Wireless Sensor Network in Smart City Pilots: The Case of Salerno in Italy (from 2015 to 2019)

Giuseppe Di Leo, Matteo Ferro, Consolatina Liguori, Antonio Pietrosanto, and Vincenzo Paciello

Abstract Citizen quality of life can be improved through facilities and services that must be thought to ease citizen interaction with municipal authorities, offices, and structures. Advanced metering infrastructures (AMIs) can be proposed as the backbone of smart city projects. The chapter deals with this topic by describing devices and results of a pilot project designed and carried out by the authors for experiencing the RF 169 MHz wM-Bus in AMI. The AMI was installed in Salerno, an Italian middle city of about 1,40,000 inhabitants and covering a land area of 58.96 km^2. Five public services have been loaded on the AMI to help find the affordability of necessary investments: gas and water metering, car parking management, elder tele-assistance, and pollution measurements. The pilot project has involved the 1.5% of the citizens in 11 city districts. Results provided a great amount of data and information about reliability and efficiency of devices and networks and have been held into account by the authors of the national standard on the shared management of the 169 MHz frequency band (UNI CEI TS 11762:2019). These results let understand that in the next future solutions like those described in the chapter can become products and services available for all citizens.

Keywords Advanced metering infrastructure · Investment affordability · Gas and water metering · Car parking management · Elder teleassistance

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E. Estevez et al. (eds.), *Smart Cities and Smart Governance*, Public Administration and Information Technology 37,
https://doi.org/10.1007/978-3-030-61033-3_14

Introduction

In this chapter, the authors present the experience they are having in developing technologies and devices for smart city. In particular, they propose some 169 MHz wM-Bus-based solutions for water metering, public car parking, and elder tele-assistance, which have been designed to be added on the AMI they installed for gas meters. More than an architecture, the smart city is a concept: technologies must improve the well-being of citizens. Citizen well-being and life quality in general depend on lot of factors, which are different in weight and in typology. Some of them like geographical location of the city, dimension, map, modernity of buildings, and structures as well as the civic sense of the inhabitants are not easy to be controlled. On the contrary, other factors like public transportation, traffic and parking management, resource (energy, water, gas), furniture and payment, social care of weakness, pollution, and waste disposal, fully belong to the sphere of responsibility of municipal authorities and companies that provide services on their behalf (David et al., 2012; Lan, Qilong, & Du, 2008). On the basis of similar considerations, in 2015 the Italian National Authority for Gas and Energy started a competition among proposal of pilot projects, to finance those would have had the best fitting with the Authority specifications. Among the winners, the pilot project for the City of Salerno that had the aim of assessing the technical feasibility and the economic sustainability of Advanced Metering Infrastructures (AMIs) in urban context. On the behalf of the Salerno Utility company "Salerno Energia Distribuzione", the pilot project was realized by the authors in cooperation with some ICT companies. The aim of this chapter is describing the research questions generated by the challenge the authors accepted. Two main questions arose: (1) how adding more and more services on the same AMI without saturating the 169 MHz channel bandwidth; (2) how providing a 3D distributed measurement of pollution. As for the former question, the authors adopted the solution of charging the leaf nodes of as much computation as possible. The distribution of computational tasks among peripheral devices, gateways, and central unit required to be accurately designed to avoid that battery powered devices had reduced their life. As for the latter, a solution to the problem was found in embedding a PM10 pollution sensor within electronic devices for water metering. Since the device is based on a cheap optical sensor, a calibration was necessary to evaluate performance and compare with European regulation in the field.

In the following, at first a brief introduction on some technological problems concerning smart city applications will be given. Afterwards, we will widely describe the AMI installed as test bed in the city of Salerno (Italy), where more than 2500 devices are being experienced. Then four devices suitably designed by the authors to fit the specification of water metering utility, public parking, elderly assistance service, and 3D pollution measurement will be detailed.

Finally, results collected in the first year and half of experimentation will be briefly resumed.

Technologies for Smart City

An intelligent city integrates information and communication technology with physical infrastructure in a strategic effort to support efficient services and ensure a high standard of sustainable living for citizens. Tao et al. in (Yin et al., 2015) conducted a survey of intelligent cities and extensively revised existing literature on intelligent city definitions to elaborate a taxonomy from four different perspectives: technical infrastructure, application domain, system integration, and data processing.

From a level perspective, the intelligent city will consist of three levels. After all, physical infrastructure includes all physical services (sensors, controllers, etc.) that already exist as part of an ecosystem in a city. The medium is the IT infrastructure, which involves all IT and communication techniques to interconnect different components. At the top, services are included that involve relevant processes and activities aimed at providing services to the needs of society.

In view of the active research work undertaken on this topic, one should still expect the evolution in the definition of the term "intelligent city" and also the classification of its various dimensions. The classification of these dimensions can take on different forms and compositions through research and development efforts, but only a few elements within these dimensions are currently receiving serious attention from research. Numerous projects have been carried out to update the concept of smart city, while many of them are ongoing and have yet to take place.

Enabling IC technologies are being the main innovators in smart city application. While digital networks provide the basic framework upon which smart cities make information flow, smart meters and all other peripheral devices (Corotinschi & Găitan, 2015; Ferrigno, Morello, Paciello, & Pietrosanto, 2013) lie at the foundation of digital networks. Smart devices and digital networks together allow citizens to reach or to be reached from service utilities. Numerous small and mega projects have been implemented in various efficiency-oriented smart cities. For example, the University of Iasi, Romania, tried to provide a solution for monitoring and managing the heating and electricity systems of a campus, consisting of 11 buildings, for energy efficiency (Mohassel, Fung, Mohammadi, & Raahemifar, 2014). The BCI project in Barcelona Intelligent City, is another, which proposes a solution that adopts open standards and flexible platforms for the integration of multivendor systems (e.g., Wireless Sensor Networks) to ensure the interoperability necessary for the concept of smart city (Gea, Paradells, Lamarca, & Roldan, 2013). The ICeWater project (Kulkarni & Farnham, 2016) studied connectivity problems with water monitoring and management infrastructures. Advanced metering infrastructures (AMIs) have been designed just for this, in the specific field of gas and water. Their infrastructure typically includes: i) meters at the customer site; ii) the communication network between the customer and a service provider; and iii) a management system that makes information available to the service provider.

As for AMIs numerous solutions have been experiencing until now, which adopted different physical channels and different communication protocols (Razavi & Jahed, 2017). Due to its high obstacle penetration capability and scarce power burden, the 169 MHz wM-Bus is emerging as the most convincing physical channel for smart meters, even if the short range (350 m) requires the installation of suitable gateways allowing smart meters to get to the Internet, via either fiber or GSM-GPRS. Bandwidth is constrained in few kBytes, nevertheless it is wide enough for most of smart city services. The low power radio module is compliant with battery powered device autonomy that should last at least 50 years. The wM-Bus, coupled with DLMS-COSEM (Carratù, Ferro, Paciello, Pietrosanto, & Sommella, 2017; Di Leo, Liguori, Paciello, Pietrosanto, & Sommella, 2016; IEC, 2006) protocol, has been founding wide application as the best solution for communication and data structuring in gas field.

The problem is that one gateway would be able to manage the communication with some hundreds of smart RF devices, but the actual density of gas meters in urban area rarely get to this value in a radius of 300 m. When the capability of gateways is not exploited properly, the costs to pay for each meter reading arises so much that gas utilities are discouraged from investing in AMIs. The solution proposed by the authors is that infrastructure cost be shared among more and more services that can be furnished through the same AMI.

While energy meters can trust the power line to be accessible and powered, water metering is quite far from this scenario. Even though some remote accessible solutions are market available, actually the most of installed meters are still mechanical. The major obstacle to wide spread is represented by cost and reliability of the newest measurement devices (i.e., ultrasound-based meters) (Capriglione et al., 2014). To give a solution to this problem, the authors designed and realized an add-on device to extract information from mechanical meters. On demand this device takes a digital picture of the meter display and transmits it to the gateway via 169 MHz wM-Bus radio module. In daily use, the add-on device showed to be reliable and effective, but the wireless channel occupation seemed to be excessive if other services had to be loaded on the same infrastructure. In this chapter is described the solution the authors found to reduce the channel occupation, via onboard OCR. Other services have been experiencing elsewhere, like the public illumination control, but always through proprietary solutions. Air pollution monitoring usually trusts few multisensor stations in the city. The author in this chapter proposes some 169 MHz wM-Bus-based solutions for the elderly assistance, car parking, and pollution distributed monitoring, which have been integrating with gas and water metering services on the same AMI.

The Advanced Metering Infrastructure in Salerno City

Smart metering and sharing of communication infrastructures are very topical concepts that have been the founding principles of the pilot project carried out in the municipality of Salerno, a city of about 1,40,000 inhabitants in southern Italy. Smart metering is changing the relationship between the consumer and the supplier. Both home users and business users today demand that through IoT technologies they be provided with higher quality services without significant cost variation. Service providers, in turn, take advantage of smart technologies for optimized delivery and operational efficiency. From this point of view, smart metering immediately appears as a win-win path, where you can have advantages for both counterparts.

The project pursued two objectives, to which utility companies tend with great interest:

- Meter-to-bill: The possibility to obtain—continuously—useful information for billing from meter reading.
- Meter-to-grid: To be able to intelligently manage the network, by activating remote events that impact both the status and the configuration parameters of the smart devices themselves.

The AMI has been designed to make available the same effective means of communication to several services all characterized by different methods and amounts of data to be exchanged. On the infrastructure basis, an application has been designed to integrate both front and back office functions, with a portal which partners and other players access with different profiles. In addition to the remote reading of water and gas consumption, two other smart device types have been developed specifically for 169 MHz wM-Bus networks: one for the hourly payment of parking on public roads, and the other for remote assistance to the elderly. AMI was designed to collect measurements or events coming from smart devices and make them accessible to utility companies. Suitable gateways, called concentrators, send data to and receive command from a central unit, which is featured with web interfaces suitably designed to allow any control strategy to be executed, and pricing data and commands to be sent to the various devices (see Fig. 1).

The AMI's communication architecture is characterized by hierarchical topology where leaf nodes (smart meters) are connected to master nodes (concentrators). The leaf nodes are battery devices that perform medium or short-range radio transmissions

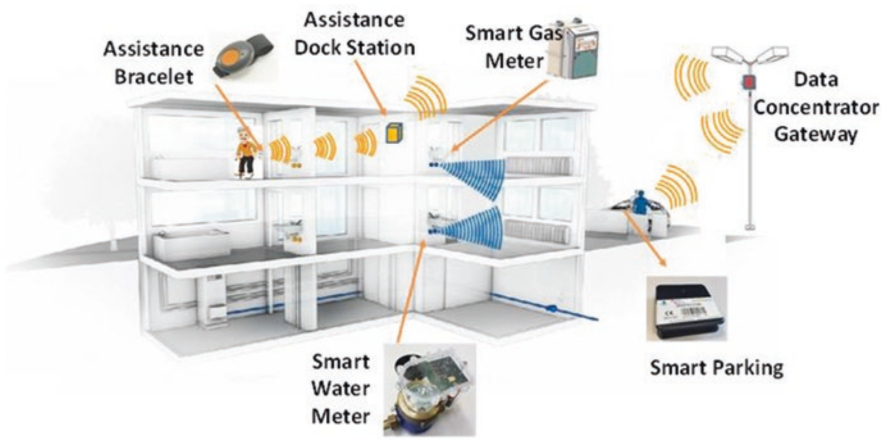

Fig. 1 The architecture of the AMI

in wM-Bus at 169 MHz with a low power consumption, while master nodes add a GSM-GPRS modem (or a fiber cable connection to Internet) to get also long-range communication capability. Each master node stores all data generated from a certain number of leaf nodes and transfers them to a central unit. Usually, unlike leaf nodes, master nodes are either grid or solar cells powered. Both the technical feasibility and the economic convenience depend on the concentration ratio (number of smart devices for each concentrator). Since both such factors can only be evaluated through experiencing urban areas characterized by different densities, at the first stage of the project, 11 city areas were identified, belonging to neighborhoods characterized by different population densities: rural, suburban, urban, and densely urban. Smart devices and concentrators were spread in these 11 city areas, as listed in Table 1 and reported in detail in Fig. 2.

With the objective of assessing the technical and economic feasibility of smart metering, the installation of the concentrators was carried out on available public buildings and sites. The choice of users to install the smart devices was determined by the coverage range of concentrators installed. All citizens were informed of

Table 1 List of smart devices and concentrators installed in the city of Salerno

City area	Address	Density	N° of gas meters	N° of water meters	N° of car parking sensors	N° of elderly assistance	Total N° of smart devices	N° of concentrators
1	Via S. Nicola di Giovi	Rural	3	6	–	–	9	1
2	Via Tramontana	Rural	10	14	–	1	25	1
3	Via Monticelli	Rural	12	12	–	1	25	1
4	Via Postiglione—Ogliara	Suburban	40	47	–	4	91	1
5	Viale degli Etruschi	Suburban	40	56	–	4	100	1
6	Via S. Eustachio	Urban	110	135	–	5	250	1
7	Via Passaro	Urban	90	155	–	5	250	2
8	Via Seripando	Densely Urban	95	90	–	15	200	1
9	Via Gaeta	Densely Urban	125	160	–	15	300	1
10	P.zza M. Luciani	Densely Urban	125	160	100	15	400	2
11	Corso Giuseppe Garibaldi	Densely Urban	350	385	100	15	850	3
Total			*1000*	*1220*	*200*	*80*	*2500*	*15*

Fig. 2 (**a**) The 11 city areas in Salerno map; (**b**) in the zoomed view of area n.7, the position of concentrators and meters

experimentation through the media and those where the smart meters were installed were contacted directly by utility companies.

The final results of the pilot project are analyzed in order to determine:

- The effectiveness of the technology, in particular of the 169 MHz RF physical channel;
- The efficiency of smart metering respect to the traditional methods of reading in terms of economic sustainability and service quality perception; and,
- The compatibility between metering and event-based services (parking and elder assistance) when served by the same communication mean.

These conclusions are going to influence the future policy of public administration and utility companies and so the perspectives of the smart city trends in this ambit.

Furthermore, the national authority for gas and energy is collecting the results of all the similar experiences carried out in the Italian country to update the regulations in the field.

The 169 MHz RF Modules

The infrastructure cost directly depends on the number of "concentrators" installed to cover the whole area of interest. As consequence, the number of smart devices connected to each concentrator (concentration ratio) is the main relative parameter to estimate the cost of services. The wider the coverage range of RF antenna, the higher the concentration ratio, the lower the costs. As for battery devices, transmission power and antenna gain must be compatible with battery capacity to assure long life of devices (Capriglione et al., 2014). The *wireless M-Bus* (EN 13757-4:2013) is suggested by national authority because of its good trade-off between coverage range and power requirements. The transmission mode, over 169 MHz frequency band, allows good coverage range (hundreds of meters in urban area) due to the inherently lower path losses, while the reduced data rates permit higher sensitivity for the receiver, with a consequently reduction of the transmission power at the transmitter or a longer transmission range using the same transmission power (Di Leo, Liguori, Paciello, Pietrosanto, & Sommella, 2015a, 2015b; Ferrigno, Pietrosanto, & Paciello, 2006). The channel bandwidth (7 kHz) is wide enough to allow both uplink and downlink (referred to the central unit). The transmission scheme is that leaf node starts the transmission to the master; after the transmission of the first packet, the master can send commands or requests, in a small reception time window. This means that battery devices can remain in sleep mode as long as they want, thus saving battery. If the leaf node receives a command/request in the reception window, it repeats the last message periodically with a determinate delay, until a new command/request is received from the master. The repetition stops for a termination message, or for timeout. Even though a physical channel like Lora-Wan would allow the same meter reachability and lightly longer coverage range at lower transmission power in uplink, it would not give enough bandwidth for gas meters in downlink, for:

- Configuration of meters.
- Management of commercial parameters (consumption profiles, billing interval).
- Setting of security parameters.
- Meter firmware upgrade.

The Concentrator

The concentrator main task is collecting data from the 169 MHz smart devices and sending them to the AMI central unit.

Concentrator architecture usually includes: i) a power PC board to processing information at application level (DCU functionalities); and ii) as many microcontroller-based radio modules as the number of simultaneous services (gas, electricity, water, etc.…). At DLMS/COSEM protocol level, the concentrator is both client (with respect to smart devices) and server (with respect to the central unit) and grants a transparent end-to-end communication.

The DLMS/COSEM communication profile is implemented by the concentrator also over TCP/IP (developed for GPRS transmission within a public network).

The Central Unit

Data coming from smart devices are indispensable to utility companies for billing and service quality analysis. The central unit must be addressable via the Internet by utilities that need to download data from smart devices and to upload commands.

The central unit consists of three software modules: (1) a JAVA module that implements the DLMS-COSEM protocol to communicate with concentrators through the mobile (GPRS/UMTS) network; (2) a web application developed in PHP that allows users and utilities to send commands to the smart devices and access the stored data; and (3) a MySQL relational database that records all data uploaded by the smart devices.

Also end customers may access their own data by adopting a user-friendly web interface, which makes the underlying communication protocols and objects transparent. About the security features, the Central Access System implements mechanisms for authentication to allow access to the concentrators and utilities.

The data is exchanged among head-end system and concentrators, whereas utilities are encrypted with AES-GCM 128 bit. It is ideal for protecting packetized data because it has minimum latency and minimum operation overhead.

The DLMS/COSEM specifies an interface model and communication protocols for data exchange with metering equipment, including the data encryption and decryption by using a 128-bit AES-GCM algorithm. Moreover, the central unit guarantees the following data security requirements:

- Access control: Authorized users of remote management operations must carry out a double-factor identification (user and machine) to the system, and consumption data are associated to users through pseudonymization techniques managed by the service management company.
- Identification and authentication: The users of the SAC, the automatic processes, functions, or transactions acting against the SAC in the name and role of authorized users, the devices and other information systems that interact with the SAC are identified, authenticated, and tracked.
- System and information integrity.

Smart Add-On for Water Meters

The authors designed a smart device that has to be added on traditional analogue water meters to extract the reading from the photo of the front panel (see Fig. 3).

The method allows the device to be released from any metrological specifications. Its enclosure has been designed to allow easy installation (without detachment) on a good number of meter models and to let the water meter readable by customers. The smart add-on is made of a microcontroller (ARM®Cortex™-M4 32-bit RISC core) based system, featured with the following devices:

- Digital microcamera with a field of view that includes consumption digits and serial number.
- 169 MHz wM-Bus RF module with antenna
- Battery power supply.
- Containment enclosure made of transparent plastic material.

Fig. 3 The smart add-on for water meters

The DLMS-COSEM is implemented in the firmware thus making the device full compliant with the most widespread concentrators. Autonomous power supply (lithium battery with slow discharge) ensures a useful life of the device not less than 5 years. Radio-frequency channel transmission is not subject to government concession, and the transmission distance is higher than 150 m in urban environment. On demand, the photo can be requested by the concentrator.

The meter sends the part of the binarized image that includes the five digits (see Fig. 4). It takes 11 data packets and digits can be either read by human operator or extracted by an off-line OCR software module, which has been integrated with the SAC web interface.

In its last release, the smart add-on firmware implements also an OCR feature that allows the five digits to be online extracted from the image and transformed in a numerical value of the consumption. After the bitmap image has been downloaded from the camera, it can be processed by a six steps procedure (Fig. 4). The main steps of the procedure are: (a) image digitalization through an adaptive threshold; (b) localization and extraction of the decimal counter from the image; (c) measurement and correction of the rotation angle due to installation inaccuracy; (d) digit extraction and separation; (e) cross-correlation of each digit with a suitable pattern which was set up to hold into account also the different lens distortion among the five digits; and (f) numerical evaluation of consumption.

The consumption value takes one packet to be uploaded to the concentrator, but also when only the consumption has been transmitted to the central unit, the photo can still be requested by the utility through a further command.

As for the performance of the OCR feature, a statistic about only 130 readings is available, all made in the last 2 months by add-ons upgraded to the last release. It

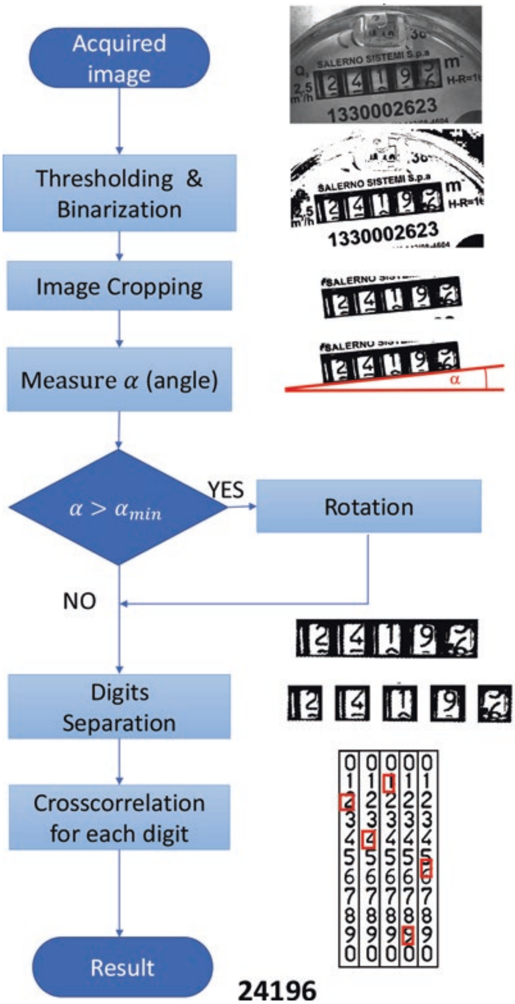

Fig. 4 Onboard OCR procedure

has to be highlighted that: (1) the light conditions should be determined only by the onboard white led because all smart water meters have been programmed to take pictures and transmit packets during the night, while daily times have been reserved to gas meters; (2) the relative position of the add-on respect to the meter display is forced during installation by a suitable hollow on the lower face of the add on, corresponding to a protrusion on the water meter display; and (3) the camera focus is optimal in case of perfect installation.

Nevertheless, in some cases (14% of the total), these three conditions were not fully satisfied. The percentage of correct extraction was 90% and all the remaining 10% belongs to the 14% of installation errors.

Elderly Assistance Service

The multiservice communication infrastructure is used to support an elder tele-assistance service, with the aim to protect the well-being of users (mainly elderly and disabled people), allowing them a more serene stay in their living environment. The realized "tele-assistance" service can generate an alarm for any type of emergency, active 24 h a day, every day of the year (Fig. 5).

The user is provided with:

– A push-button radio remote control (radio-frequency battery device in free loan) to generate the intervention request and for safety the user must wear or carry on the button.
– A dock-station (the sensor for tele-assistance) powered by an electrical source with dual radio communication, towards radio remote control and towards the nearest concentrator, according to the 169 MHz wM-Bus and DLMS/COSEM protocol.

The dock-station is then able to connect to the multiservice.

Concentrator to route the request for assistance to the central unit that collects all data coming from concentrators. Finally, the central unit activates an Automatic Alert Report (through appropriate prerecorded SMS message) in favor of the elder's trustworthy peoples (listed during registration to the service). The dock-station is programmed to send an acoustic luminous signal of the absence of the service, both when the radio link with the concentrator is interrupted and when the concentrator cannot communicate via GSM-GPRS with the central unit. Other similar systems are available on the market, which send SMS messages to registered numbers. All of them require either a Wi-Fi connection or a land/cell phone line. The device proposed by the authors works within the coverage range of an installed concentrator, without requiring direct access to the Internet or a telephone connection.

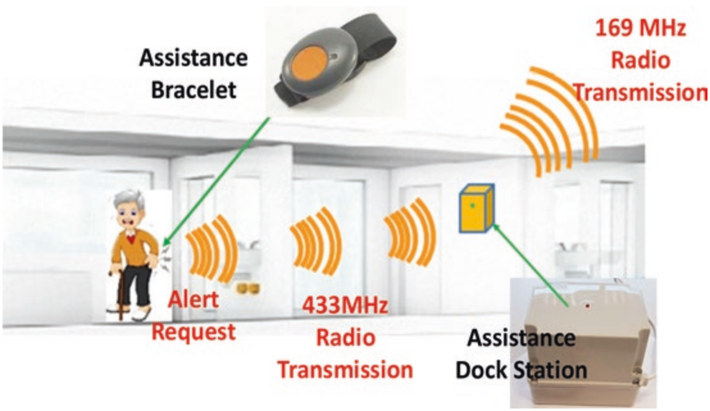

Fig. 5 The smart devices for elder tele-assistance

Tele-Parking Service

The multiservice communication infrastructure is used also for managing the public parking slots (blue strips, gates) in order to improve both the perceived quality of the service (ease of access) and the efficiency of the provider. The tele-management service works thanks to a battery powered device that must be kept in the car by the user: a radio-remote control featured with a button that must be pushed when the car has been parked to communicate its identification code to the nearest concentrator according to the wM-Bus and DLMS-COSEM protocol. The equipment is provided, on loan, to the user at the time of registration at the tele-parking service.

The starting of the parking time is activated manually, by the user by means of the push button; the remote terminal communicates at the multiservice concentrator which provides to route the request to start at the central unit. The request activates the system for charging the service provided. The end of the stay is automatically detected by the loosing of the connection between the remote terminal and the multiservice concentrator, when the car leaves. This condition indicates to the central units the end of service and allows the corresponding payment to be computed. In comparison with the parking platforms present on the market today, based on the adoption of SMS messages and/or smartphone applications, the proposed solution offers the advantage of greater simplicity and speed of access. No position, no expected duration, no information must be given, just a button push. The payment stops with max delay equal to the resolution of the tele-parking (10 min), which is determined automatically by the movement of the car with radio remote control still in ON state since the new spontaneous transmission that is of the addressed type does not receive acknowledgment from an eventual different concentrator visible from the radio-remote control during the movement (Fig. 6).

Fig. 6 The tele-parking device

The user must be sure only to stay in the coverage range of a concentrator. The status of the connection is signaled by a suitable multicolor led, and the average waiting for connection time is about 1 min. The device must always be visible on the dashboard of the car and if the user does not push the button the led remain turned off thus allowing controllers be alerted.

PM_{10} Sensor Prototype

In October 2013, the specialized cancer agency of the World Health Organization, the International Agency for Research on Cancer (IARC), declared “outdoor air pollution a leading environmental cause of cancer deaths.” It was also demonstrated that cardiovascular health consequences of exposure to airborne particles could be even worse than those due to pulmonary ones. The IARC evaluation showed an increasing risk of lung cancer with increasing levels of exposure to particulate matter (PM) and even more ultrafine particulate (UFP), among the major components of outdoor air pollution. The European Environment Agency (2017) has recently confirmed that key air quality standards for the protection of human health, including particulate matter (PM) and UFP, are currently not met in many air quality monitoring stations in the European Union. However, instruments for UFP measurement are very expensive and this causes sparsity of measurement points. PM sensors can be, on the contrary, cheaper, nevertheless PM measurement stations are still very few and not widespread in urban areas. Therefore, in order to meet actual and future demand of distributed measurement systems, low cost PM and UFP wireless sensors could be thought to be connected to RF networks that are being today widespread in smart cities. Waiting for a new generation of low cost UFP sensors, the authors tried to connect some 169 MHz wM-Bus wireless prototypes featured with a PM_{10} sensor to the concentrator network in Salerno. PMs are classified in terms of diameter, i.e., PM_{10} has a 10 μm diameter or less. Both $PM_{2.5}$ and PM_{10} particles contain nonvolatile components such as sulfur, heavy metals, and elemental carbon. Primary outdoor sources of PM_{10} are burnt fuel from automobiles, construction equipment, and power plants. The choice fell on PM_{10} because low cost sensors are widespread on the market. The PM_{10} sensor that was integrated with a wM-Bus radio module, like that of the water meter add-on, is the GP2Y1010AU0F manufactured by Sharp and reported in Fig. 7a). Due to the implementation of wM-Bus and DLMS-COSEM protocols in the firmware, the prototype can be easily connected to the 169 MHz network and communicate with a concentrator. As consequence, after its installation at home of some utility customers, near water or gas meter, it will be automatically included in the concentrator white list.

The sensor is based on an optical sensing device which exploits the light reflection (thanks to the inclusion of a suitable infrared light emitter). When the light hits the particulate matter, a phototransistor discloses the presence; the corresponding measure comes out as a voltage signal in the (expected) range 0.9–3.4 V (Fig. 8). The PM_{10} sensor output signal is acquired by the visual add-on thanks to a suitable

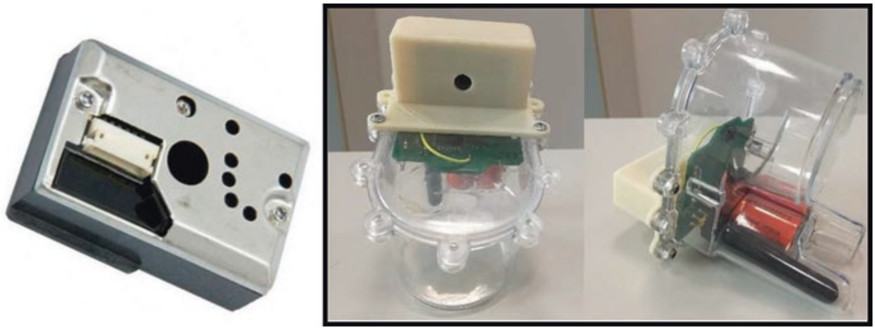

Fig. 7 (**a**) The GP2Y1010AU0F sensor. (**b**) The water add-on like PM_{10} sensor

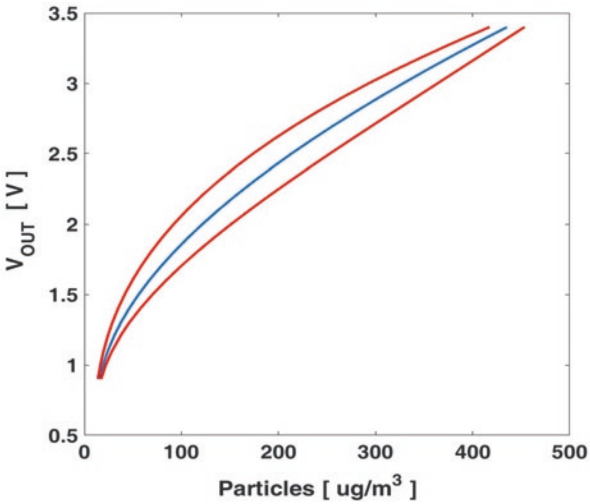

Fig. 8 PM sensor calibration curve (blue line). Red lines represent the uncertainty range

external conditioning circuit. In detail, the circuit drives the PM_{10} sensor infrared diode according to the pulse-driven waveform suggested by the manufacturer: a PWM with a period T of 10 ms and a T_{on}/T_{off} interval respectively equal to 0.32 and 9.68 ms. The single measured value is obtained by averaging 64 consecutive readings from the 12-bit ADC within 1 s. The current consumption during measurement operations is low; the mean value is around 11 mA with a peak of 20 mA.

The result is in Fig. 8. Metrological characteristics of 30 PM_{10} sensors were evaluated according to the procedure suggested in (Rajasegarar et al., 2014; Semple, Apsley, & MacCalman, 2013) in comparison with the Dylos Pro-1100 device as reference instrument. The 30 PM_{10} sensors and the reference instrument were placed inside a hardboard box (internal volume = 1 m^3). A lit cigarette (kept at the middle of the box) was used as PM source during the calibration, whereas the sensors (previously synchronized with time resolution of 1 s) were collecting one sample each

60s. The lit cigarette was left in the box for a total time of 5 h. The PM_{10} sensor outputs got suddenly to saturation; starting from the 150th minute they gradually decreased. By adopting the cubic polynomial fitting suggested in (Semple et al., 2013), the calibration curve has been computed for each PM_{10} sensor. The results are shown in Fig. 9 in terms of mean value and standard deviation within the output range of interest (0÷500 μg/m^3). The PM_{10} sensor uncertainty obtained from the metrological characterization ranges from 5 to 25% of the corresponding reading. The sensors are enough accurate for the implementation of a macroscale 3D model to be adopted for PM_{10} monitoring. The power battery sensors could be spatially distributed like water and gas counters are, thus providing as many as you want PM_{10} measurement points in a three-dimensional space. If the daily PM_{10} concentration single measurements wanted to be used instead for air quality evaluation according to European and national directive (European Parliament, 2008), the requested data uncertainty of 25 μg/m^3 (with 95% confidence level) could not be assured by this cheap sensor. Nevertheless, if a great number of battery powered wireless sensors were widespread in the urban area to be monitored, the output of little sets of near sensors could be averaged to obtain a mean value with uncertainty decreased with $1/\sqrt{N}$, where N is the number of the set. Thanks to this, the metrological performance can be compensated through the average by exploiting the data availability from spatially distributed sensors within the WSN. In detail, the comparison between the worst case for the estimated measurement uncertainty (80 μg/m^3 at PM concentration equal to 230 μg/m^3) and the prescribed data quality (12.5 μg/m^3) leads to a requirement for the number of the sets (N = 50) which could be assured by the WSN in Salerno, where no concentrator has saturated its concentration ratio. Still few prototypes have been installed until now at household level, but an installation campaign is getting start that involves the Salerno very center (City Area N.11), where the need of tree dimension distributed pollution measurements is particularly felt.

Main Results of the Pilot Project

The experimentation in the City of Salerno, started at the end of 2015, in November, is still ongoing. The AMI has been installed between November 2015 and July 2016. It is made of 15 concentrators, which were collocated in 11 city's districts characterized by different densities of customers and different typology of buildings. Two screenshots of the SAC web interface are in Fig. 9. It is possible to note that the network manager profile allows the real-time visualization of the status of meters through the different color they appear on the map. In particular, the green color means that meter transmitted last data within a week, while the yellow within a month and the red one more than a month. It is to be considered that water consumption is requested every 2 months, while gas meters transmit four times a day.

Experimental results have been collecting in the central unit data base and for sake of brevity were summarized in Table 2, in Table 3, and in Table 4. In Table 2,

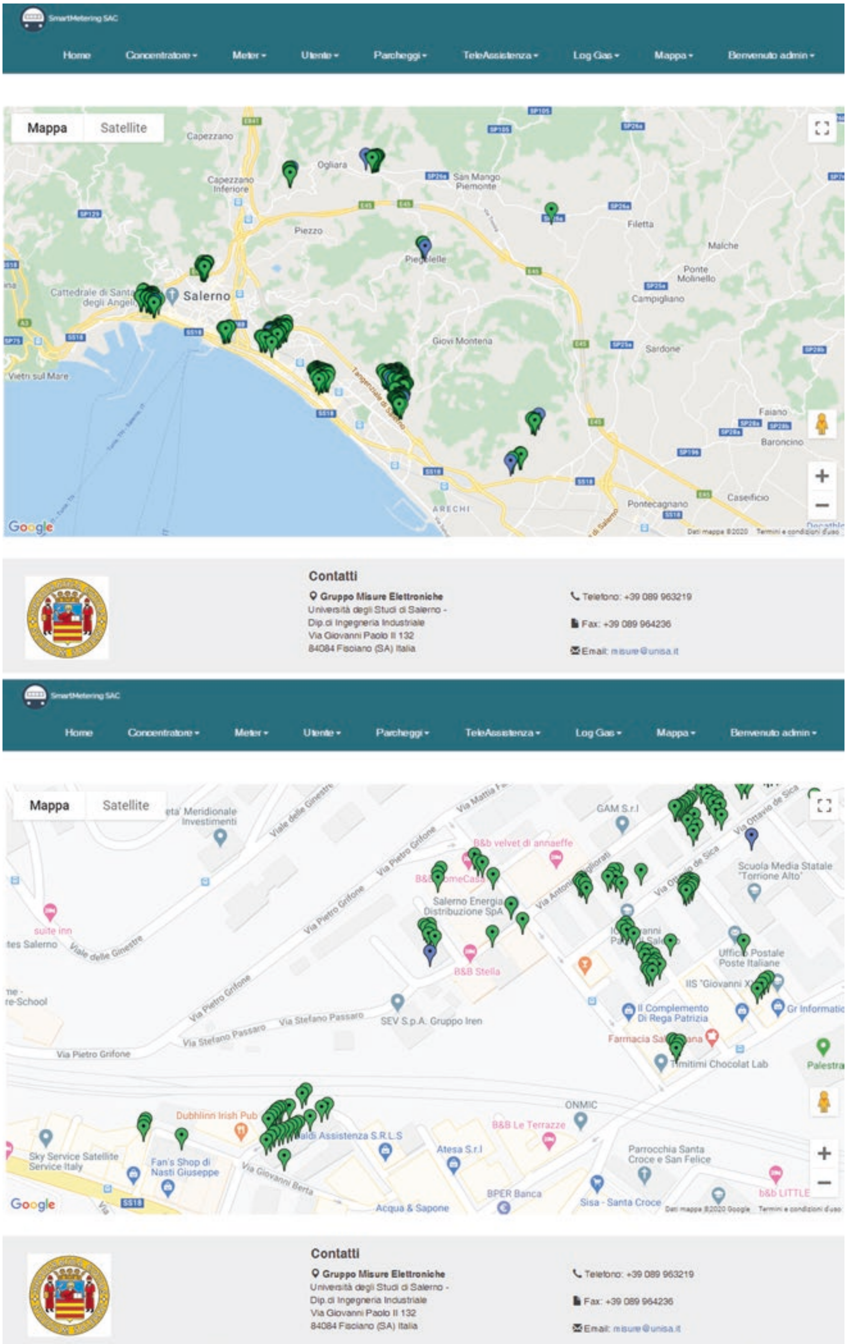

Fig. 9 Two screenshots of the SAC web interface: (**a**) all the map; (**b**) zoomed part of the map

Table 2 Summary of Application requirements

Application	End-points	Uplink			Downlink		
		Periodicity	Dataset (bytes)	Daily load (bytes)	Periodicity	Dataset (bytes)	Daily load (bytes)
Gas metering	1000	3times/day	150	450	1 time/ month	50	–
Water metering	1200	3 times/ day	150	450	1 time/ month	50	–
Parking management	200	6 times/h	50	300	6 times/h	50	3
Health alert	80	Random	50	–	Random	50	–
Electricity metering	20	3 times/ day	150	450	1 time/ month	50	–

Table 3 Performance indices for Gas and Water Meter in terms of Reachability (R) and SAC (A)

Index	Gas	Water
	R/A	R/A
Number of working points at the start	1.400	1.200
Monthly average reachability DAILY rate	91%	89%
Monthly average reachability WEAKLY rate	97%	95%
Reachability rate in the MONTH	99%	97%

Table 4 Performance indices for Gas and Water Meter in terms of Reachability (R) and SAC Availability (A)

Index	Gas	Water
	R/A	R/A
Number of working points at the start	1.400	1.200
Monthly average reachability DAILY rate	91%	87%
Monthly average reachability WEEK rate	93%	93%
Reachability rate in the MONTH	96%	95%

the average data rate of each smart device is reported, both in uplink and in downlink (referred to the central unit). Uplink is periodic only for gas and water meters and concerns consumptions, while for the other services the data flow is unpredictable. Downlink is generally reserved to commands to be sent to devices for either commands of firmware upgrade.

In Tables 3 and 4, the report of reachability at both concentrator and central unit level of gas and water meters is showed at the early and the today stage of experimentation, respectively.

The missing meters are still a few, after 24 months. The value let hope that battery capacity be enough to reach the expected goal of 5 years battery life for the most of devices. The behavior of parking and elder assistance devices has been more difficult to characterize until now because their number is too low to produce significant statistics in so few months. However, the customers questioned by phone by the staff of the utility company, said they were satisfied. These interesting results have been held into account by the authors of the national standard on the shared management of the 169 MHz frequency band (UNI CEI TS 11762:2019).

Conclusions

The AMI designed, implemented, and experienced by the authors in the City of Salerno demonstrated the feasibility of the approach to smart city context. All devices showed to be well designed to provide reliable services to customers. Battery devices exhibited enough autonomy to make the money investment convenient. All devices adopt DLMS-COSEM protocol, which leaves very few points of ambiguity in communication if its implementation is rigorous and complete. The occupation of the channel showed to be compatible with all the needs, also when all the services are fully working. Among these, the highest amount of transmitted data is due to a smart add-on for water meters. However, its newest release strongly reduces the number of packets to be transmitted to the concentrator thanks to an onboard OCR feature that demonstrated very good performance in case of right installation of the device. The device for elderly tele-assistance showed to grant an effective fast service to people that can be either disabled or unused to IoT smart devices. Both tele-parking service and PM_{10} distributed measurement look like being effective, but they will be useful when the RF network coverage will be extended to the whole. Concerning these last, from the calibration emerged that the space distribution of the sensors allowing the measurement uncertainty do not exceed the European standard threshold and are compatible with the AMI architecture. The result of experimentation lets imagine that in the future these devices and infrastructure can be widespread. Battery device future developments will be focused on increasing autonomy and reducing dimension. As for the water smart meter, future efforts will be dedicated to decrease the sensitivity of the add-on device to the installation inaccuracy.

Acknowledgments The experimentation would not have been done without support and contribution of "Salerno Energia Distribuzione SpA" management and personnel.

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