Smart Water Measurements: Literature Review

Berhane Gebremedhin
Water-M Project
Center for Wireless Communications (CWC)
Department of Communications Engineering, University of Oulu

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1 Introduction

The rise of the global population and the limited availability of fresh water are key issues of public concern over water availability, water quality, failing water infrastructures, and overall water management complexity. As a result, the market for safe, available water and for the infrastructure and technologies that treat and transport water is expected to grow rapidly as stakeholders look for new solutions and approaches to integrated water resource management. The adoption and integration of ICT to the water sector is one viable solution for a better decision support and improved productivity.

Smart water systems apply ICT to deliver solutions to numerous water-related issues that are currently handled inadequately by inefficient and often manual processes. For example, these systems can remotely and continuously monitor (hydraulic and water quality), report water consumption, and diagnose problems (leakage and burst detections); pre-emptively prioritize and manage maintenance issues, and remotely control and optimize all aspects of the water distribution network using data-driven insights. They can also be used to provide water customers with the information and tools they need to make informed choices about their behaviors and water usage patterns, and to comply transparently and confidently with regulatory and policy requirements on water quality and conservation [1].

1.1 Required technologies

In order to achieve a comprehensive smart water network solution, water systems require measurement and sensing devices (smart meters, sensors, and actuators), real-time communication channels, basic data management software, real-time data analysis and modeling software, and automation and control tools to conduct network management tasks remotely and automatically.

1.2 Challenges

The key challenges to implementing smart water systems are lack of of the following issues [1, 2]: a strong business case (customer propositions/pricing/availability), cooperation between water utilities and/or between other utilities, policy and regulation (privacy / security/encryption), standards and reference architectures (technology and protocols, both national and international), and technology architecture (systems integration/ communication/ event handling).

1.3 Opportunities

Despite many research and development projects carried out in the field of smart water infrastructures and applications [3, 4], the extensive deployment of smart water systems is still immature. Leveraging the sector across different services and stakeholders including utilities and municipalities, policy regulators, investors, industry and utility associations, technology providers and academia may revolutionize the field. On top of that, existing and emerging opportunities which have a big role in facilitating the development of smart water systems are listed below.

- Energy Smart Grids - many of the solutions developed in the Energy Smart Grids could be implemented in Water Smart Grids with minor modifications [5, 6].
- Advances in battery and power storage technologies, and power harvesting mechanisms.
- Constant miniaturization of electrical devices and advances in power electronics.
- Advances of wireless sensor networks (WSNs), communication and sensing technologies, internet, emergence of new wireless communication technologies (e.g. machine-to-machine communication).

In this report, a survey of the state of the art in smart water measurements is presented. The objective is to provide a better understanding of the current research issues in this emerging field. The remainder of this paper is organized as follows. First, the water quality monitoring application is discussed in Section 2. Next, smart water meter reading is discussed in Section 3. Existing communication protocols and algorithms for water measurements are covered in Section 4. Section 5 gives a review of the various power harvesting mechanisms in water smart grids. Finally, Section 6 concludes the paper.

2 Water quality monitoring

Clean drinking water is a critical resource, important for the well-being of all humans. Due to the limited water resources, growing population, ageing infrastructures, increasingly stringent regulations and increased attention towards safeguarding water supplies from contamination, water utilities are looking for better on-line water quality monitoring systems. Water quality monitoring is key to measuring and understanding the chemical and biological quality of water and for taking a reactive remedial action. Traditional water quality control mechanisms are inefficient because of the following drawbacks.

- Lack of real-time water quality information to enable critical decisions for public health protection (long time gaps between sampling and detection of contamination).
- Poor spatiotemporal coverage (small number locations are sampled).

- It is labor intensive and has relatively high costs (labor, operation and equipment).

Therefore, there is a clear need for continuous real-time water quality monitoring with efficient spatio-temporal resolution.

Drinking water quality standards are determined according to World Health Organization (WHO) [7], EU [8], and US Environmental Agency (USEPA) [9] guidelines for drinking-water quality. These organizations set the standards for drinking water quality parameters and indicate which microbiological, chemical and indicator parameters must be monitored and tested regularly in order to protect the health of the consumers and to make sure the water is wholesome and clean. Most water quality monitoring systems are required to be low cost, reliable, continuous, and based on WSNs. Sensor nodes measure predefined qualitative water parameters (temperature, turbidity, conductivity, oxidation-reduction potential, pressure, pH level, chlorine, or dissolved oxygen) and the WSN sends the parameters' measurements through the internet to Remote Control Centers for recording and analysis.

Research related to water quality monitoring applications has increased recently. Continuous monitoring is critical to detect microbiological and chemical contamination events. The state of the art in using sensor networks for water quality monitoring is reviewed below.

A number of multi-parametric sensor arrays have been proposed and developed based on various sensor technologies. A prototype monitoring system to monitor hydraulic and water quality parameters, and water levels using WSN was developed in [10]. This research work provides operational challenges of using WSN as well as hardware and software limitation to manage a large scale water supply system. The system has neither power access nor an energy harvesting mechanism, and thus, the sensors depend on battery operation. Batteries have to be replaced every 60 days. Besides, it lacks water quality anomalies and contamination detection algorithms. In [11], a low-cost WSN that can be used at consumers sites to continuously monitor qualitative water parameters and contamination detection is developed. The paper emphasizes on low-cost, light-weighted implementation, and reliable system operation. The proposed system has contamination detection algorithm and provides spatiotemporally rich data. The limitation of this work is it does not have power saving nor power harvesting mechanisms. Besides, the system is prone to false alarm in the network. A recent review on multi-parametric solid-state sensors for water quality is presented [12]. A chemical water quality monitoring WSN is presented in [13]. The authors designed and developed a reusable, self-configurable, and energy efficient system for real-time monitoring. The system implements an energy efficient routing protocol and a sleeping scheduling mechanism to prolong the network lifetime, and provides a web-based information portal for customers and administrators.

In addition to the research works on WSN for water quality monitoring, there has been efforts to develop software and algorithms for the detection of water quality anomalies and contamination events. The detection of anomalous water quality events has become an increased priority for drinking water systems, both for quality of service and security reasons. Because of the high cost associated with false detections, both missed events and false alarms, algorithms developed for this purpose must be evaluated to understand their capabilities and limitations. In [14], water quality change detection algorithms were developed and their performance studied for different water quality anomalies. Moreover, the authors detailed the steps necessary for evaluating detection tools. A general water contamination event detection method that can be implemented in any water distribution system is given in [15]. The methodology can provide both visual and statistical indications of contamination events. Finally, CANARY software [16] was developed to provide a platform within which different event detection algorithms can be developed and tested. These algorithms process the water quality data at each time step to identify periods of anomalous water quality. It indicates possible contamination events by using a range of mathematical and statistical techniques to identify the cause of anomalous water quality incidents from online raw sensor data, while at the same time, limiting the number of false alarms that occur.

In recent times, the research work in water quality monitoring has been advancing. However, a number of limitations are observed in many of the research works done so far, and among them are:

- High installation and operation costs.
- Lack of hardware (e.g. power management circuits) and software platforms for real-time monitoring.
- Lack of water quality anomalies and contamination event detection software and algorithms.
- Lack of energy harvesting techniques (short network lifetime).

3 Smart water meter reading

Smart water systems use the AMR (Automatic Meter Reading) technology to automatically collect meter measurements and transferring to the central database for billing, troubleshooting, and analyzing. A key element in an AMR system is communications between meters and the utility servers. Several communication technologies have been proposed in the literature for this purpose [17, 18]: RS-232 interface, Infrared, short range radio frequency, internet, cellular e.t.c. Whichever technology is used, the AMR should be capable of providing, but not limited to, reliability, scalability, real-time communication, and security. The next key element of the AMR system is energy efficiency, as the meters are mostly battery powered. Desirably, the lifetime of the batteries should be as along as the maintenance or calibration cycle of the meter, which typically is 8-12 years.

The design of a smart water meter makes a tradeoff between data transmission rate and power efficiency, as continuous transmission is an aggressive power consumer. In general, the meter applies three data transmission modes to send the measurement data: event driven - e.g. for leak detection, water misuse or fraud, demand driven - by polling from data collection center, and scheduled - for regular reporting and considers bandwidth, power and other resources in the design.

AMR gives multiple benefits to customers and utilities [19]: real-time pricing, remote modification of meter functionality, easier to identify customer and system loses, increased revenue from previously unaccounted water, and demand management by providing real-time information about water usage. While giving these benefits, an AMR also experiences many challenges such as low cost meter design which provides a high rate metering while being autonomous, low operation cost, battery lifetime, and lack of standards- many AMR producers design their systems to be interoperable with most existing water meters. Battery lifetime depends on the transmission duration, transmission power, metering rate, and environmental conditions like variation in temperature.

In recent times, several research works on smart water meter reading have been proposed in the literature. It is observed that the AMR system is heavily dependent on WSNs (such as Wi-Fi, Bluetooth, ZigBee) for short-range communications between the meters and the gateways, and on various technologies (such as 2G, 3G, WiMax, satellite) for a backhaul communication between the gateways and data centers. The key issues in choosing an optimal communications technology for an AMR system include cost of deployment, security, regulatory compliance, range, and power consumption [20].

The authors in [21] present an energy autarkic, RF-based water meter with energy aware routing. They claim that the developed meter is cost efficient; integrates an energy harvesting and storing mechanisms and an energy aware routing protocol, which is developed based on the Q mode of wireless M-Bus (WM-Bus) protocol. The meters use WM-Bus protocol to communicate with the gateway, and ethernet is used for the communication between the gateway and the central unit. They also try to show that energy harvesting systems are capable of being applied in real industrial applications. In [22], a design schema of a wireless smart meter reading system is given. In this work, the authors propose a smart water meter which uses ZigBee to communicate with the gateway, and GPRS for the long-range communication. However, they did not provide any experimental or simulation works in the paper. N.S. Islam et al. [23] discuss an SMS based integrated prepaid water metering system. In the system, water is supplied only when the meter is recharged with some balance. When the credit expires water supply is halted. The server also halts water supply whenever there is a security breach. The meters are fitted with GSM modems and thus send remaining credit, water used, and security breach information by SMS to the server. The authors argue that data collection can be done at any time: hourly, daily or monthly. However, they do not discuss about the source of power.

A. Zabasta et al. [24] present a battery-powered AMR system which uses WM-Bus protocol for communication between the sensors and data concentrators, and GSM between the data concentrators and the central server. The developed metering system tries to utilize existing mobile operator networks to expand the water services without major investment. Furthermore, it provides a web-based information portal for customers and administrators. Others like in [25, 26, 27] discuss ZigBee based smart water meter reading systems.

In general, even though there is an effort to develop smart water meters from the academia and industry, there are not many products yet. There are two main reasons for this: one is power consumption and the other is the cost. And the power consumption is an important problem to restrict the mass usage of smart water meters.

4 Communication Protocols

A typical communication architecture for Advanced Metering Infrastructures (AMIs) or AMR in smart water grids is based on a hierarchical topology: sensors nodes/meters are connected to master nodes, acting as gateways, which in turn collect data and send them to a central unit, where data are stored and processed. The gateways send measurement data to the central unit using different wireless technologies. To this aim, gateways are usually powered by the grid, or from solar cells, due to their long-range transmission requirements. On the contrary, the sensors usually located at public, domestic, or industrial sites are battery-powered and capable of performing short or medium range communication at a low power consumption. Therefore, the main requirement of the communication protocol used between the sensors and the nearby gateway is power consumption minimization while ensuring the requested QoS and coverage area. Other protocol selection or design criteria for water measurements, like for AMR, are given below.

1. In AMR, packets carry unique information identifying a specific meter and the exact time of the measurement. Thus, the data from individual devices must reach the gateways while preserving its information; no data aggregation is required.
2. Devices locations are fixed. As such, a protocol that considers the device location is preferred.
3. If a device ceases to operate or malfunctions, immediate investigation and maintenance must take place. In other words, a fault detection protocol that considers the periodic data reporting and static topology characteristics is essential.
4. The protocol should support bidirectional communication to allow for device set-up and reconfiguration at any time.
5. AMR is delay tolerable for some predefined time window, determined by the metering schedule.
6. In some cases, the network size is so big. So, a protocol which is scalable, tolerant to interference, and incurring low delay is preferred.
7. Stringent security (to avoid unauthorized access, tampering with data, denial of service) and high network reliability are very crucial.

Several communication protocols have been proposed and implemented in the literature. An extensive survey of AMR technologies is given in [17]. The authors also discussed the suitability of 3G wireless systems for future AMRs. Jawhar et al. presented in [28] a routing protocol for linear structure WSNs named ROLS for water, oil, or gas pipeline monitoring. The system tries to take advantage of the linear structure to increase the reliability, efficiency and maximize the sensors battery lifetime. In [29], a power efficient data gathering algorithm for water AMRs is proposed. The authors in [30] present an overview of current and emerging technologies for supporting wide-area machine-to-machine (M2M) communications and their challenges. Most of the low power WSN implementations proposed in the literature rely on ZigBee and on WM-Bus standard. Next, among the several communication standards developed for various applications, the ones which are viable for water measurement scenarios are discussed.

4.1 ZigBee/IEEE 802.15.4

ZigBee [31] is a communication standard developed for WSN while adopting the IEEE 802.15.4 standard [32] for its reliable communication. IEEE 802.15.4 and ZigBee are two tightly connected standards, which aim for short range (about 100 m), low complexity, low cost, low power consumption, low data rate, short delay, and bidirectional wireless networks for residential and building automation, and energy monitoring. A ZigBee network has self-organizing and self-healing capabilities, and supports complex network topology and a variety of strong routing protocols. The network not only has good scalability, but also makes reliable data communication between sensors. Its other features include low duty-cycle to enhance long battery life, low latency which is suitable for real-time observation, collision avoidance mechanisms and retransmissions, and multiple channels (16 channels in the 2.4 GHz ISM band, 10 channels in the 915 MHz band, and 1 channel in the 868 MHz band).

ZigBee has been implemented in a wide range of WSN applications in the literature [33, 34, 35, 36]. Because of its good features, it has received big attention as a solution in smart water applications recently. A water quality monitoring system using ZigBee based WNS is presented in [37]. In [38], a web based water quality monitoring WSN that relies on ZigBee and WiMax technologies is proposed. Other research works in this area are also given in [11, 13, 39]. Even though ZigBee is a viable protocol for smart water grids, it is worth noting a number of limitations. Bandwidth is very low (20 kbps at 868 GHz and 250 kbps at 2.4 GHz) [40]. Its short transmission range has an impact on the application area. To cover a large area, large number of concentrators are required, or multiple-hop way of communication must be implemented in each network. But this method is not energy efficient. With the increase of the number of sensors, interference increases dramatically. In such scenarios, its connections and routing paths become unstable and incurs high delay, thus making the technology less reliable and scalable for water AMR.

4.2 IEEE 802.15.4k

Recently, IEEE adopted IEEE Std 802.15.4k [41] as a communication protocol for low energy critical infrastructure monitoring (LECIM). It is an amendment of IEEE 802.15.4 with the aim of providing physical layer (DSSS and FSK) and MAC layer specifications which meet the LECIM requirements [41], and has the following main features:

- Supports professionally installed, thousands of sensor nodes.
- Large coverage area, upto 10 km radius.
- Capable of operating in areas with propagation pathloss of upto 120 dB.
- Low data rate, up to 40 kbps, which is sufficient for water measurement applications.
- Ultra low power consumption.
- Low installation cost.
- Star topology.
- Asymmetric communication link, and
- Priority access (which is useful to transmit urgent messages with high priority).

Looking at some of its features, IEEE 802.15.4k can be a viable communication protocol for water measurement networks which ZigBee networks can not support.

4.3 WI-SUN

WI-SUN [42] is developed based on the IEEE802.15.4g-2012 standard [43] defined to be a communications protocol for Smart Utility and related networks. It is a protocol optimized to support mesh networks, and is used in many Smart Utility Networks: home energy management systems, AMI, demand/response, distribution automation, low power meter reading e.g. gas metering, and in smart cities - e.g. street lighting. However, due to the high data rate and mesh network topology it supports, it is not a suitable protocol for smart water metering.

4.4 Wireless M-Bus

The WM-Bus [44] is a new European standard proposed by the Open Metering System group [45] for remote reading scenarios and recommended for use in smart metering as well as for various sensors and actuators. Wireless meter reading requires communication for small amounts of data with little protocol overhead. WM-Bus transceivers provide low energy operation as the standard supports low overhead protocol, Transmission-only modes, and long sub-GHz transmission bands. The first version of the standard (EN 13757-4:2005) is designed to operate at 868 MHz ISM band, whereas the second version (EN 13757-4:2013) added the 169 MHz band for new Transmission modes. As there are different requirements for different applications, WM-Bus has different communication modes and corresponding data rates in both frequency bands [44]. Depending upon the application, one of a number of communication modes can be selected. The 169 MHz band enables longer transmission range than the 868 MHz one due to the reduced pathloss experienced by the propagating radio signal. Moreover, the lower data rates in the 169 MHz band enable higher sensitivity for the receiver, allowing a reduction of the transmission power at the transmitter, or a longer range at the same transmission power. Compared to ZigBee/IEEE 802.15.4, WM-Bus can achieve longer transmission ranges. This is because WM-Bus uses lower frequency bands than ZigBee, and thus, the lower frequencies enable the RF waves to travel longer distances for a given output power and receiver sensitivity.

Despite the suitability of the WM-Bus characteristics for smart water metering, the research work in this area is at its early stage. Some of the publications in the literature related to WM-Bus for water measurement scenarios are discussed as follows. The authors in [46, **?**, 47] made extensive research on WM-Bus for smart water grids. First, they made performance evaluation of the standard in terms of packet error rate (PER) and maximum transmission range for five communication modes. In their next work, they did an evaluation of energy consumption issues of the standard implemented on HW/SW platform by taking batteries and energy harvested as the power supplies. They verified that the 169 MHz band has a better performance over the 868 MHz band. Finally, the authors developed a prototype demonstrator of a smart water metering infrastructure and confirmed the feasibility of the solution in that application. Other research works made on WM-Bus in the same area are given in [21, 48, 49].

4.5 SigFox

SigFox [50] is a cellular style system that enables remote devices to connect using ultra narrow band (UNB) technology, mainly developed for low throughput M2M / Internet of Things (IoT) applications. It is set up to provide low power, low data rate, and low cost communications where wide area coverage is required and which until recently was served using the ill-suited cellular connections. SigFox is a wireless connectivity optimized for low-bandwidth applications. The use of UNB is key to providing a scalable, high-capacity network, with very low energy consumption (very low transmitter power levels), while still being able to maintain a robust data connection. SigFox operates in the globally available ISM bands (868 MHz in Europe and 902 MHz in the USA) and co-exists in these frequencies with other radio technologies, but without any risk of collisions or capacity problems. The density of the cells in the SigFox network is based on an average range of about 30-50 km in rural areas and in urban areas where there are usually more obstructions and noise is greater the range may be reduced to 3-10 km. The range can even extend up to 1000 km for line-of-sight outdoor devices.

SigFox network has the following characteristics.

- Up to 140 messages per object per day, payload size for each message is 12 bytes, and wireless throughput up to 100 bits per second.
- Supports unidirectional (allows extremely low power consumption) and bi-directional communication.
- Uses very simple and easy to rollout star-based cell infrastructure.
- Provides highly reliable and secured communication.
- Supports large network capacity - up to a million devices, the network is easily scalable to handle more devices by augmenting the density of base stations.

In a typical SigFox network, the devices are fitted with certified SigFox compatible modems to enable them communicate with SigFox transceivers (base stations). To minimize energy consumption, the network is used only when the device needs to transmit a payload. The exact power consumption over time obviously depends on how many messages are sent and how often. To illustrate this, a smart energy meter that transmits 3 messages a day using a 2.5 Ah battery can last up to 20 years, which is a few months if the traditional cellular network is used.

Its application area includes smart metering, healthcare, automotive management, remote monitoring and control, retail including point of sale, shelf updating, etc, and security. So, looking at its features, SigFox is a good wireless connectivity for water measurement applications.

4.6 LoRa

LoRa [51] is another cellular style wireless system developed to enable low data rate, ultra low power and long-range communications for M2M and IoT applications. It is similar to SigFox in many ways except that LoRa is optimized for wideband CDMA implementation [52]. While using the ISM bands (868 MHz for Europe, 915 MHz for North America, and 433 MHz for Asia), the technology applies new specifications and a protocol to support long-range, optimal battery life, and minimal infrastructure requirement, which results in improved mobility, security, bi-directionality, and lower costs. LoRa uses a star-of-stars topology in which gateways are transparent bridge relaying messages between end-devices and a central network server in the backend. Gateways are connected to the network server via wired or wireless connections while end-devices use single-hop wireless communication to one or many gateways. The communication between different end-devices and gateways utilises several different data rates. To maximize both battery life of the end-devices and overall network capacity, the network server manages the data rate and RF output for each end-device individually by means of an adaptive data rate scheme. Moreover, LoRa supports various classes of end-devices to address the energy requirements of various applications: bi-directional end-devices (for minimal energy consumption), bi-directional end-devices with scheduled receive slots, and bi-directional end-devices with maximal receive slots.

LoRa technology has the following salient characteristics.

- Long range: 15 - 20 km, in favorable environments, and more than 2 km in dense urban environments.
- Data rates range from 0.3 kbps to 50 kbps.
- Supports millions of devices.
- Long battery life: in excess of 10 years.
- provides secured (using AES128 keys) and reliable data communication.

LoRa networks can be applied in smart metering, inventory tracking, vending machines, automotive industry, utility applications ... in fact anywhere where data measurement and control may be needed. And compared to SigFox, LoRa standard supports higher data rates and deploys more base stations.

4.7 LTE-M

LTE-M represents LTE for M2M communications. Currently, M2M/IoT applications are supported using cellular networks such as GSM, cdma1x, and UMTS. With the widespread introduction of LTE, many M2M/IoT applications are migrating to LTE for greater security, longevity, ease of deployment, efficiency, speed, and reliability. However, most M2M applications do not need the higher bandwidth of 4G/LTE as data rates of a few hundreds kbps could meet their needs. LTE is a complex system capable of carrying high data rates. To successfully support massive M2M deployment, the key requirements for LTE are: wide service spectrum, support of large network capacity, low cost devices, long battery life, large coverage, easy deployment, interoperability, and support for last-gasp scenario. Besides, since a number of M2M networks like LoRa and SigFoX are being deployed, LTE needs its own M2M capability to ensure that it is able to compete with these growing standards. Otherwise LTE may not be suitable for carrying this form of low data rates from M2M devices. LTE-M is the cellular operators' answer to this, an optimized LTE for M2M/IoT communications [53].

The evolution of LTE to LTE-M began in 3GPP Rel-12, where low cost M2M devices (Cat-0) were specified. In Rel-12, low cost M2M devices with reduced capability were introduced. The cost of the modem for this device is approximately 40-50% of regular LTE devices. These low cost devices are restricted for M2M services, and have reduced capabilities such as one receive antenna and slower speed Max. 1 Mbps UL/DL data channel. In addition, coverage enhancement techniques, which would be required to support M2M in LTE, will be standardized in Rel-13. Some of the proposed features in Rel-13 are reduced bandwidth to 1.4 MHz for uplink and downlink, reduced transmit power to 20 dBm, and reduced support for downlink transmission modes. With the completion of LTE-M in 2017, the standard will offer long battery life (up to 5 years for AA batteries), low cost devices, enhanced coverage by 20 dB etc.

By making LTE-M compatible with LTE, it is possible to use the same hardware and share a spectrum without coexistence issues as shown in Fig.1. In addition, LTE-M can simply plug into the LTE core network. This allows all network services such as authentication, security, policy, tracking, and charging to be fully supported.

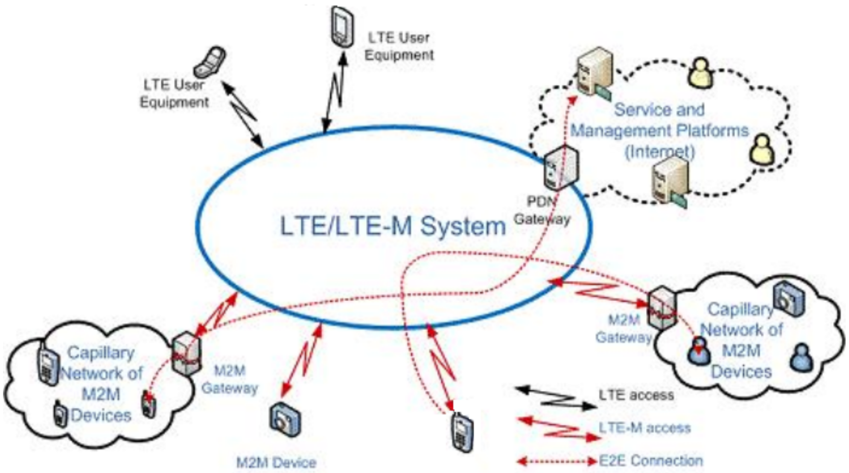

Figure 1: LTE and LTE-M networks sharing the same resources [54].

LTE-M is likely to evolve beyond Rel-13 (bandwidth will be reduced to 200 KHz) to enhance local mesh networking, very low cost devices ($5), very long battery life (up to 10 years), and low data rates with two-way (including duplex) communication. For M2M communication, a narrowband system has certain advantages as presented in [55]: low cost device, coverage improvement, and efficient use of spectrum as a smaller bandwidth is needed.

Typical LTE-M applications include utility metering, vending machines, automotive applications, medical metering and alerting, and security alerting and reporting.

5 Power harvesting in water measurements

Unlike in smart grids, the sensors or devices in water grid applications enable measurements in harsh or isolated environments, such as under extreme heat, cold, humidity, or corrosive conditions, and cannot be easily wired to the electrical power grid. So, a big issue remains somehow troublesome in these applications, i.e, how to ensure power supply for operating the sensors and sensor networks for sensing, processing, and communication. The power supply and power management strategy affects the number or position of sensors, the maintenance costs, the transmission technology and range, the type of application (low power requirements limit the transmission rate, information acquisition rate and data throughput), and possibly their interoperability.

The current wireless sensor networks rely on batteries to supply the required energy for their operation. However, batteries have their own drawbacks: they have short lifetime, contain hazardous chemicals, and need replacement regularly which is uneconomical and unmanageable in hard access environments. Besides, their limited power capacity does not support continuous water measurements as it is an aggressive power consumer. Implementing energy saving communication algorithms, energy efficient routing protocols, MAC schemes, and special operating systems are some of the solutions proposed to extend battery lifetime. But still these solutions do not support autonomous WSN water measurements as battery replacement is not avoided, which causes a lot of errors and data missing.

A simple but effective way to power sensors in the water grid is by means of energy harvesting. The harvested energy enhances autonomous and continuous monitoring applications using sensor networks. Powering sensor networks in water grids encompasses energy harvesting from the surrounding environment, energy management and storage, and implementation of energy saving communication mechanisms. These energy saving methods include long sleep times, energy efficient MAC schemes and routing protocols, and energy harvested amount based mode of data transmission (smart usage of the stored energy to optimize the execution of certain tasks) [56].

Several energy harvesting techniques have been proposed in the literature. solar [57], mechanical [58], thermal and radio waves.

- Solar - Solar power is a promising alternative used to power WSN, but this option is not feasible as it is not abundantly available in all water measurement scenarios.
- Mechanical - kinetic energy harvested from vibrations of objects is used to generate electric power using piezoelectric or electromagnetic mechanism. Also, mechanical energy obtained from turbine wheel rotation in fluids is used to generate electric power. The energy generated from turbine wheel rotation is proportional to the flow of the fluid.
- Thermal - temperature difference applied over two junctions of a conducting material generates electric power through the Seebeck effect. The Peltier Cell is a common material which is used to convert thermal energy into electrical energy.
- Radio waves - RF energy harvesting is becoming a viable source of energy by converting radio waves into AC power. In this case, energy can be harvested from different wireless energy sources such as from intentional remote power transmitters, or from TV and mobile base stations.

Hoffmann et al [59] developed a low-cost radial-flux energy harvester based on a flow-driven impeller wheel in domestic pipelines. The energy harvester is used to power a smart metering system buried underground. The authors are able to generate an output power of 15 mW at 5 l/min flow rate to 720 mW at 20 l/min flow rate. The limitation of this work is when the flow rate is below 5 l/min, the output power is very low. Besides, power management and storage mechanisms are not discussed.

Mohamed et al [56] discuss the application of WSNs for continuous monitoring water distributions systems, necessary power harvesting solutions, and energy management algorithms which help to optimize the system performance based on the energy harvested. Moreover, the authors outline the main design challenges of energy harvesting for continuous monitoring using WSNs as follows.

- Potential resources for power harvest - choosing an appropriate one between available resources and techniques according to how much power will be generated, feasibility to integrate in sensor node and deploy within the water pipelines.
- Estimating the generated power from flow induced vibration is not easy.
- Communication - determining a suitable transmission medium, power budget of transceivers, and the type of communication protocol used.

- Power Storage - choosing an efficient storage to store the power during inactive period. Rechargeable batteries have hazard problems in the pipelines.
- Integration - integrating different parts such as communication, processing, sensing, power harvesting along with power management algorithm is needed to optimize the performance of the sensor node in water distribution networks.

6 Conclusion

In this report, the current research on smart water systems (smart water measurements) is reviewed. More specifically, the report presents and evaluates previous proposals published in the areas of water quality monitoring, smart water metering, power harvesting, and communication protocols. Furthermore, the potential benefits and current development stages of smart water systems and the critical challenges they are experiencing are discussed.

Smart water systems are expected to be very useful solutions with a potential to offer a wide range of benefits to utilities and their stackholders through remotely and continuously monitoring and diagnosing problems and remotely controlling and optimizing all aspects of the water distribution network using data-driven insights. These systems are critical to dealing with the water challenges of today and in the future, and ICT has a lot to do with it. Therefore, it is possible to conclude that the vision of safe and clean drinking water for all can be realized only through the implementation of smart water systems.

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