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1

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Trends in metering potable water

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Abstract

Sustainable management of drinking water distribution systems requires information on the operating status of system components to identify the best operational management measures. The ability to acquire information on tank levels, pipeline flow and real-time pressure offers an efficient and cost-effective management perspective, and enables wider monitoring, which can improve (physical) security as well. The technology of measuring instruments for hydrodynamic variables, used to monitor potable water systems, differs in their independence from electronic data acquisition components and ability to connect to remote data communication systems. Advanced water measurement infrastructure is characterized by the ability to capture data with measurable errors from anywhere in the system, without restrictions on communication type. This paper deals with the measurement of hydrodynamic parameters and a proposal for water meter classification. It includes analysis of the main water meter and data tele-acquisition infrastructure. Several selection criteria are evaluated with respect to their ability to support mathematical hydraulic models and expert systems for water distribution system management.

Key words: advanced metering infrastructure (AMI), internet of things (IOT), potable water, sustainable water management, water distribution system (WDS)

INTRODUCTION

The ability to set up a sustainable development model (EUCOM 2005a, 2005b) is linked to resource monitoring, quantifying sustainable use (CPS 2005; Maiolo *et al.* 2005, 2006) and identifying management operations to ensure the current opportunities for future generations. Water resource management creates objective problems in achieving sustainability goals (Gleick 2010; Sandoval-Solis *et al.* 2010).

Measuring instruments, real-time network monitoring and control equipment must be included in a water distribution system (WDS), to enable real-time intervention for malfunctions or hydrodynamic imbalances. Measurement and control functions are conceptually linked to promote advanced management of the WDS; indeed, real-time measurement of hydrodynamic parameters is very significant if it enables the realization of controls that can carry out operating corrections.

Systematic monitoring of network operating conditions supports management objectives, including:

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1. Real-time knowledge of the available flow rates at source, and prediction of total or partial inadequacy of supply (O'Flynn *et al.* 2010; Quevedo *et al.* 2010; Stewart *et al.* 2010; Maiolo *et al.* 2017)
2. Using mathematical hydraulic models, expert systems and/or artificial intelligence structures, for WDS simulation, calibration and management (Gupta & Bhave 1994; Ghorbani *et al.* 2010; Nourani *et al.* 2011; Maiolo & Pantusa 2016; Carini *et al.* 2018; Maiolo & Pantusa 2017a, 2017b, 2018)
3. Integrated management of reservoirs and networks, under normal conditions and during resource shortages, with the potential for re-balancing the network to avoid overpressure, water troughs and overflow in reservoirs (Mousavi *et al.* 2005; Liu *et al.* 2006; Rao & Salomons 2007)
4. Knowledge of working pressures, definition of districts, identification of losses, and monitoring of network performance indices (Alegre *et al.* 2000; AWWA 2004; Almandoz *et al.* 2005; Alegre *et al.* 2006; Di Nardo *et al.* 2012; Giugni & De Paola 2015)
5. District water balances, estimates of physical losses in pipelines, and breakdown predictions (Bao & Mays 1990; Kleiner & Rajani 1990; Mutikanga *et al.* 2011; Annus & Vassiljev 2014)
6. Administrative management of consumer consumption with the ability to modify the billing timescale (Domene & Saurí 2006; Stewart *et al.* 2010; Wang *et al.* 2010).

To achieve these goals, dedicated flow and pressure measurement infrastructures need to be implemented, and remotely controlled actuating valves installed (Rao & Salomons 2007; Wang *et al.* 2010).

Such infrastructure is characterized by the choice of both measuring instruments enabling remote data acquisition (defined for precision and accuracy) and a communication system providing secure remote data management.

The basic measurement requirements for drinking water distribution systems are quantitative – single-user water volumes, reservoir and piezometric tower levels, and flow rates and pressure at significant points in the network – and qualitative – organoleptic, chemical, physical and biological parameters, including disinfectant concentrations (Maiolo & Pantusa 2015).

In WDSs, free surface level measurements are required for supply sources, and can be carried out as either hydrostatic pressure measurements or direct measurements of the free surface level.

Floating and spring pressure manometers can be used to transmit measurement because they are connected by actuators that determine, for example, pumping or flow interruptions. Floating manometers rely on the elastic deformation in metal bellows caused by pressure variations. An elliptical section of varying shape is deformed elastically in spring pressure manometers, by pressure variations (Pulci Doria 1992; Longo & Petti 2006). Flow measurement instrumentation for pressure pipes is rapidly evolving in terms of technologies that provide more accurate measurements to permit data collection from locations that are difficult to reach (Alsdorf *et al.* 2007).

The information on the state of a WDS and the water quality within it requires a wide monitoring system that enables adequate countermeasures for security by protecting critical water supply infrastructure (Janke *et al.* 2014; Taormina *et al.* 2017).

Finally, the availability of large amounts of real-time data accumulated in modern non-relational storage systems and supported by modeling, enables the use of data-mining algorithms and modern artificial intelligence techniques (Nguyen *et al.* 2017). Such tools, aimed at automating learning (machine learning), can yield proactive behavior in emergencies and predictive behavior, when service efficiency or user safety could be endangered (Cardell-Oliver & Gigney 2015).

DESCRIPTION, PROPERTIES AND CLASSIFICATION OF WATER METERS

The many different types of water meter are commonly categorized into 10 sub-divisions by measurement method:

- differential pressure

- volumetric
- variable area
- fluid dynamics
- tracer
- turbine
- electromagnetic
- ultrasonic
- transducer, and
- mass flow

They can also be classified by recording method (continuous or totals) and on their dependence on electronics (obligatory or optional). These latter classes include all flow meters currently in production. Meters can also be characterized by intrusiveness and energy classification. The proposed classification is shown in Table 1.

Table 1 | Water meter classification

Meter type			Intrusiveness	Energy classification
Optional electronics				
Differential pressure	Venturi tube		Intrusive	Extractive
	Baffle		Intrusive	Extractive
	Nozzle		Intrusive	Extractive
Volumetric			Intrusive	Extractive
Variable area			Intrusive	Extractive
Fluid dynamics			Intrusive	Extractive
Tracer			Intrusive	Extractive
Flow rate	Turbine		Intrusive	Extractive
		Single jet	Intrusive	Extractive
		Multiple jet	Intrusive	Extractive
	Helical turbine		Intrusive	Extractive
	Whirlpool		Intrusive	Extractive
	Combined		Intrusive	Extractive
Obligatory electronics				
Electromagnetic			Not Intrusive	Additive
Ultrasonic			Not Intrusive	Additive
Transducer			Not Intrusive	Additive
Mass flow			Intrusive	Additive

The measuring system cannot be chosen solely by evaluating different meter types, but other features must also be considered. Measurement accuracy (maximum instrument error) is important in electronic instruments (Harney 2009). The maximum adjustable flow rate and its instrument rendering constant are also important for accuracy: unlimited partition of the measuring scale, represented by a constant, maximizes accuracy. For this reason, electronic meters provide better accuracy.

Instrument sensitivity, the ratio between the electrical or mechanical quantity, measured by the instrument, and that to be measured, increases with flow with a single scale. On multi-scale instruments, sensitivity decreases with increasing flow. The definition of sensitivity and the potential for improving it are limited by the threshold value. Beyond this the instrument reaches its physical limits and operation is not reliable. There is a precise relationship between sensitivity and threshold value, giving high sensitivity to instruments that would otherwise have low threshold values. The threshold value – the minimum differential of the measured quantity that can be observed – is also known as the absolute threshold value, which distinguishes it from the threshold value related to the background quantity of the measuring scale.

The versatility of electronic instruments manifests itself in the possibility of maintaining the linearity of the final reading scale, which depends on the relationship between the instrument constant and the amplitude of the constant partitioning of the reading scale. For electronic instruments, non-linear magnitude variations can be translated to the reading scale linearly by inserting non-linear compensation. The type of movement requires a particular ability of the measuring instrument to obtain reliable data. The instrument resolution and frequency are an important feature to increase the significance of the mean values provided by the instrument. In this context the electronic instrument has a high level of performance.

Another useful comparison feature is flow disturbance, and therefore the current-induced load losses due to meter insertion (Farley & Trow 2003; Arregui *et al.* 2006; Criminisi *et al.* 2009). Although both mechanical and electronic instruments are intrusive with respect to flow, mechanical units need to draw power from the flow itself. For electronic instruments, however, the signal can be minimized by reducing the signal amplitude and amplifying it in subsequent electrical processing. For electronic meters it is important to evaluate the signal output distortion (this is fundamental if using an output signal for electronic acquisitions/transmissions), which is useful if it is low, and the signal/disturbance ratio (an important feature of the background noise), which is very important in urban water networks. Good quality instruments have signal/noise ratios of 30/40 dB. In choosing between meters suitable for specific contexts, the environmental context of the measuring station must also be considered (Fallico *et al.* 1992; Lamberti *et al.* 1994; Howell *et al.* 1996; Smith *et al.* 1997; Storey *et al.* 2010).

In order to control and measure operations in WDSs, appropriate instrumentation must be installed in wells, basements and reservoirs – physico-climatic changes are often caused by temperature, pressure, and/or humidity changes, and such variability can affect the functioning of the water system. In such contexts, mechanical (turbine and volumetric) metering devices tend to be prevalent, with optional electronics, where the difficulty of power supply and communication requires new solutions. An example is the miniature hydroelectric turbines sometimes introduced into pipelines (Maiolo *et al.* 1989; Maiolo *et al.* 1990; Paish 2002; Morais *et al.* 2008) and new communication systems.

It is important for advanced metering infrastructures (AMIs) to be able to capture data with precisely measurable errors (Koppel & Vassiljev 2012) and from anywhere in the system.

The measuring instruments for hydrodynamic variables and control in water networks form part of tele-acquisition systems, enabling remote reading of water meters. Data flow is either unidirectional – i.e., from the meter to the detector (automatic meter reading – AMR) – or bidirectional, between the water meter and the AMI (Beigi Mohammadi *et al.* 2014).

DESCRIPTION AND PROPERTIES OF MAIN NEW ADVANCED METERING INFRASTRUCTURES

The technological scenario supporting water management systems evolves constantly, with a slow but continuous series of experiments aimed, partly, at minimizing human intervention. This has moved on from manual meter reading, when an operator goes close, reads the meter and transcribes the reading to paper (Tei 2012) via ‘walk-by’ systems (Tamarkin 1992; Harney 2009), in which the operator retrieves the meter’s data with an electronic device, to ‘drive-by’ (Tamarkin 1992) systems. In the latter, the operator approaches the meter in a car and retrieves the meter’s data electronically. The unsatisfactory results of such attempts, due to poor technical-managerial performance, show that, without AMR, the performance increases are insufficient to justify the investment costs (Tamarkin 1992; Harney 2009). On the other hand, AMR is difficult to implement – e.g., requiring ad hoc telecommunication networks – and involves substantial investments (Rouf *et al.* 2012).

Administrators, while aware of the opportunities and needs of AMI acquisition systems, tend not to adopt innovative solutions for automated monitoring and/or WDS control.

With AMI systems it is possible to integrate data acquisition with analysis and processing systems, using mathematical hydraulic models. The main reason for delay is the immaturity of communication technologies and consequent difficulty in identifying the most suitable solution (Farr *et al.* 2010; Gungor *et al.* 2011; Khalifa *et al.* 2011).

Evaluation of current technological solutions (Khalifa *et al.* 2011) is likely to provide the best solution for the various scenarios, given that the technologies considered will be consistent with the 'Internet of Things' (IoT). Indeed, smart water meters are a form of IoT, in that they can monitor the status of physical objects, and capture meaningful data and communicate it – e.g., by wireless – for analysis. New network solutions are emerging that would make IoT a reality, but the choice is not easy.

A very wide variety of wireless communication technologies is available, matching the range of services and requirements that might use them. Every IoT application has its own communication requirements (latency, consumption, distance, bandwidth, costs), and it is virtually impossible to identify a single technology that meets the requirements of each application (Liu *et al.* 2011; El-Mougy *et al.* 2015; Qiu *et al.* 2016).

Figure 1 shows a possible radio technology classification based on coverage offered and transmission speed. Short-range devices usually operate on unlicensed bands – e.g., 868 MHz and 2.4 GHz in Europe, in general. Application-specific technologies (eg ZigBee for Home, Wireless MBus (Meter-Bus) have been established for metering, with others like low power Bluetooth for wearable equipment and healthcare, NFC (Near-Field Communication) for payment, etc (Fantini *et al.* 2016).

To meet the needs of applications requiring broader coverage but not high bit-rates, a number of LPWANs (low power wide area networks) have been developed – e.g., Sigfox and LoRa (Centenaro *et al.* 2016; Nolan *et al.* 2016; Georgiou & Raza 2017). New radio access profiles (Cellular-IoT or Machine-Type-Communication) have been made available (Lin *et al.* 2015; Mahmoud & Mohamad 2016; Palattella *et al.* 2016) to increase existing mobile network coverage. This has reduced consumption and has costs comparable to current GPRS modules, which are often used in these contexts,

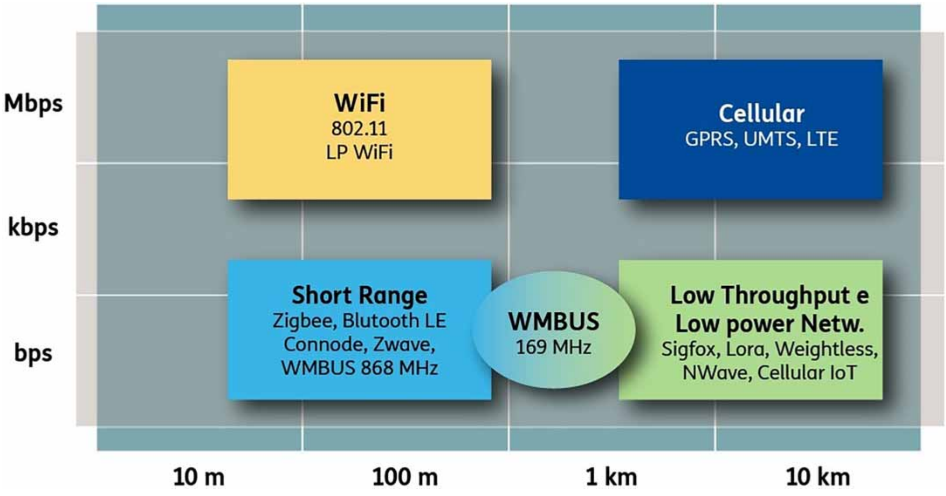

Figure 1 | Range and bit-rate of some communication technologies for IoT (Fantini *et al.* 2016).

ensuring the reliability and use of standard operating solutions on licensed bands, including the Narrow Band – Internet of Things (NB-IoT) (Fantini *et al.* 2016).

Generally, smart water business can be implemented using a 'multi-tier' approach, so that water meter data are directed to the collector and thence to the concentrator. Equipment like water meters, collectors, and concentrators from different vendors are rarely compatible and are, thus, hard to connect. Protocols customized by different vendors are also incompatible, complicating maintenance and replacement.

This paper is focused on a 'single-tier' approach based on the use of a single, low-complexity technology. This ensures low costs and power consumption, and avoids problems of strong interference.

When focusing on this 'single-tier' type of network, it is important to analyze the technical aspects and limitations, and the business model associated with building an IoT system. In reality, the focus is often on the cost of the radio modules but, over their life, this constitutes 5% or less of the total. Data use is usually the largest variable cost. Technologies like NB-IoT may seem inexpensive but the cost per byte is many times higher than that in traditional cellular systems. Understanding how much data a system will use is a major part of modeling its costs (Ray 2017a, 2017b, 2017c).

The transmission technology for smart water metering depends on many factors, which influence the choice for the particular cases. NB-IoT, LoRa and Sigfox all exist and have high performance, but to compare them it is important to note that the transmission distance for NB-IoT is not affected by land use (rural or urban areas). Moreover NB-IoT is an optimal solution where the devices are located in places that are not easily accessible, eg, basements, and/or are protected in metal containers.

Many case studies show the advantages of these technologies, eg:

- [Pays de Gex – France, 2016] The association of municipalities of Pays de Gex (CCPG) decided to set up a revolutionary smart water management, based on new generation IoT networks, using Sigfox.[1]
- [Waterloo – Canada, 2017] IoT technology using LoRa was applied in a Smart City project in Waterloo Region to test real-time, automated data collection from the region's water supply production and monitoring wells.[2]
- [Rende – Italy, 2018] An experimental service for monitoring potable water was started on residential buildings in Rende. This service, based on new generation meters that carry out and transmit in real-time consumption measures (pressure and flow) through NB-IoT technology anticipates some of the capabilities of future 5G networks.[3]

CONCLUSION

IoT offers many opportunities for innovative application and, through standardized solutions like NB-IoT, will boost many IT services. Smart metering networks in the energy sector allow operators and companies to improve production efficiency and offer customers an enhanced service.

The availability of NB-IoT will enable a new range of services based on future smart objects. The ability to acquire real-time information on hydrodynamic variables in water systems will improve sustainability and efficiency. Current technology for remote measurement and monitoring in water supply systems enables the use of mathematical hydraulic modeling capable of reproducing realistic

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[1] http://www.connit.com/en/iot-smart-water-management-in-pays-de-gex/?lang=en

[2] http://eleven-x.com/eleven-x-and-region-of-waterloo-partner-for-canadas-first-smart-city-water-monitoring-project-utilizing-lorawan-network/

[3] http://www.telecomitalia.com/tit/it/archivio/media/note-stampa/market/2018/NS-TIM-Olivetti-NTT-acque-potabili-11giugno2018.html

operating conditions. The availability of real-time data, with errors that can be measured precisely and from any point in the system (without limitation on the communication system), opens the prospect of management implementation supported by artificial intelligence.

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