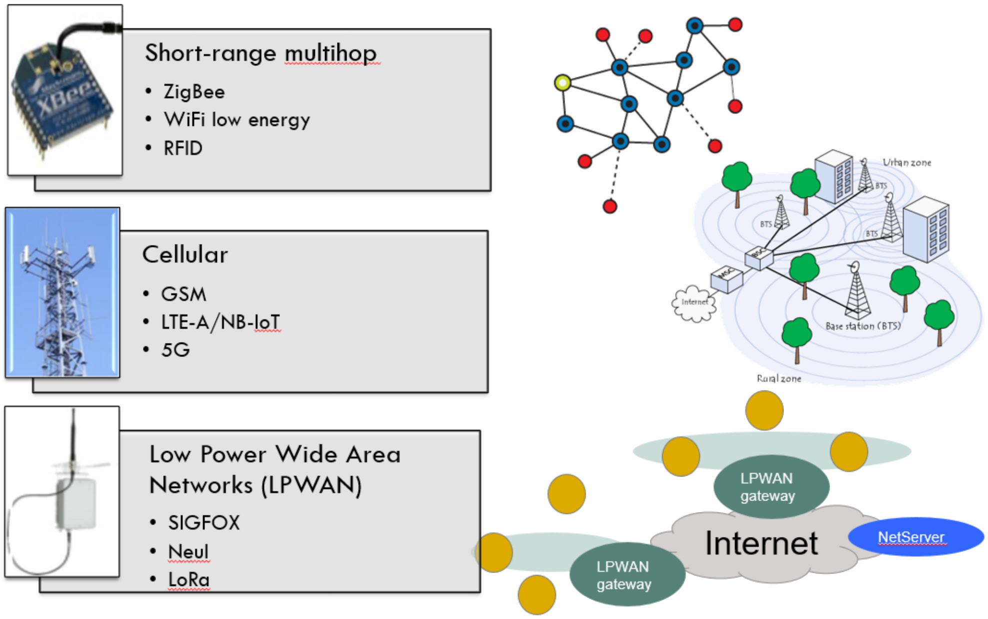

Figure 2. MTC wireless technologies classification.

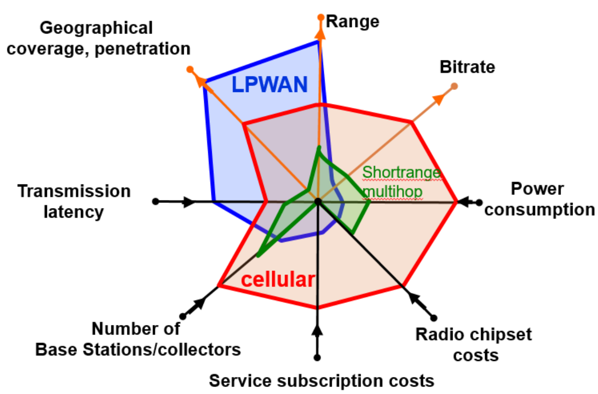

Figure 3. Comparison among MTC wireless technologies.

IP technologies. Both these protocols offer low bitrates in uplink, though LoRaWAN can also support a certain downlink traffic [20], while SigFox is rather limited in this respect. Furthermore, LoRaWAN also allows for confirmed traffic (i.e., end devices may require the NetServer to acknowledge the reception of uplink packets), though enabling this mechanism may yield to performance reduction [21].

We can see that the different classes of MTC technologies posses rather complementary characteristics, as shown in the spider graph of Fig. 3. Therefore, it is likely that all of them will find application in the Smart City scenarios, depending on the specific application to be supported. The harmonization will then occur at a higher protocol layer, likely the IP layer, thanks to the data sharing protocols described next.

C. Share data

As mentioned, the most popular approach to collect data from the peripheral nodes is by means of proxy devices, the gateways, that have the role of bridging sensor nodes and Internet nodes, enabling two-way communications. Typically, the gateways can receive commands from control stations or servers, located somewhere in the Internet, and forward them to the peripheral nodes, using the MTC technology employed in that specific system. Analogously, the gateways make the data generated by the node accessible from external (authorized) nodes. This second functionality can be provided with different approaches, the most common of which are the *request-response* and the *publish-subscribe*, described next [22].

a) Request-response: this approach is commonly used to access Internet resources, such as web pages, files, or others: the client sends a request for a specific resource to the server, which replies by sending back the requested element to the client, if available, or with an error message if the resource is not available to the server. Each resource is hence uniquely identifiable by means of an Universal Resource Locator (URL), and the clients can use Hyper Text Transfer Protocol (HTTP) to retrieve the data of interest. This approach requires that the gateways (or the end devices) support an HTTP server. Typically, the sensor nodes are not sufficiently powerful to run a full-fledged HTTP server (or, better, a full TCP/IP protocol stack). To overcome this problem, the Internet Engineering Task Force (IETF) has designed the 6LowPAN protocol stack, a light version of the TCP/IP protocol stack that can be more easily implemented in low-end devices. The gateway, then, needs to support both the standard TCP/IP and the 6LowPAN protocol stacks, operating the translation between the two domains. In particular, the 6LowPAN stack includes the *Constrained Application Protocol* (CoAP), which is a light version of HTTP that allows for a very simple and direct mapping of the HTTP commands into CoAP commands, and *vice versa*. The use of this approach greatly simplifies the design of the end services that can be developed by following the standard programming practice used for any Internet application. On the other hand, the request/response paradigm is not ideal to read dynamic data, since the request may not be synchronized with the actual availability of the data, thus possibly resulting in a waste of transmission resources and energy.

b) Publish-subscribe: this paradigm somehow mimics an exchange market, where a broker collects data from the producers and then dispatch them to the consumers, depending on their specific requests. Consider for example an application that wants to check the temperature in a classroom. Rather than sending a periodic request to each sensor node in the classroom to retrieve the last temperature reading, as for the previous approach, with the publish-subscribe approach the sensor nodes will *publish* (i.e., report) their new readings to a broker, which is a software module typically running in the gateway, while the consumer will *subscribe* to this type of information at the broker. Whenever a new temperature value is published by a sensor node, the broker will push the data to all the consumers that have subscribed that service. The most popular protocol that implements this paradigm is the Message Queue Telemetry Transport (MQTT), which is light an simple. This approach is very efficient, since the communication occurs only when a data is actually available. However, the applications need to be designed by following a different paradigm than the standard REpresentational State Transfer (REST) approach used by most web applications. Today, however, there are a number of freely available MQTT brokers (e.g., Eclipse Mosquitto) and several web services that can read data from MQTT brokers and display the values in dynamic web pages (see, e.g., https://thingspeak.com/, or http://www.sentilo.io).

D. Extract information

The technologies described so far make it possible to collect a large amount of data in a simple and effective manner. Such data, however, are rarely usable in their raw form and need to be processed in order to extract useful information, a problem known in the literature as *big data*. The data analytic methodologies are many and variegate, ranging from very basic statistical analysis to determine empirical mean, standard deviation and probability distribution of the measured signal, to complex deep learning algorithms to find correlations among the most disparate types of measurements. Rather interestingly, some useful information can be obtained even from rather simple analysis. For example, in [3], [23] it is shown how malfunctioning street lights can be easily identified by simply comparing the standard deviation of the values read by the light sensors applied to the different light poles during nighttime. More advanced techniques can be used to extract interesting correlations among different signals and build advanced services [24].

E. Build services

The last step consists in making use of the information extracted from data to provide useful services to the citizens and the city administration. Such services are generally realized by using standard web programming frameworks, but without a well defined and globally accepted reference model. This approach makes rather complicate for a city to replicate the services of another Smart City, which will likely differ in terms of required infrastructure, data access protocol, and so on. Furthermore, the exchange of data among services realized by different cities is also very difficult. This important roadblock has been recently recognized by a number of cities in the world, included Amsterdam, Dubai, Dublin, and Barcelona, which is considered one of the top most advanced Smart Cities in the world, according to several recent surveys. They have then decided to team up in the so-called *City Protocol Society*, whose aim is to define a common systems view for cities and identify or develop protocols that will help the development of such a view. The declared goal of City Protocol is hence to break the boundaries of silos solutions and interconnect different cities into an "Internet of Cities".[6] However, other similar initiatives are being undertaken by other groups so that, once again, the risk is the proliferation of multiple, incompatible models.

IV. Research challenges

The way to the realization of the Smart City concept is littered by a number of roadblocks that, in turn, generate a number of research challenges. In this section we outline some of the most interesting points that require further research.

A. Access technologies

As seen, there are a plethora of wireless transmission technologies that can be used to collect data from the peripheral nodes, each with different characteristics. However, it is not clear which technology can suit best the different requirements of smart services. Furthermore, there is still ample space for the optimization of the transmission protocols in order to reduce the energy consumption while maintaining the desired accuracy in the data collection [25]–[27].

B. Open data

Another challenge to come up with is a common representation for the data, in order to enable the development of a standardized approach to their processing, and ease the development of new applications. Furthermore, it would be essential to open the data as much as possible to involve citizens and foster the development of new ideas and findings. Unfortunately, the publication of data is hindered by a number of practical obstacles, included anonymity and privacy issues and, more importantly, the increasing awareness of the inner (economical) value of data, which makes them an important asset for their owners.

C. Data analytic

Another open area of research is related to the processing of such data. As mentioned, a lot of information can be obtained even using basic analytic tools. However, such methodologies only scratch the surface of what can possibly be done applying advanced data analysis tools to the variety of data that can be collected by the different services of a Smart City, and lot remains to be done in this domain.

[6] http://ityprotocol.org

D. Security and safety

Security, privacy, and related issues are clearly fundamental to protect the sensitive information gathered and exchanged by Smart City services from disclosure to non-authorized parties, and shield the system against malicious attacks. On the other hand, the strong limitations on the cost of devices and, therefore, on their hardware and software capabilities have contributed to relegating security to a subsidiary role in design of many IoT commercial products. This topic has been gathering increasing attention due to the growing awareness of the risks of entrusting simple IoT devices with sensitive information [28] or critical controls (e.g., building accesses, traffic lights, and so on) [29].

However, the vulnerability surface of a Smart City is extremely wide, with aspects that differ from standard Internet security. For example, the fact that sensors can be physically accessible to attackers, being placed in public areas, the limited capacities of such devices, the possibility of inferring a wealth of private information from the data collected by public sensors (e.g., road cameras), and also the possibility of injecting malicious signals into the system (e.g., to trigger alarms or other type of reactions), make the security problem in IoT and Smart City contexts unique, and even more challenging than in standard Internet scenarios.

E. Digital divide and social isolation

Another aspect that needs to be accounted for is the risk of increasing the digital divide and, consequently, the social isolation of the citizens that are less acquainted with modern technologies. To mitigate this risk, the aspects regarding acceptability and user friendliness should be part of the design process, which should be jointly carried out by engineers, psychologists, and sociologists.

V. Conclusions: the key to smartness

From the quick overview of the possible services that can be realized in a Smart City, it is apparent that the key to smartness is *integration*, intended in its widest meaning. The potential of the smart city services, indeed, can be fully unleashed only by leveraging the uncountable synergies among the different services that can be released only by adopting an integrated, systemic and holistic design of the urban system, which takes into account people, processes, and technologies. Unfortunately, the complexity of such a design effort is likely beyond the capabilities of our modern society, and the most common approach today is a sort of *best-effort* that targets the realization of subsets of low-hanging smart services, often without a clear long-term development plan. The risk of such an approach is the proliferation of a number of isolated, non-interoperable and non-replicable services, which would still represent an improvement over the current urban scenarios, but will eventually fail to fulfill the Smart City vision in all its potential.

The integration concept can actually be pushed forward by thinking to a symbiotic system where not only the information and communication technologies are used to build new services, but these very same services are used to improve the performance of the communication infrastructure. This concept, which we dubbed *Symbiocity*, has been exemplified in [30] and [31], where it is shown that by exploiting the data collected by the road traffic monitoring service it is possible to optimize the configuration of the cellular system, thus providing better service to the citizens.

In conclusion, despite the several and interesting initiatives that are being undertaken by different cities in the world, the Smart City concept remains so far an ambitious vision (and, perhaps, a bit of an utopia). The full realization of such a vision requires the solution of a number of challenges, which must be addressed by adopting a multidisciplinary approach that merges engineering, psychology, and sociology. Finally, fundamental is the full support of the public administration and the deep involvement of the citizens in the whole process.

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