New Perspectives for Smart Water Network monitoring, partitioning and protection with innovative On-line Measuring Sensors

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ABSTRACT

Cities are increasingly becoming a focal point for economies and societies at large, particularly because of on-going urbanisation and the trend towards increasingly knowledge-intensive economies. Cities need to change and develop, but this change needs to be achieved in a smart way, making cities "smart cities". Information & Communication Technologies (ICT) present new opportunities for Smart WAter Networks (SWAN) as a key asset for Smart Cities. The Ctrl+SWAN (Cloud Technologies & ReaL time monitoring+Smart WAter Network) Action Group (AG) was created within the European Innovation Partnership on Water, in order to promote innovation in the water sector by advancing existing solutions. The integration of smart meters and biosensors with cloud computing and innovative software allows the development of new network management schemes. A more effective *monitoring* in terms of quantity and quality variables makes *partitioning* of large water networks possible, thus improving customer service, quality of maintenance and *protection* from accidental or intentional contamination. The vision of the AG consists of treating the water network not as a traditional system with devices trivially added, but as a SWAN featuring new applications that result in optimal management and protection. After providing the state of the art on the best technologies already available on the market, new perspectives for SWAN monitoring, partitioning and protection with innovative sensors are proposed. Each AG partner describes methodologies, best practices, novel devices and possible integrations among meters, biosensors, models and optimization algorithms.

Keywords: Smart Water Networks, Online monitoring, Smart sensors, Partitioning, Protection, Control, Sensor network

1. INTRODUCTION

The recent development of Information and Communication Technologies (ICT) and the availability at low cost of new monitoring and management devices, for on-line monitoring and control of many water quantitative (e.g. flow, pressure, level, etc.) and quality parameters (e.g. chlorine, PH, etc.), has contributed to generating the notion of Smart City, recently recognized in the scientific and technical international community (Chourabi et al. 2012; Washburn et al. 2010). The use of these remote-controlled devices allows accelerating the alignment of Water Distribution System (WDS) to other network utilities such as electricity, gas, Internet, etc. Information & Communication Technologies (ICT) present new opportunities for Smart WAter Networks (SWAN) as a key asset for Smart Cities (Di Nardo et al., 2013a; Laspidou, 2014; Savic et al., 2014). Recently, in the framework of European Innovation Partnership (EIP) on water, an Action Group (AG), titled Ctrl+SWAN (Cloud Technologies & ReaL time monitoring+Smart WAter Network) was created – which includes universities, research centres, water utilities, start-ups and big companies – in order to promote innovation in the water sector by advancing existing solutions. Ctrl+SWAN addresses major European and global water challenges through the implementation of smart solutions into SWANs. The integration of smart meters and biosensors with cloud computing and innovative software allows the development of new network management schemes. Partitioning of large water networks, made possible by the use of smart meters and sensors, allows for a more effective monitoring in terms of quantity and quality variables, thus improving customer service, quality of maintenance and protection from contamination. In the vision of the AG, the water network is treated not as a traditional system with devices trivially added, but as a SWAN featuring new applications that result in optimal management and protection. The use of innovative (or smart) sensors with on-line monitoring can improve significantly the protection of drinking water system both in terms of accidental and intentional contamination that, after 11 September 2001, represents one of the mayor risks for human health, as reported in many national and international guidance manuals and documents (HSPDs 2002; CER 2005; US EPA 2003; USEPA 2005a, b; USEPA 2009; FPTCDW 2008). Smart sensors for online real time water quality monitoring, as reported in Lee et al. (2012), represent the first component for an Early Warning System (EWS) that allows a water utility to quickly identify any potential problem and apply remedial measures to protect the user. Thus, an effective EWS is an integrated system for deploying the monitoring technology (monitor or sensor devices), analyzing and interpreting the results, and utilizing the results to make decisions that protect public health while minimizing unnecessary concern and inconvenience (Lee et al., 2012). The Action Group CTRL+SWAN is focused not only on the importance of developing and disseminating the use of novel sensors for measuring in real time both usual and new parameters, but also to develop new methodologies, software and best practices starting from the use of massive quantitative and qualitative data provided by a diversified array of sensors. In this way, it is possible to improve significantly the SWAN management (reducing water losses, improving the maintenance, etc.) and protection (implementing EWSs capable of providing warning and safety actions on the network in order to reduce negative impact due to accidental or intentional contamination).

An interesting classification of online water quality monitoring system was provided by Lee et al. (2012) in which the authors proposed a list of parameters, measured by Real-Time monitoring sensors (without the use of chemical reagent) available on the market. In this paper, with the help of AG companies, members of the AG and European leaders of water quality meters, and with the help of SENSUS Italia company, European leader of water quantity meters, a revision of this classification is provided, indicating also which On-line Monitoring Sensors (OMS) based on the use of chemical reagents are already available on the market. Indeed OMS can already be used for the development of EWSs, thus improving water network management and protection. With reference to this last case, some AG members are researching and developing innovative devices, based on different techniques (such as Quartz-Crystal Microbalance, laser, luminescent bacteria, bio-based electrodes, etc.), synthetically described in the paper.

After a description of innovative sensors, the second part of the paper is dedicated to some novel methodologies and procedures that, starting from the implementation of ICT technologies (smart sensors, EWS, remote control, etc.), allow treating traditional water networks as SWANs, improving both management and protection practices. Specifically, the possibility of inserting remote control valves and flow meters in a SWAN allows the implementation of the paradigm of "divide and conquer", which consists into dividing a large water network into *k* smaller subsystems, in order to simplify and improve the management of a water supply system (Di Nardo et al., 2013a; Water Authorities Association and Water Research Centre 1985; AWWA 2003). Indeed, the partitioning of the network into hydraulically independent subsystems or districts, called District Meter Areas (DMAs), can significantly help the operators in water loss detection and pressure management (Wrc/WSA/WCA 1994; AWWA 2003; Di Nardo et al, 2014a) and for safety (Grayman et al. 2009; Di Nardo et al. 2014b) of Water Distribution System (WDS). With reference to this last topic, some AG members developed and experimented an approach that embeds contaminant transport modelling in the overall monitoring scenario, by including also the natural system from which water is exploited. This concept is aimed at further optimization of the sensor network and supports the maximisation of results from the distributed sensors. So, the second part of the paper describes synthetically some recent and innovative methodologies, algorithms and software that allow obtaining the best partitioning and protection of a SWAN. Then, some AG partners (water utilities, startups, national regulatory agencies, etc.) are testing some methodologies, technologies and best practices on pilot sites. Finally, some of the proposed devices, technologies and infrastructures can be implemented also in other water resources management fields (sea, river, etc.), different from WDS.

2. ON-LINE MEASURING SENSORS (OMS)

With reference to the On-line Measuring Sensors (OMS) available on the market, a review of the state of the art by Lee et al. (2012) is partially reproduced in Table 1. The original table defined three levels of the importance for water quality parameters, following three criteria to ensure that all monitoring devices could potentially be used in an efficient manner for online water quality monitoring (Lee et al., 2012). The levels of the importance were Low, Medium and High on the base of: (i) the practicality of the parameters for online monitoring, i.e., if online equipment is readily available or not, if the parameter has broad applications or not, if a reagent is needed or not, etc.; (ii) the parameter indications, e.g., if the parameter can interfere with a treatment process or is a toxic or a poisonous substance such as cyanides, or is a cause of health problems such as nitrates, for example (Lee et al., 2012). Moreover, the three criteria adopted to choose the sensors and to fill the tables were the following: 1) all sensors must detect/measure the water quality indicators without the use of chemical reagents; 2) the device must have online and remote capabilities (telemetry). 3) the device must be the most recent and up-to-date version (Lee et al., 2012). Starting from such classification, with the help of companies belonging to the Action Group, a revision is proposed in Table 1, by adding those parameters requiring the use of chemical reagents, which are characterized by a short response time and consequently permitting on-line measurements, although not fully in real time. The authors believe this choice is crucial, because some automatic commercial devices based on chemical reagents are now reliable and perfectly integrated with telemetry systems. In this way it is possible to monitor water quality and re-design many purposes to improve SWAN management and protection.

Specifically, the arrangement of Table 1 is fundamentally the same as the one proposed by Lee et al. (2012), but revised by parameters for which novel on-line sensors are now available (bold characters), or do exist reliable sensors that use chemical reagents (bold characters in brackets); both classes of devices have been shifted to the third row, based on the knowledge of Action Group members. Furthermore, the parameters for which the members of AG group are carrying out research aimed at filling the gap between the demand and the market are highlighted in italics with a star appended. Further details about marked parameters are provided in next sections.

Table 1 – List of parameters for on-line measurement (revision of the classification of Lee et al., 2012)

Availability on the market	**Importance of online measurement of a Water Quality parameter**		
	LOW	MEDIUM	HIGH
No online sensors available	Aldehydes, antimony, barium, beryllium, brominated DBP, *cadmium**, chlorate, chlorite, dichloramine, Drug metabolites, formaldehyde, glyphosate, haloacetic acids, heterotrophic plate counts (HPC) bacteria, hydrocarbons, malathion, mercury, molybdenum, parasites, *bacteria** and viruses, *pesticides**, phosphate inhibitors, selenium, silver, taste and odour, trihalomethanes, vanadium	*E. coli**, *total coliform**	-
Can be indirectly estimated using available online sensors	Assimilable organic carbon (AOC), ozone, radioactivity, stability, total suspended solids, uranium	*Lead**	-
Online sensors available	Algal pigments, (**arsenic), (boron),** (**chemical oxygen demand),** chloramine, chlorine, (**cobalt**), (**corrosion inhibitors**), dioxide, **(dissolved organic carbon)**, flow, fluorescence, (**hydrogen sulphide),** level sensors, (**manganese)**, multi-angle light scattering, multi- spectrum absorption, (**nickel), (nitrogen organic),** (**orthophosphate), (phosphate),** pressure**, (potassium), (silicon**), **(silicate), (sodium)**, streaming current, total chlorine, **total dissolved solids**, (**toxicity), ultraviolet 254 nm absorption (SAC 254), volatile organic carbon**	**(Alkalinity), (aluminium),** (**calcium),** (**chromium 6+), (copper), fluoride,** (**hardness), (iron), (magnesium),** (**nickel),** (**nitrite),** particle count, (**phosphorus), (sulphate)** temperature, total residual chlorine**, (zinc)**	Ammonia, (**chloride),** colour**,** conductivity**,** dissolved oxygen, free residual chlorine**, (nitrate),** oxidation reduction potential, pH, turbidity, (**total cyanide), (total organic carbon)**

It is worth to highlight that Table 1 arranged as in Lee et al. (2012) includes a wide range of parameters not all closely essential to monitor drinking water characteristics. Anyway, some of them are more useful to other water assets and so it was preferred not to change the original arrangement of Table 1 of Lee et al. (2012) to facilitate the comparison.

3. INNOVATIVE TECHNOLOGIES, INFRASTRACTURES AND APPLICATIONS FOR OMS

In this section, a report on new perspectives and opportunities for the real time monitoring of water is presented, with reference to products, research and best practices developed, used and proposed by the AG members in their mission as water utilities, research centres, manufacturing lines, etc. It is worth to mention that the choice of the contaminants that the research groups are studying will be steered by the companies involved in Ctrl+SWAN, in order to facilitate the transfer to the market of the research and development activities.

3.1 Water network monitoring with innovative OMS

As mentioned in the Introduction, the availability of new sensors allows envisioning of new perspectives for improving water network management and protection. Nevertheless, as reported in Table 1, some parameters can already be measured in real time without chemical reagent but others can be already measured on-line with the use of chemical reagent. Specifically, some AG members are committed in the development of smart devices aimed at measuring online many parameters by means of innovative techniques.

The research activity, aimed at the development of innovative sensors, is carried out by considering essentially four types of transducers: piezoelectric, optical, microwave and electrochemical. All of them aim at being smart sensors to be placed in water distribution networks for a fast and online detection of an enlarged set of microbiological and/or physical-chemical parameters in order to monitor and to assess water quality. In the rest of this section, the main research contributions of each partner regarding OMS are synthetically described highlighting the innovative methodologies.

The piezoelectric sensors are based on the Quartz-Crystal Microbalance (QCM) produced by Novaetech srl and functionalized at the Department of Physics of the University of Naples “Federico II”. These two AG partners are applying a novel antibody immobilization technique, Photonic Immobilization Technique, PIT, (Della Ventura et al., 2011) to the gold surfaces of a Quartz Crystal Microbalances (QCMs), thus achieving an immunosensor with the high sensitivity typical of QCM coupled to the intrinsic specificity warranted by the antibodies. The resulting device has been optimized for the fluidic circuit thus achieving a “miniaturized” QCM (see Figure 1(a)) with positive effects on stability and robustness. In Figure 1(b) the typical output for a single measurement is illustrated, from which it is evident that only few minutes are required to achieve the response from the device, whereas Figure 1(c) reports a dose-response curve for Parathion from which a limit of detection (LOD) of approximately 60 nM (nano Molari) can be deduced (Funari, 2013). Several other light analytes have been tested (see e.g. Funari et al. (2015) for the patulin) showing that the LOD is always in the range 10-100 nM (approximately few micrograms/kg for these molecules). Leveraging on these promising results and given the ample range of contaminants detectable with such a method, the research is now aiming at the detection of bacteria in water.

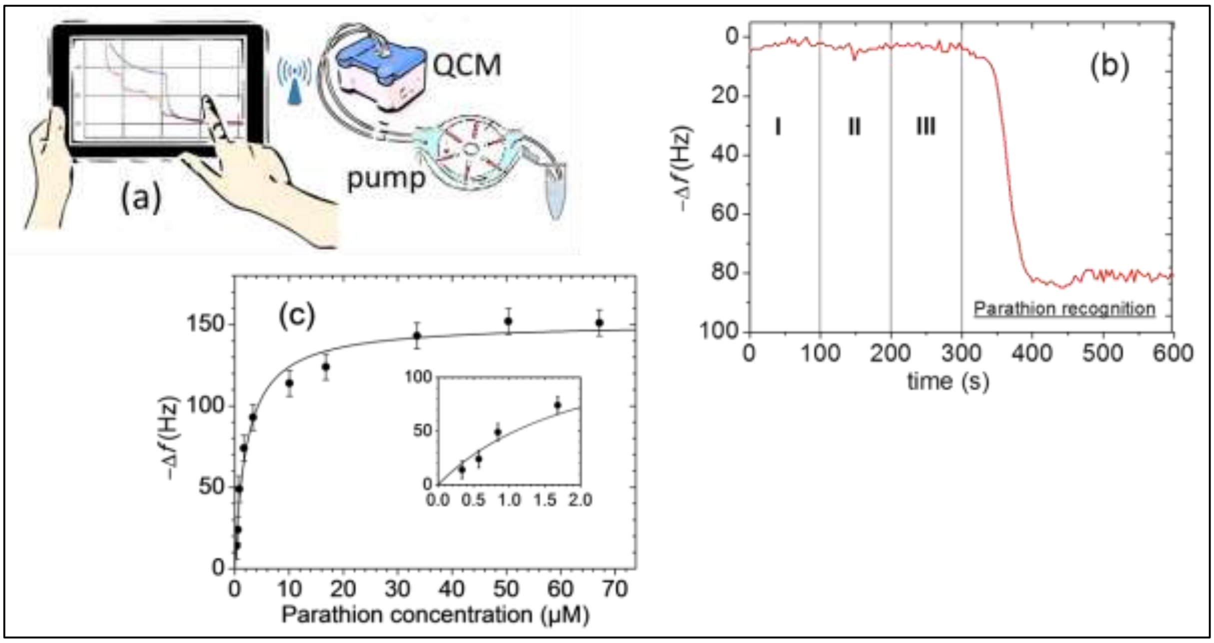

Figure 1 Quartz-Crystal Microbalance (QCM). (a) QCM realized by Novaetech srl connected to the liquid to analyze by a pump. The output can be read in remote. (b) Typical immunosensor output: I – washing with PBS (1X) solution; II, Bovine Serum Albumine to check that all the gold is well covered by antibodies; III, washing with PBS (1X) solution. The stability of the frequency is a demonstration that the electrode is fully covered with antibodies well tethered to the surface. After the steps I-III a solution with 1.7 □M of Parathion is conveyed to the QCM and a change of approximately 80 Hz is observed. The whole measurement takes about 5 minutes. (c) Dose- response curve of the immunosensor showing that a limit of detection of approximately 60 nM is achievable with such immunosensor.

The Institute of Information Science and Technologies of National Research Council of Italy (CNR-ISTI) is conducting a research activity focused on the experimentation of nanofiber materials, based on electrochemical techniques. The experimental setup is essentially based on a potentiostat able to detect metal pollution in water. This activity is finalised to the experimentation of electrochemical sensors consisting in electrospun nanofibers made of polianiline, as well as other conductive polymers. Such works are still in progress and currently to be considered as a new concept at the sensor level, still needing further research and development.

The activity of Institute of Electromagnetic Sensing of the Environment of National Research Council of Italy (CNR -IREA) is being carried out along two main lines. The first one concerns the development of sensors based on an optofluidic jet waveguide, which represent a state of art technological solution for water analysis and monitoring. This sensor exploits the electromagnetic phenomenon of the total internal reflection occurring in a water jet stream with the aim of delivering signals opportunely excited towards a detector. The water jet acts, at the same time, as the solution flow to be analysed and as the collecting optical waveguide. This extremely promising approach has demonstrated to avoid the typical drawback coming from the fluorescence arising from solid walls, which are necessary to contain the solution to analyse (Persichetti et al., 2012). In fact, the wave-guiding effect of a water stream enables high enhancement of the detected signal. For this reason, this approach can be profitably used for the development of non-specific and high sensitive sensors based on fluorescence detection or for high selectivity sensors based on Raman spectroscopy. Both these spectroscopic techniques have been investigated during this first year of activity. Fluorescence and Raman spectroscopic sensors based on jet waveguide do not require any sample pre-treatment. This makes them particularly useful for the field measurements and in early warning systems providing continuous monitoring. In particular, optical sources emitting in the in the ultraviolet region have been considered in the design of a fluorescence based sensor; this choice has been performed since many organic pollutants exhibit auto-fluorescence (as for instance hydrocarbons) if suitably irradiated at those wavelengths (Persichetti et al., 2013).The use of different excitation sources as lasers and LEDs has been investigated, by considering also the trade-off between a low-cost final device and the possibility to obtain a suitable detected signal. The same perspective has been also employed in order to determine a suitable detector for the fluorescence signal. For the design of a specific sensor based on Raman scattering, different excitation approaches have been considered. In order to exploit the maximum excitation volume, a probe consisting of two side-by-side optical fibers has been designed; for this strategy, one fiber is used to deliver laser excitation in the liquid and the other collects the Raman signal. The minimization of the mismatching between the jet diameter and the collection optical fiber size has been achieved by an excitation configuration, where a single optical fiber, with diameter close to the jet diameter size, provides for Raman signal collection, whereas an excitation laser source orthogonally excites the liquid stream under analysis. The schematic of the spectroscopic Raman sensor based on a water jet waveguide is depicted in Figure 2. The first results show the possibility to detect pollutants at level around 100 mg/l: as an example, nitrate has been measured with a limit of detection of 80 mg/l with fiber excitation/collection approach.

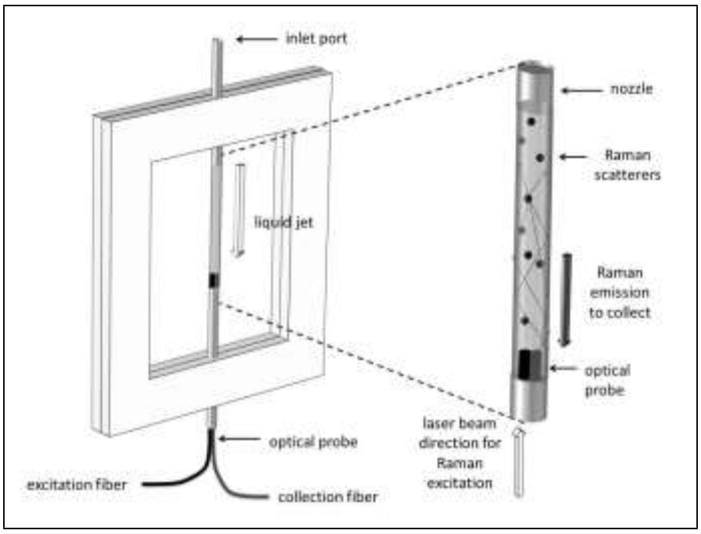

Figure 2. Schematic of the sensor for Raman spectroscopy based on a liquid jet waveguide. The optical probe, aligned with the liquid jet, is used to excite and detect the Raman signal.

The other main research line at IREA-CNR concerns feasibility study on the possible application of a sensor working at microwaves for real-time and on-line water pollution monitoring. In particular, a sensor has been designed and realized, based on a rectangular electromagnetic (EM) resonator tuned at about 1.91 GHz when the cavity is empty. The sensing principle relies on the change of the electromagnetic cavity response occurring when the EM properties of the water solution under test, i.e., dielectric permittivity and conductivity, change for the presence of impurities. The working principle of the sensor has been tested by designing and constructing a microwave sensor prototype for concentration measurement of liquid solutions, which has been characterized by means of a vectorial network analyzer (VNA) (G. Gennarelli, et al., 2013). During this first year of activity, the technological solution has been engineered and optimized, by realizing a portable measurement system suitable for on-field deployment and capable to perform real-time monitoring; this portable system enables a low-cost solution compared to those based on a standard VNA. The scheme of the portable system is depicted in Figure 3.

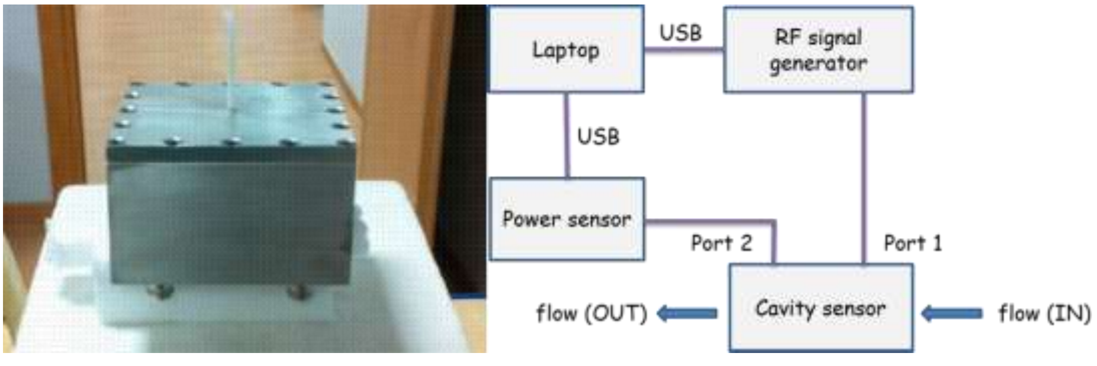

Figure 3. (a) Photo of the cavity-based sensor. (b) Block diagram of the portable measurement system.

SYSTEA SpA is mainly focused on the application of discrete technology for the early warning and on-line monitoring of drinking water networks. Specifically, SYSTEA SpA is developing a device, named Easychem TOX on-line, that is an original direct-reading robotic multi-parametric analyzer, for fully automated toxicity measurements of water samples using live cultures of luminescent bacteria, combined with the quantitative measurement of chemical parameters applying standard spectrophotometric/fluorimetric methods. The analyser can reliably be used as an early warning water quality monitoring system to safeguard the drinking water networks from accidental or intentional contamination, protect the biological treatment in wastewater plants from irreversible noxious effects of toxic influents, monitor urban and industrial effluents, and keep under control natural water bodies. By the use of suitable isotonic buffer, toxicity measurements can be performed as sample duplicates and always compared to reference blank measurements. The use of a set of vials of freeze-dried bacteria that are mechanically opened and rehydrated allows long unattended times. The kinetic luminescence decrease is measured every 40 seconds and the result consistency is confirmed by programmable quality analysis of positive control solutions at known concentrations.

The analyser can also measure several chemical parameters including Nitrates, Nitrites, Ammonia, Orthophosphates, Silicates, Alkalinity, Chromium 6+, Copper and other metals. Additional automated methods like Volatile Phenols, Total Cyanides, Total Nitrogen and Total Phosphorus can be executed using external sample treatment devices. The analyser is managed as an autonomous water quality monitoring system by dedicated software running on touch screen panel PC, allowing the integration of third party sensors, water samplers and flow meters, featuring a remote control capability and data delivery to the Web.

Moreover, Systea has recently developed a specific application to measure Arsenic in drinking water at µg/L levels by a very sensitive spectrophotometric method running with SYSTEA's exclusive Loop Flow Analysis (LFA) technology; full method selectivity is ensured by an original arsine-stripping protocol. The result of this development is the Micromac C Arsenic that is also suitable to be combined with the Easychem TOX on-line for the detection of low concentration of Arsenic in drinking water. Among several already in use all over the world, a Micromac C Arsenic unit is currently installed by an Arsenic-removal plant managed by ACEA ATO-2 water utility and located in Velletri (RM). In addition, an on-line automated analyzer manufactured by Systea for the measurement of Free and Total Cyanide based on Batch Continuous Flow Analysis technology was recently the subject of a Bachelor Thesis in Applied Chemistry, at the Università degli Studi of Roma Tor Vergata. An original in-line distillation technique followed by a well-tested spectrophotometric method compatible with forthcoming integration within the Easychem TOX on-line allowed to detect ppb levels of cyanides.

Edgelab srl research in AG are developing electrochemical modified sensors able to detect different pollutants as fecal coliform, concentration level of pesticides, elements of the nitrogen cycle in water (ammonium, nitrites and nitrates), which are particularly diffused in intensively cultivated areas, and are one of the most diffused reason of urban water pollution. It is important to note that each parameter needs a different electrode modification. To analyse phosphate, a cobalt-based sensor is used. Song et al. (2014) have realized a fully integrated cobalt (Co) electrode, which is a layer of carbon conductive ink (C) physically doped with Co powder, and Ag/AgCl reference electrode. While the products of nitrogen will be analysed from Edgelab using electrodes with graphite ink modified with specific enzymes which are attached to the sensor through the use of a insulating ink, UV polymerizable (Albanese et al., 2010).

Promete srl recently started a specific task devoted to the design and development of bio-based electrodes, i.e. electrodes based on electro-conductive polymers, showing autonomous electrochemical behaviour to build solid body probes able to detect Pb (lead) and Cd (cadmium) in ionic or metallic form, in water or pre-treated water samples, with a detection sensitivity of 0.1 ppm/liter. The electrodes will be composed of a copolymers synthetized by radical polymerization method. Promete is now working on the first phase of the R&D program that will be constituted by the investigation of relevant factors influencing copolymer synthetization in order to find the optimal monomer ratio, the concentration, the polymerization temperature and the initiator concentration. Further activities will also encompass the electronic system for signals elaborations, in order to obtain proper results in terms of both qualitative and quantitative presence of the metals in the sample.

The Centre for Water Systems, at the University of Exeter, has been working on the use of smart water and energy meters in households and utility networks for monitoring water use, improving water efficiency and promoting behavioural changes in consumers. Currently they are leading iWIDGET (Savic et al, 2014), an ongoing FP7 EU funded research project (2012-2015), aiming to advance knowledge and understanding about smart metering technologies in order to develop novel, robust, practical and cost-effective methodologies and tools to manage urban water demand in households across Europe. The main scientific challenges for iWIDGET are the management and extraction of useful information from vast amounts of high-resolution consumption data, the development of customised intervention and awareness campaigns to influence behavioural change, and the integration of iWIDGET concepts into a set of decision-support tools (‘widgets’) for water utilities and consumers, applicable in differing local conditions, in three case studies in the UK, Portugal and Greece. iWIDGET is one of ten EU-FP7 similar and complementary research “sister” projects funded in parallel under the theme “ICT and Water Management”, forming the *ict4water.eu* cluster (http://ict4water.eu). All research, investigate and promote market solutions for *ICT and water efficiency*, a key EU policy issue with potential for new research area that includes decision supporting system for the measurement of water quality and quantity including the recycling and water reuse processes. This necessitates increased interoperability between water information systems at EU and national levels and efficiency of water resources management. Thus, one of the main activities of the ict4water.eu cluster is the development of standards and standardisation for smart water technology, lead by iWIDGET.

Summarizing, in the following Table 2, a synthetic description of a list of parameters targeted by AG members that are working for on-line measurement available on the market or by way of advanced research or development, is reported.

Table 2 – List of parameters measured with innovative on-line sensors targeted by AG members.

On-line measured parameters	AG member	Methods/Techniques	Research	Development	On market
Pesticide	Novaetech srl, Department of Physics of the University of Naples	Quartz-Crystal Microbalance with antibodies		X	
Bacteria	Novaetech srl, Department of Physics of the University of Naples	Quartz-Crystal Microbalance with antibodies	X		
Alkalinity, ammonia, chlorine dioxide, chloride, chloramine, corrosion inhibitors, dissolved oxygen, hardness, hydrocarbons, fluoride, nitrate, nitrite, orthophosphates, ozone, phosphate, sodium, silicate, sulphide, total suspended solids, total organic carbon, total/free residual chlorine, total cyanide, turbidity, ultraviolet 254 nm absorption	HACH LANGE	Amperometric, digital, optical probes, ion-selective electrode (ISE) technology, photometric analyzers, UV absorption, electro chemical sensors, radical advanced oxidation, light scattering analytics,			X
Alkalinity, aluminium, ammonia, arsenic, chromium 6+, copper, fluoride, hardness, iron, manganese, nitrate, nitrite, orthophosphates, silicates, volatile phenols, total cyanides, total nitrogen, total phosphorus	SYSTEA SpA	Applying standard spectro-photometric methods, with the use of liquid reagents			X
Acute toxicity	SYSTEA SpA	Luminescent bacteria, combined with the quantitative measurement of chemical parameters applying standard spectrophotometric/fluorimetric methods		X	
Lead, cadmium, mercury	SYSTEA SpA	Fluorimetric methods using specific organic liquid reagents		X	
Heavy metals	ISTI-CNR	Nanofiber materials, based on electrochemical techniques.	X		
Hydrocarbons, nitrates, organic compounds, phosphates	IREA-CNR	Optofluidic jet waveguide	X		
Ammonia, chlorides, nitrates	IREA-CNR	Microwave resonator	X		
Ammonium, E. coli, heavy metals, nitrites and nitrates, phosphate, total coliform	Edgelab srl	Electrochemical	X		
Cadmium, Lead	Promete srl	Bio-based electrodes	X		

3.2 Water network partitioning and sectorization

The use of real time monitoring devices, such as flow and pressure meters and automatic gate valves, allows to implement the paradigm of “divide and conquer” in WDS, defining DMAs that significantly simplify the water network management, water loss detection, pressure management, maintenance planning, sectorization, etc. (Di Nardo et al., 2013a). This approach, which can be extended also to other water networks and not only to drinking water, is crucial to transform the traditional management of a water distribution network into a modern and proactive management.

Network partitioning and sectorization is very difficult because the choice of the pipes to be closed with gate valves is usually based on empirical suggestions (number of properties, length of pipes, etc.) and on approaches such as ‘trial and error’, even if used together with hydraulic simulation software. These approaches are hardly applicable to large water supply networks (Di Nardo et al., 2013a) without a significant alteration of the hydraulic performance of the system due to the reduction of topologic (network loops) and energetic (diameter sections) redundancy (Mays, 2000; Di Nardo et al., 2013a). Only recently, some optimization procedures that allow overcoming the empirical approaches and identifying the optimal Water Network Partitioning (WNP), in compliance with the required level of the service for the users, have been proposed. Such procedures are based on different approaches: spectral clustering (Herrera et al., 2010); graph theory (Sharma and Swamee, 2005; Tzatchkov et al., 2006; Gomes et al., 2012; Alvisi and Franchini, 2013; Di Nardo et al., 2013a), multi-agent (Izquierdo et al., 2011, Di Nardo et al., 2014a); and community detection (Diao et al., 2013). Some members of AG CTRL+SWAN, specifically DICDEA, DII, PROMETE and IMTA, are working on optimization procedures, based on a graph partitioning approach, hydraulic simulation and heuristic optimization criteria that allow to define the partitioning of a large water network comparing the performance of different layouts by means of hydraulic indices (Di Nardo et al., 2013a). In particular, recently, DICDEA and PROMETE have developed, in Python v2.7.6 language, a software, named SWANP (Smart Water Network Partitioning) (Di Nardo et al., 2014c) that allows to automatically define the best partitioning and sectorization of a WDS. The SWANP software, based on graph partitioning algorithms (Karypis and Kumar, 1998), an energetic approach and performance indices (Di Nardo et al., 2013a) provides the operators and the water utilities with an effective tool to obtain different water network partitioning layouts. The software is arranged as a Decision Support System, as it allows comparing different layouts using several performance indices. The software, tested on real case studies, allows finding automatically the best results minimizing the number of flow meters in compliance with the required level of service of the water network. In Figure 4, the Graphical User Interface of SWANP is illustrated. The first release of the software is currently being improved by implementing other partitioning algorithms and a GIS (Geographic Information System) interface.

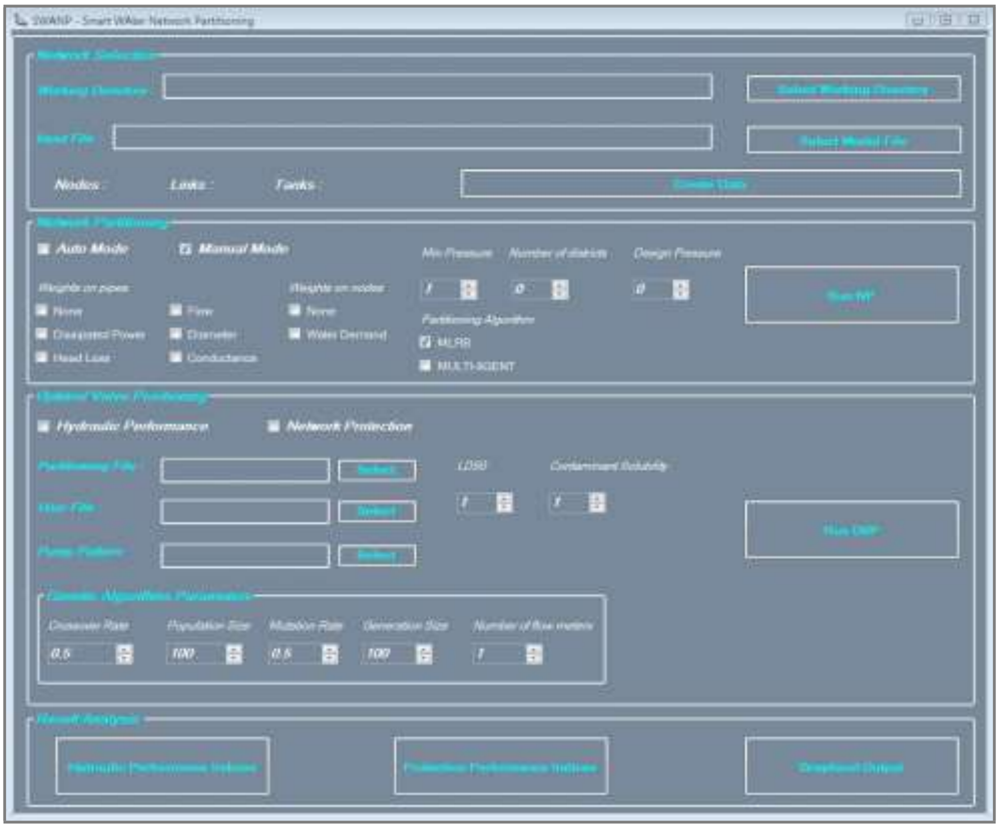

Figure 4. SWANP 2.0 software GUI

3.3 Water network protection

Some AG members are working on techniques aimed at protecting water network systems from accidental and/or intentional contamination. Specifically, as anticipated in the Introduction, if innovative sensors allow to measure in real time some quality parameters and an effective EWS is implemented, it is possible to activate safety actions for the users. Recently, starting from previous works (Grayman at al., 2009; Di Nardo et al., 2014b) that investigated the possibility of reducing the negative effects of contamination through the implementation of water network partitioning and sectorization, DICDEA, PROMETE srl and IMTA proposed a novel methodology to protect drinking water networks.

The possibility of implementing the paradigm of “divide and conquer” and, consequently designing districts and sectors, reduces the number of affected people, because several points of contaminant introduction would be needed to produce a wide negative impact on a sectorized network. Recently, in Di Nardo et al., (2014b), a possible terroristic backflow attack with cyanide in a small test case, was studied analysing the advantages of the sector isolation designed also for network protection and not only for network management. Indeed, the design of the water network partitioning is essentially based only on limiting the reduction of the negative effects on the hydraulic performance of the network, caused by the insertion of the gate valves needed to define districts and sectors (Di Nardo et al., 2013a), but not on the minimization of the negative effects of a possible contamination. In this study a novel methodology is proposed that allows to optimize the design of water network partitioning both for compliance of hydraulic performance and for water protection. The methodology, based on heuristic optimization techniques (graph partitioning and genetic algorithms) that minimize a constrained multi objective function, has been implemented in a new release of SWANP 2.0, in which an advanced tool to define an optimal partitioning, aimed also to protect the network from an intentional contamination based on a backflow attack model (Di Nardo et al., 2014b), and a new network partitioning algorithm were added. The methodology respects the criteria of *dual-use value* (Kroll and King 2010; Di Nardo et al., 2014b), because the Water Network Partitioning (WNP) and Water Network Sectorization (WNS), in addition to protecting the network from contamination, are defined for other aims (e.g., water balance, pressure management) to optimize costs. In other words, the first goal (and thus the "main-use value") for any WNP (Water Authorities Association and Water Research Centre, 1985; Water Industry Research Ltd, 1999; AWWA, 2003) consists of the following: a) the identification and reduction of water loss; b) the management of pressure; c) the improvement of speed and quality of leak repairs; d) the planning of maintenance; e) the prediction and control of water quality; and f) the measurement of water demand. The secondary goal (or the "dual-use value") consists of providing water protection from accidental or intentional contamination (Di Nardo et al., 2014b). This methodology has been applied to both the cases of a network equipped and not equipped with an EWS; in this last case the warning for the contamination is given some hours after the backflow attack. The methodology showed good results in terms of reduction of exposed users in both cases. Obviously, the availability of innovative sensors able to measure in real time a wide range of parameters and the implementation of EWS can improve the safety actions by reducing the response time. Another essential aspect for improving water network protection consists in developing effective (in terms of time response, parameter range, etc.) transport models, which can help EWS and safety actions. With reference to this topic, the joint activity of the AG members from the Institute of Geosciences and Earth Resources (CNR-IGG) and CNR-ISTI consists in the study of the physical/chemical processes implied with the exploitation of water bodies for human consumption, which is seen as an essential tool for the optimisation of the monitoring infrastructure.

The work focuses on groundwater resources, due to their increasing importance in the context of human consumption (Zhu and Balke, 2008; Martínez et al., 2008; Hiscock, 2010; Baoxiang and Fanhai, 2010; Siebert et al., 2010). According to the proposed approach, the physical and data-driven modelling of transport phenomena in groundwater can help optimising the sensor network and validating the acquired data. In particular, the combined usage of physical and data-driven modelling can provide a support to the design and maximisation of results from a network of distributed sensors. The validation of physico-chemical measurements and the detection of eventual anomalies by a set of continuous measurements take benefit from the knowledge of the domain from which water is abstracted, and its expected characteristics. The application of change-detection techniques based on non-specific sensors (Scozzari et al., 2007; Di Natale et al., 2014) may take benefit from this general concept. In this context, the definition of "anomaly" in terms of distance from an expected value or feature characterising the quality of water implies the definition of a suitable metric and the knowledge of the physical and chemical peculiarities of the natural domain from which water is exploited. In this particular context, CNR-IGG and CNR-ISTI are carrying on a joint activity with IbnTofail (a Moroccan University member of the AG) about the production of synthetic scenarios and the experimentation of a mixed approach (physical/data-driven) to the flow and transport modeling, including the co-tutorship of a dedicated PhD. A proof of concept of the proposed practice has been experimented in the context of the Italian national project "Acquasense" (funding mechanism Industria 2015). The project consisted in the development of a monitoring infrastructure based on a combination of non-specific sensors, aimed at the surveillance of water quality for a drinkable water network.

3.4 Innovative infrastructures for online monitoring systems

The University of Thessaly and UTH are developing two buoy nodes that can be used to host any sensors/biosensors for in-situ monitoring of quality parameters in marine environments. The overall architecture of the deployment is divided in 2 tiers, the shore-side and the sea-side components. Two buoy nodes floating on the sea surface are used to host sensors and to transmit their measurements to the shore-side components, which are used to control and manage the sea-side deployed buoys, as well as to provide remote access to the entire system. The overall architecture of the deployment is illustrated in Figure 5. The shore-side components consist of several devices such as a server machine, an Ethernet switch and the Access Points (APs). The server machine runs all the required services for managing the APs and the buoy nodes while it also provides access to remote users (through the existing Internet connection) for the visualization of the data. The APs are connected to the server machine through the Ethernet switch and provide wireless backbone connection to the buoy nodes. The sea-side components are the buoy nodes deployed in the sea surface dedicated to host the sensors. The buoy nodes are built on the Raspberry Pi B+ board (http://www.raspberrypi.org/), which is characterized by sufficient power processing capabilities (ARM processor at 700MHz with 512MB RAM) and low power consumption. Raspberry board runs the Raspbian Operating System, which is a Linux distribution optimized for the Raspberry Pi hardware.

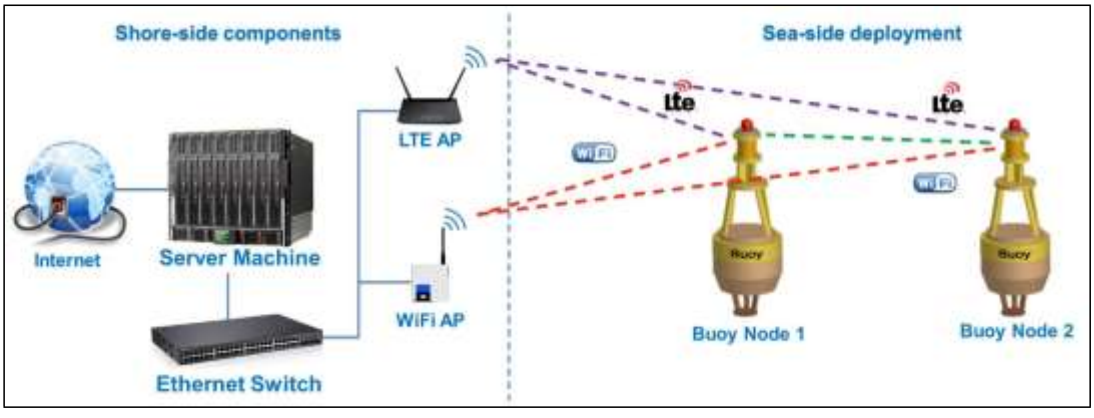

Figure 5. UTH's Deployment Architecture

Moreover, it features 4 USB ports for attaching external USB dongles and also several GPIO pins and communication ports (SPI, UART, I2C). In our implementation, Raspberry is equipped with a WiFi and an LTE dongle to communicate with the shore-side components and a GPS module that provides the coordinates of the buoy. The buoy nodes are autonomous regarding energy, as they harvest energy through their solar panel and exploit a power management circuit that charges the internal battery when possible. The architecture of the buoy nodes along with the nodes before and after deployment are all illustrated in Figure 6.

Figure 6. NITOS Buoy node architecture, nodes before deployment and buoy nodes deployed.

Also EdgeLab AG member is working on an innovative infrastructure for online monitoring systems and, in particular, on a sensorial node to work on a remote sensor module used for environmental monitoring (analysis on the field, in springs, lakes and hard to reach sites) hosting them on board of buoys or AUVs (Autonomous Underwater Vehicles) capable of performing established surveys.

4. CONCLUSIONS

The activities of the Ctrl+SWAN AG are focused on research and development of innovative real time sensors and analysing the new possibilities offered by the implementation of OMS in water resources both in terms of improvement of management and user safety. The effort of some companies and research centres are dedicated to enlarge the list of parameters that can be monitored with on-line sensors, developing robust smart devices with sustainable costs for water utilities. Some of these AG members are ready to put on the market their innovative devices. Then, some other partners are developing methodologies, algorithms, software and best practices to optimize the use of these smart sensors thereby significantly improving the management and the protection, and transforming the traditional water distribution system in a modern SWAN, improving water efficiency and developing customised interventions for influencing consumer water use through smart water and energy meters. The AG members are developing these techniques in compliance with the criteria of dual use value, in order to facilitate the implementation optimizing the costs and accelerate the alignment of SWANs to other network assets (as electricity, gas, Internet, etc.). Finally, some AG partners (Costrame srl, MARES Costruzioni srl, IMTA, etc.) are experimenting methodologies, technologies and best practices on pilot sites.

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