An Integrated Web Portal for Water Quality Monitoring through Wireless Sensor Networks

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ABSTRACT

Wireless sensor networks (WSNs) are aiding water quality monitoring with support for real-time and remote quality measurements in terrain. Environmental monitoring portals receiving data from sensors have been a practice since a while among researchers. However, the Web portal introduced here is essentially an integrated portal since it supports modeling and management of both, the observational stream data on water quality coming from wireless sensors – dynamic data, as well as of the data describing the WSN itself, its devices and the corresponding site allocation data – static data. Access is given to a wide range of individuals, from water experts to WSN engineers, to general public. Experts' module infers statistics about water parameters given the experts' data and rules. The portal is further distinguished for its level of scalability: it allows adding with ease new components, like add certain new regulatory documents for water quality, and directly compare data measured by sensors with corresponding quality standards. The aim is to enrich the portal with semantics in future.

***Keywords**: Web Portal, Wireless Sensor Networks, Water Quality, Statistical Data, Water Expert Rules*

INTRODUCTION

According to a United Nations report (UN, 2012), around 120 million people in Europe had no access to safe drinking water in 2012. This alarming figure, made the international community react, by making clear that an extra care will be given to the water distribution, its quality and also quantity monitoring. That care would be facilitated by securing an automatic system for the quality monitoring (Zennaro et al. 2009).

Quality of water is determined through tests which are based on physical, chemical and biological characteristics (Bartram & Ballance, 1996). Throughout time, scientists have measured water temperature, its mineral contents and number of bacteria, which then were compared towards numerical standards and guidelines to determine if water is suitable for usage. Those standards and guidelines are created in order to classify water, whether it can be used for drinking, recreation or even for agricultural purposes. Some of the basic parameters commonly measured are temperature, pH, dissolved oxygen, and turbidity. In most of the developing countries, those measurements are done manually. That incurs considerable delays in the monitoring process, which could fairly be reduced if the monitoring in real-time would have been implemented, at least for some basic parameters, and thus giving an early warning for the necessary measures to be taken (Alkandari, 2011).

Latest technologies, such as wireless sensors (Sohraby, Minoli & Znati, 2007; Garcia et al, 2012), can be used to ensure a constant monitoring of surface water quality. A wireless sensor network (WSN) is composed of compact-size, relatively inexpensive sensor nodes known as motes (Deshpande et al, 2004) which may sense the environment where they are deployed, and also of a base station which gathers sent data from motes for local or in distance processing (Zennaro et al. 2009; Sohraby, Minoli & Znati, 2007; Jiang et al. 2009). With the latest achievements of the micro-electro-mechanical systems (MEMS) technology, sensors are becoming even smaller and versatile (Warneke & Pister, 2002). Tiny sensors support rapid and massive deployment with promising future and involvement in different new fields. WSNs were proposed and are being developed for a variety of environmental applications, but they usage in water quality is still considered a new discipline (Porter et al., 2005). The rationale in favor of WSN technology vs. traditional water sampling has further been elaborated by authors. They conclude with a motivation sentence to interdisciplinary teams towards exploring the implementation of WSNs in different ecological disciplines they showcased via a number of existing example deployments.

In this paper, we propose an integrated Web portal for modeling and management of both, the observational data on water quality coming from wireless sensors, as well as of data describing the WSN itself, its devices and the corresponding site allocation data. Access is given to a wide range of individuals, from water experts to WSN engineers, to general public. Experts may infer statistics about water parameters, or classify water bodies using the intelligent module of the portal.

The paper is organized as follows: Section 2 provides a discussion on related work regarding portals in support of water quality monitoring though wireless sensor networks. Section 3 is an overview of the portal. Section 4 represents data modeling in the portal including modeling of observational data, WSN-related data and experts' data, as well as expert's rules evaluated by the portal. The portal's interface with its four modules each for access by water experts, WSN engineers, wide public, and an administrator is presented in Section 5. Some peculiarities of the portal's implementation are presented in Section 6. Finally, Section 6 concludes the paper and reveals some of the future perspectives of the portal.

RELATED WORK

Wireless Sensor Networks represent an active scientific research field due to their importance in development of many applications, including environmental monitoring, healthcare, traffic control, military network systems (Khedo, Perseedoss & Mungur, 2010), and precision agriculture (Baggio, 2005). Moreover, environmental monitoring portals receiving data from sensors have also been a practice since a while among researchers.

Portal SemantEco is an environmental portal which uses a semantic technology-based approach to emerging monitoring systems based on linked data approach (Wang et al., 2012). Its focus is on water quality and air quality by using ontologies: high level monitoring ontologies and mid-level domain ontologies. Pollution is detected by integrating data from different sources and other regulation ontologies, not only restricting to federal but also state guidelines. The general SemantEco approach, featuring facet generation, query answering and validation, is used to describe the implementation which has been built out substantially in the water domain creating the SemantAqua portal, and highlight some of the potential impacts for the future of semantically-enabled monitoring systems (Wang et al., 2011).

In another paper related to SemantEco portal (Patton et al, 2014), it is stated that "the aim is to inform the development of decision support tools for resource managers who need to examine large complex ecosystems and make recommendations in the face of many tradeoffs and conflicting drivers". They follow semantic approach with the usage of ontologies and linked open data. New architecture to SemantEco is added in order to support modular extensions and make it easier to support additional domains, including wildlife observation and wildlife health impact and examination of the effects of pollution on ecosystems (Patton et al, 2014).

Another research project that dealt with real-time water quality monitoring and data visualization is DEPLOY (Regan, 2011). It demonstrates a technology project which aims to investigate how state of the art technology can be implemented for cost effective, continuous, real-time monitoring of a river catchment, while presenting sensor network capability in collecting real-time water quality data using state of the art water quality monitoring systems and deployment infrastructure required to meet the demands of the European Water Framework Directive legislation (Lawlor, 2012). A group of researchers in Ireland, in the framework of a project, have developed a web portal for bathing water quality - Smart Coasts[1]. It is the national bathing water information website to find out information about the 135 identified bathing waters around Ireland. Throughout the bathing season, one can find out the latest bathing water monitoring results and water quality status, and check out if there are any current bathing water warnings or notifications.

The Susquehanna River Basin Commission (SRBC) initiated the establishment of the Remote Water Quality Monitoring Network (RWQMN)[2] in January 2010. This monitoring network continuously measures and reports water quality conditions of smaller rivers and streams located in northern tier Pennsylvania and southern tier New York. Therefore, any changes or the existing quality conditions of the water can be tracked by the agency officials in real time and continuously.

Finally, in another on-going work within our InWaterSense project[3], an SSN-based (Compton et al. 2012) ontology framework for water quality monitoring based on data originated from WSNs or manually collected water samples, is developed to enable the InWaterSense, an intelligent wireless sensor network for surface water quality monitoring (Ahmedi, 2013). The ontology can be paired with SWRL rules to infer new knowledge, and by using Water Framework Directive or any other local or international regulation ontology coupled with SWRL rules may be employed to reasoning over sensor data in order to classify water bodies and eventually identify sources of pollution. The InWaterSense ontology is only one building block of the overall InWaterSense system which we aim to provide to water experts and wide public interested in water quality, including the portal introduced in this paper (Ahmedi, 2013). An expert system capable to infer new implicit knowledge using rule-based system over the InWaterSense ontology and its water quality instances provided by sensors is further developed and presented in (Jajaga, 2015).

THE PORTAL AT A GLANCE

In this paper, a Web portal in support of water quality monitoring in real-time is introduced. It essentially is an *integrated* portal since it supports modeling and management of both, the observational stream data coming from wireless sensors – dynamic data, as well as of the data describing wireless sensor network itself, its devices and the corresponding site allocation data – static data. Moreover, the portal is distinguished for its level of *scalability*: it allows adding with ease new components/functionalities, e.g., add certain new international regulatory documents for water quality, like are WFD (Water Framework Directive), EPA (Environmental Protection Agency), or other, and directly compare through the portal the data measured by sensors with the quality stand-

[1] http://www.smartcoasts.eu
[2] http://mdw.srbc.net/remotewaterquality/
[3] http://inwatersense.uni-pr.edu/

ard values as defined by those corresponding regulations.

In Figure 1, the architecture of the web portal is depicted. It mainly consists of the *Data and Rules* component (the left-hand side panel) residing at the backend of the portal, and the interface component (the panel in the middle) at the frontend of the portal which then extends to the **Visualization** module for external use of the portal.

The so-called **Data and Rules** component covers modeling of the observational data, WSN-related data, as well as modeling of expert data and evaluation of expert rules (the corresponding modules in Figure 1). *Observational Data* include data streams delivered by sensors, i.e., values obtained through measurements by wireless sensors of arbitrary water quality parameters monitored, like temperature, electrical conductivity, pH, dissolved oxygen (DO), turbidity, biochemical oxygen demand (BOD), etc., as well as timestamps and geographical coordinates of measurements conducted – all of them dynamic data. *WSN-related Data* include static data describing the wireless sensor network in the field, its configuration which might involve node types, like sensing nodes, gateway nodes, central monitoring node, and description of sensors as devices, as well as data about the deployment sites, like sensors' location, the river basins, municipalities the rivers belong to, etc. *Experts Data and Rules* include data through which the water quality is classified, like water regulators, water status definitions, as well as expert rules in form of statistical formulas for calculating different advanced water quality measures which indicate the wealth of waters.

Depending on user privileges set up by the administrator of the portal, users may have access to the portal through distinct modules of the **Interface**: the Administration Module, System View, Public View or Experts' View of the portal. The *Administration Module* serves to add/modify/remove components or modules within the portal. Experts, be it water experts interested in different statistical data inferred through the measurements, or engineers interested in the functionality of the wireless sensor network at any arbitrary level of granularity of devices in the system, are given access through the *Experts View* or *System View* of the portal respectively. Finally, the *Public View* of the portal provides wide access to general public, i.e., an end user may access the portal, its public module, without acquiring any user privileges (logging in) mediated by the administration module of the portal.

DATA MODELLING AND RULES

In the following, a detailed discussion on how data are modeled and the rules evaluated as supported by the Data and Rules component of the portal, its *Observational Data*, *WSN-related Data*, as well as *Experts' Data and Rules* modules is provided.

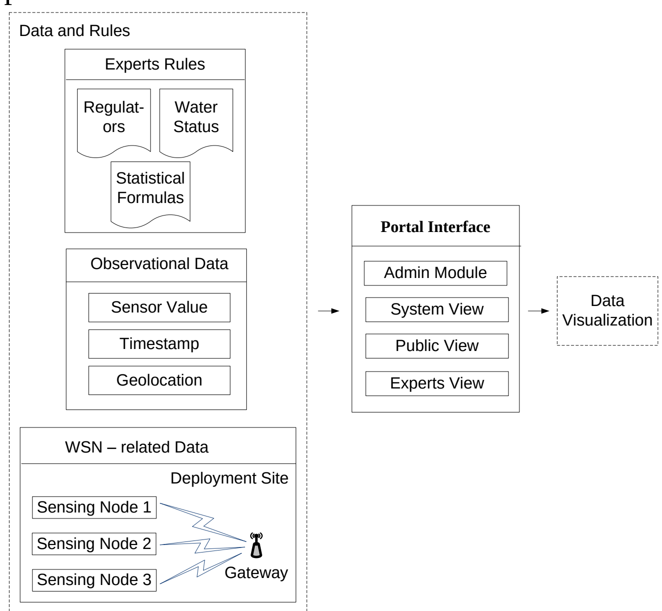

Figure 1. Web portal architecture

WSN-related Data

A wireless sensor network is an infrastructure consisting of the measuring, calculation and communication units, which give administrators the ability to survey and react in cases of different phenomenon in a specific environment. Usually the administrator is a civil entity, governmental, commercial or industrial body. Environment can be physical world, biological system or a frame of information technology (IT). Systems of network sensors are seen as an important technology which will have a wide usage in following years in a big number of applications (Dargie & Poellabauer, 2010; Kenchannavar, Math & Kulkarni, 2013). According to (Yick, Mukherjee & Ghosal, 2008; Srivastava, 2010), WSN applications can be classified into two categories: monitoring and tracking. Monitoring applications include indoor/outdoor environmental monitoring, health and wellness monitoring, power monitoring, inventory location monitoring, factory and process automation, and seismic and structural monitoring. Tracking applications include tracking objects, animals, humans, and vehicles.

Sensor networks applied for environmental monitoring as in our case for water quality monitoring usually consist of four basic components (Sohraby, Minoli & Znati, 2007):

- A number of sensors distributed or localized.
- A connected network (usually, but not always, based on wireless network).
- A central point of collecting information.
- A set of calculating sources in central point for treating correlation (reciprocal connection) of data, trends of cases, status of the questionnaires and data mining.

In our portal, we currently assume and support modeling a water quality monitoring WSN system as suggested in (Jiang et al. 2009), consisting of the following types of nodes:

- Central monitoring node.
- Gateway node.
- Sensing nodes (wireless sensors / mobile sensors).

These nodes and how they are related to each other in a typical wireless sensor network, as currently assumed for our portal, are presented in Figure 2. Sensors are in charge of measuring certain water parameters (e.g. the water temperature) and send measured values to the sensing nodes which then are in charge to further transmit measured values to the central monitoring node by using a gateway node. As illustrated in Figure 2, modeling the mobile sensing nodes is also supported by the portal which, as their name implies, have no static location and hence send measured values directly to the central monitoring node, i.e., not intermediated by a gateway node.

Figure 3 shows the relational schema diagram of the data related to the WSN and its deployment as provided in the following:

- Data about *sensing nodes* (i.e., name, description, geographical position, node status as either active or passive), *sensing node types* as either wireless sensor, or mobile sensor) including *gateway nodes* and *central monitoring nodes*.

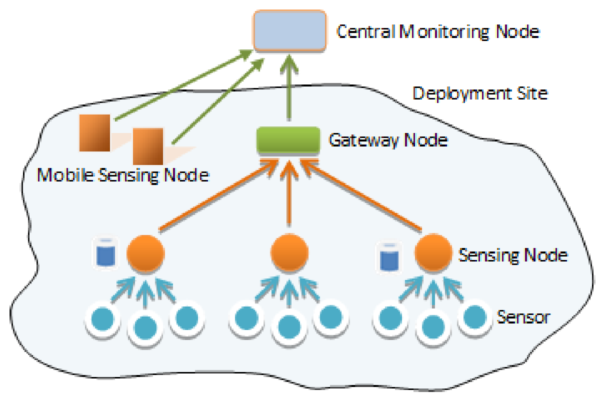

Figure 2. Nodes of different types connected in a network

- Data about *devices* (i.e., name, description, serial number, producer, device type like sensor, cable, actuator, etc.).
- Data describing *rivers* under monitoring and their *basins*, *deployment sites*, as well as the *municipalities* the given rivers pass through.

The portal may further be customized by enabling certain reactions in response to certain data values registered through this module. For instance, the portal has currently the ability to automatically register all sensing nodes which are out of function (the passive status for those nodes). These nodes will visually be represented in the portal as nonfunctional, and also trigger a notification email addressed to the administrator of the portal to inform him/her in real-time for nodes which are out of function.

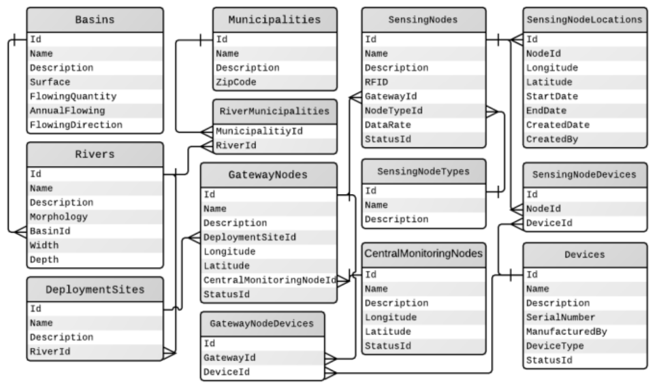

Figure 3. WSN data model

Observational Data

The portal may receive stream data, referred to as observational data, from wireless sensors measuring water parameters such as temperature, electrical conductivity, pH, dissolved oxygen (DO), turbidity, oxygen biochemical demands, ammonium, sulphates, nitrogen, phosphorus, pressure, active chlorine, etc. Modeling observational and measurement data has also been a concern of the International Organization for Standardization as ISO 19156 (Cox, 2011), but for a broader scope. Data received by sensors are represented in corresponding numerical formats, e.g., in °C such as 16.5°C when measuring the temperature, and may be configured to get refreshed every certain time interval, for example every 20 minutes. This time interval may of course be adjusted in the portal to meet the needs of the system or personnel.

The schema diagram of the observational data in the portal is presented in Figure 4. It covers modeling of the following data:

- *Parameter* data consisting of parameter name (such as temperature, electrical conductivity, pH, dissolved oxygen (DO), turbidity, oxygen biochemical demands, ammonium, sulphates, nitrogen, phosphorus, pressure, active chlore, etc.), parameter unit (°C, %, µS/cm, mg/l, mgO2/l, NTU, etc.), parameter value – measured value that is sent by the WSN, timestamp – time when the measured value has been sent, as well as geo location – geographical position from where the sensor has sent data.
- *Parameter types* may take values out of the following set: hydromorphological, physico-chemical, biological, specific synthetic, and specific non synthetic.
- *Sub-parameter types* on the other side may takes values such as: hydrological regime, river continuity, morphological conditions, thermal conditions, oxygenation conditions, salinity, acidification status, nutrient conditions, invertebrate fauna, etc.

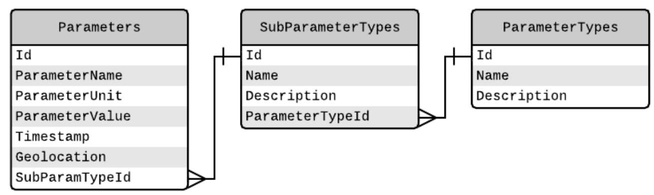

Figure 4. Observational data model

Experts' Data

For classification in real-time of waters depending on their observed parameter values, whatever standard water regulation is appropriate may be integrated into the portal. Modeling of experts' data which cover water quality standard regulations and water statuses, their relational schema, is shown in Figure 5, and includes:

- *Regulation* data consisting of (among others) the regulation name, the parameter it applies to, the from and to values according to that regulation for that parameter, and the water status for that range of values, etc. Among the *regulation type* instances actually incorporated into the portal are the WFD (Water Framework Directive) regulation, and the EPA (Environmental Protection Agency) regulation. More regulations may be integrated into the portal as deemed necessary by experts in a given usage scenario.
- *Water status* data with allowed values as high, good, moderate, poor, bad, or fail. A water is assigned a certain status based on its observed value for a given parameter and the

(fromValue, toValue) range of values within the regulation data for that same parameter that observed value belongs to. The *water status types* data, on the other side, might take values such as the ecological status, chemical status, etc.

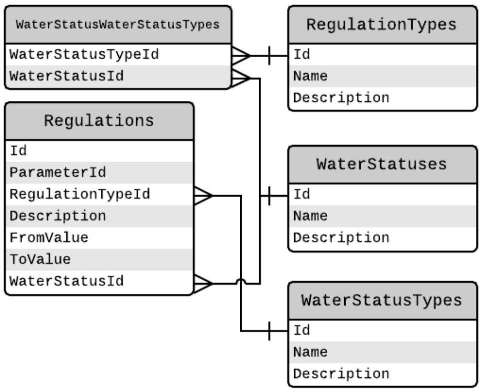

Figure 5. Experts' data model

For the needs of experts of the waters domain, it is very important to generate reports and different statistical data, such as mean, median, percentile, and standard deviation metrics supported by the portal, which are reviewed below.

To calculate the arithmetic mean of a set of the sensor data for a given parameter, the measured values (x) under consideration must first be summed up and then divided by the number of measurements performed (n).

The median value of a set of the sensor data for a given parameter is the middle value of the ordered data. That is, the data must be put in numerical order first.

Percentile of value (x) is calculated by the ratio of the number of values below (x) to the total number of values. The percentile formula is defined as:

$$percentile = \frac{number\ of\ values\ below\ (x)}{total\ number\ of\ values} * 100$$

The standard deviation gives a measure of how far the data tends to be from the mean value. The standard deviation is calculated using the following formula ($\bar{x}$ is the notation used for the mean of a set of data):

$$standard\ deviation = \sqrt{\frac{\sum(x-\bar{x})^2}{n}}$$

THE INTERFACE

As presented in Figure 6, the interface of the portal provides four access modules: admin module, system view, public view, and experts view.

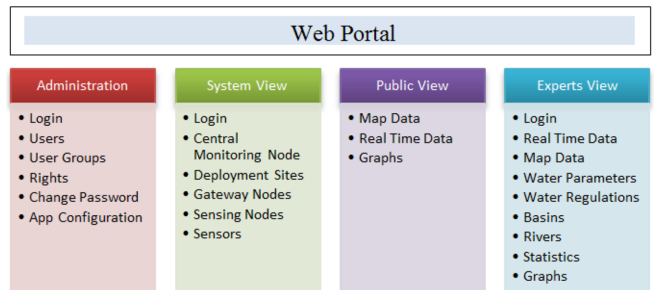

Figure 6. The Web portal map

Moreover, the intelligent behavior of the portal represents an advanced interface to water experts.

Admin Module

The administration module of the portal serves for common administration portal tasks, i.e., to manage (add / modify / remove) users, groups of users, and their rights for login. It also supports the configuration of the web portal, such as setting up the default map zoom, which nodes (sensing/gateway/central monitoring) to show/hide in the map, the default map location, configuration of the SMTP server and of emails to which the portal may address notifications in cases when, e.g., a WSN node is not functional.

System View

System View supports managing with WSN nodes such as central monitoring node (name, location, active / passive status), deployment sites (name, description and river in which are deployed), gateway nodes (name, location, active / passive status, deployment sites, and to which central monitoring node they send data), sensing nodes (name, description, location, active / passive status, and to which gateway node they send data), and sensors (name, serial number, manufactured by, active / passive status, and water parameters they measure).

System View enables monitoring of the working status of the system. If any sensing node does not work properly, the system notifies that the sensing node is not sending data to the server. System View also uses a map to visualize all system components such as central monitoring node, gateways nodes, and sensing nodes (wireless sensors / mobile sensors).

Public View

Through the *Public View* module, interested citizens may access the portal and observe the quality of water on certain geographical points in Google Maps marked as measuring nodes along the rivers on the map. Figure 7, the window on the left side displays the measuring nodes in the map with access to the wide public for observational purpose. The "recent data" table beneath it lists the latest (simulated) measurement data transmitted by the WSN and the mobile component, including details about the measuring node from where the data originates, type of the measuring node, the water parameter being measured, the measured value, measuring unit, and the timestamp. When clicking over a whatever marker, the latest measurement values obtained for that point will be shown, as depicted in Figure 7 (top-right window).

If we want to see the measurement values for a specific parameter in detail, then we may click over the *Show chart* link, and the measurements will be shown in graphical form as provided in Figure 7 (right-down window).

Experts View

The Experts View module is accessible only by experts with credentials granted by the portal administrator in that role. Through this module, experts may access in real-time data sent by wireless sensors. Nodes are represented in the map, similar to how they are represented in Public View, but with the possibility to access not only data related to the sensing nodes, but also to the gateway nodes, deployment sites, and the central monitoring node. Data on water parameters, water regulations, basins, and rivers are all managed through this module.

Experts through the Experts View may in addition derive reports and different statistics related to the water quality, like mean, median, percentile, standard deviation, and similar water quality statistics evaluated through the Experts Rules module.

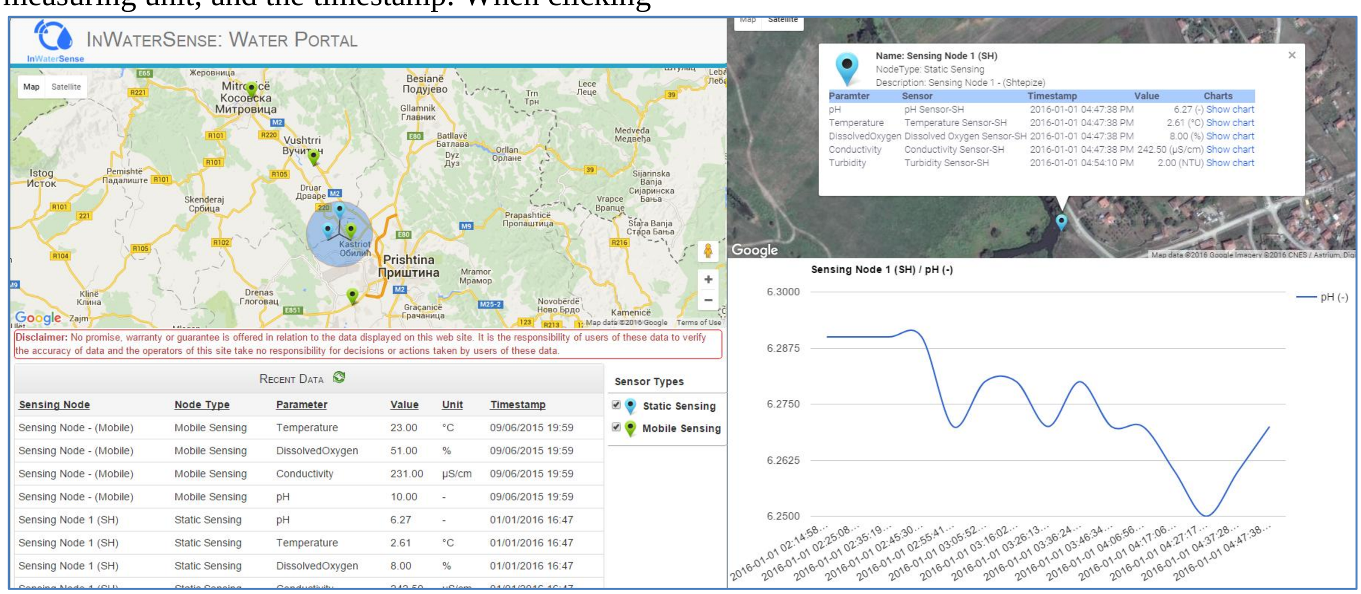

Figure 7. The public module of the Web portal

In Figure 8, an example statistical report generated by the web portal is provided. Filtering parameters for reports are: gateway node, sensing node, water parameter(s), and the time frame. Given each of these filtering criteria are provided through this interface, the statistical report for each water parameter selected in the form will be shown which include: the number of data samples sent by WSN, mean value, maximal value, minimal value, and the standard deviation. In a similar way, other reports as per need by the expert may be modeled and generated by the portal.

Intelligent Behavior

Besides the fact that it supports the real-time monitoring of water quality, the web portal behaves as an intelligent system capable to support water quality classification based on different regulation authorities such as WFD (Water Framework Directive) (EC, 2009), UNECE standards (United Nations Economic Commission for Europe) (ECE, 1993), or any other classification regulatory provided by experts. As illustrated in Figure 8, the portal automatically classifies the status of water bodies given the quality values measured and the authority regulation to apply for classification that has been selected by the user.

One of the classification schemes mentioned above, the WFD classification scheme for water quality includes five statuses: high, good, moderate, poor and bad. For example, the classification in regards to conductivity is as follows: high: (0 – 500) µS/cm, good: (500 – 700) µS/cm, moderate: (700 – 1000) µS/cm, poor: (1000– 2000) µS/cm and bad: (2000 – 5000) µS/cm. Therefore, if choosing this regulator, the system will assign the appropriate status to each parameter measured based on measured average parameter value during a selected period. The example in Figure 8 shows 5161 measured data for conductivity during a selected time period by the user, with an average value of 267.39 µS/cm. According to the average calculated by the portal, the system classifies water status as High. The same classification procedure is applied for any other measured parameter and recorded in the portal.

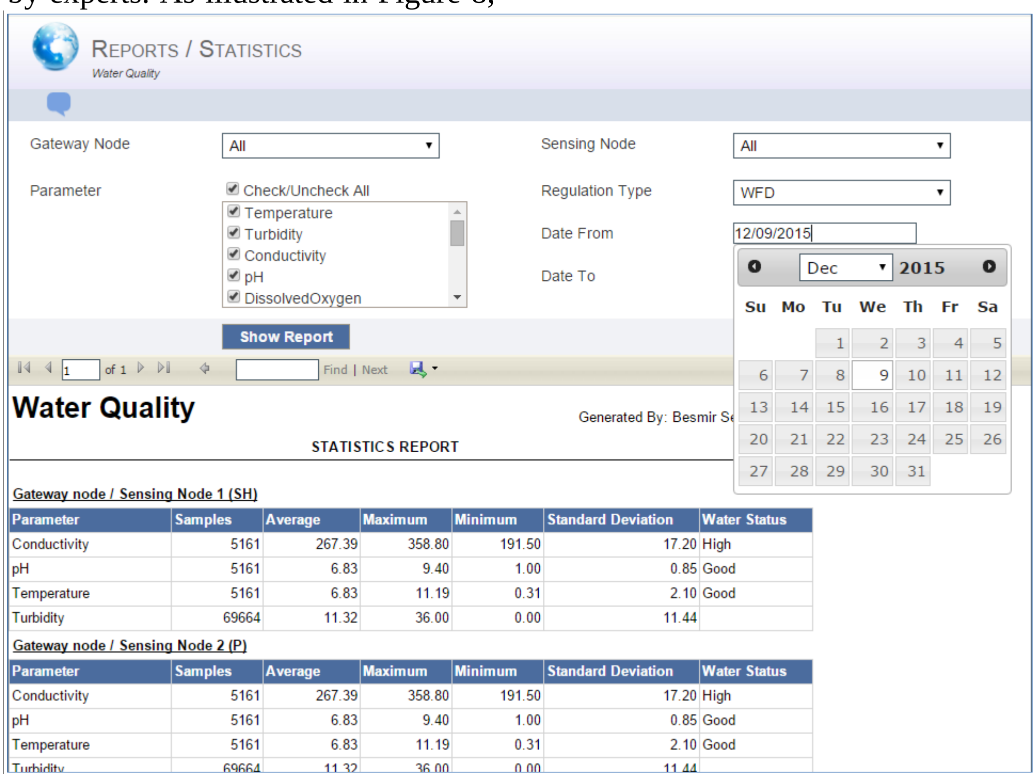

Figure 8. A statistical report of water parameters for a given time frame

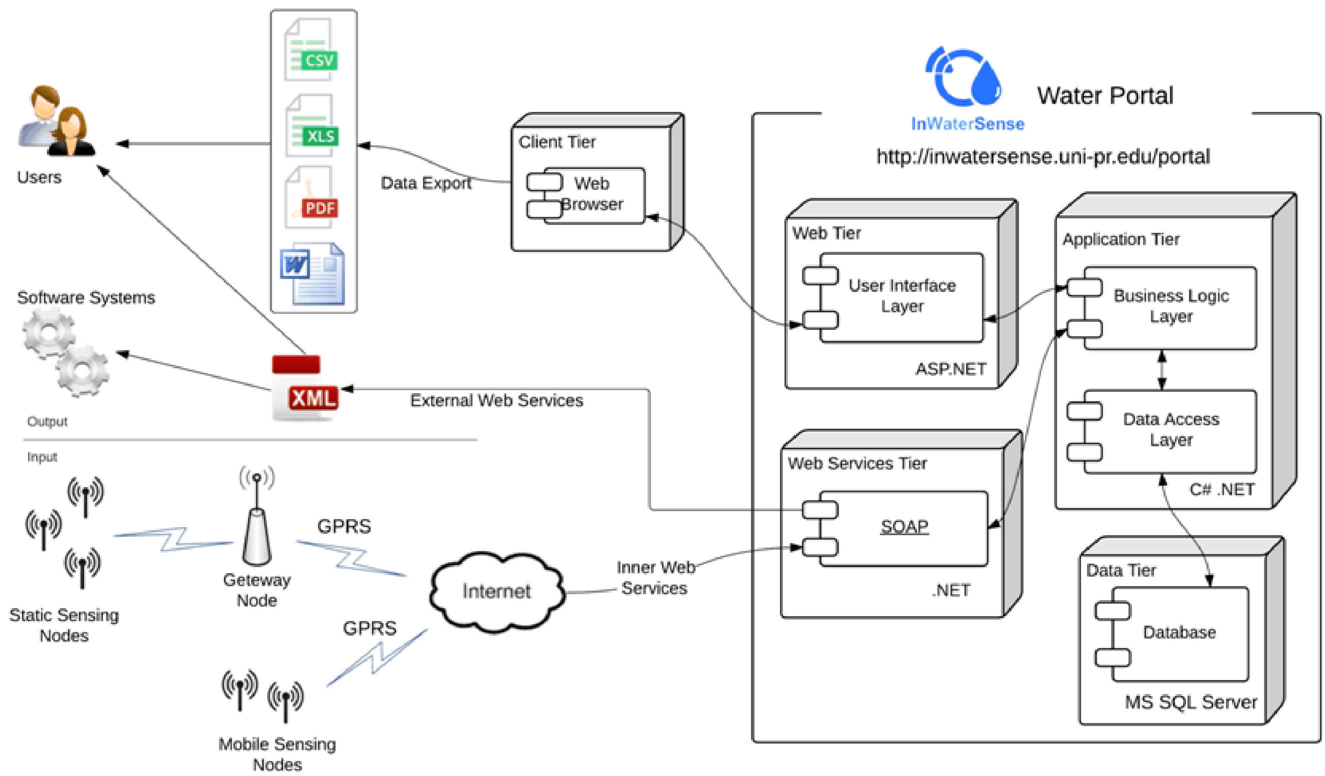

Figure 9. The implementation architecture of the Web portal: UML deployment diagram

IMPLEMENTATION

The portal introduced in this paper is developed in Microsoft .NET Framework 4.0 platform, and the programming language used is C# (ASP.NET). For managing with data, the MS SQL Server 2008 is used.

Moreover, a layered architecture is followed while developing the portal, enhancing thus its performance, the ability to treat a greater quantity of work, flexibility, as well as facilitating reuse and maintenance of the source code. The organization of the code into five main logical layers is approached: *Data Store*, *Data Access Layer*, *Business Layer*, *Web Service Layer*, and *UI (user interface) Layer* (Figure 9).

Web services developed in ASP.NET are used for data exchange. We distinguish between inner and external web services in the portal. The *inner web services*' responsibility is to accept all requests coming from sensors, and send them to the portal for further processing and / or presentation. On the other hand, **interaction with external agents**, be it users or other software systems, is supported by means of *external web services* developed to extend the availability of data to a wide community and developers. Web services access to acquire data is regulated through user credentials (username, password) granted to the interested parties by the system administrator. Particular web methods exposed over web services provide data filtering by water parameters, sensing nodes, and certain periods of time, just to mention few. For illustration, following are some of the web methods available to access the data through the portal:

`Authenticate(usename,password)` - a web method for authentication.

`GetDataByPeriod(fromDate,toDate)` - a web method to retrieve data filtered by a period of time.

`GetDataByPeriodAndWaterParameters(fromDate,toDate,waterParameters[])` - another web method to retrieve data not only filtered by time interval they cover (first two date interval parameters), but also by certain water parameters listed as an array (third parameter).

`GetDataByPeriodAndSensingNodes(fromDate,toDate,sensingNodes[])` - a web method to retrieve data filtered by date interval, as well as by sensing nodes.

A typical URL of a web service to invoke a certain web method, e.g., the `GetDataByPeriod` method, is presented as:
`http://inwatersense.uni-pr.edu:5001/SensorWebService.asmx?op=GetDataByPeriod`

Further in the light of extensibility of the portal, **export of data** into several formats, i.e., spreadsheet (Microsoft Excel), CSV, PDF, and text file (Microsoft Word), is supported.

Simulator

As the name implies, in the simulator module (Figure 10), the simulation of sensor data as assumed may get transmitted in real-life scenarios by sensors, is implemented. In the left upper corner of the simulator page, users can configure the time interval (seconds or minutes) in which simulated data will be generated. Further down in the simulator page, the river branches, areas where sensors are deployed, nodes that connect measuring nodes, measuring nodes, sensors that contain measuring nodes, and parameters measured by the sensors are structured and displayed in the form of a tree. In order to visualize any of these nodes in the map and display the parameter values, users have to select a check-in box next to the given node / parameter. Displaying a parameter in the map means actually to display a graph (the right-hand side in Figure 10) with the curve representing randomly generated values within a predefined range provided in the Expert's module. Simulated values of temperature, say, shown in Figure 10, are generated based on a previously predefined range of values provided usually by water experts for each given parameter, say from 0.5 °C to 22 °C for the temperature. The range of values may also be specified by a researcher to serve his/her assumptions in a given study. For instance, for the time interval set to 10 seconds, the following random values are generated within a minute by the simulator: 13.40 °C, 7.23 °C, 3.54 °C, 21.03 °C, 17.13 °C and 5.34 °C.

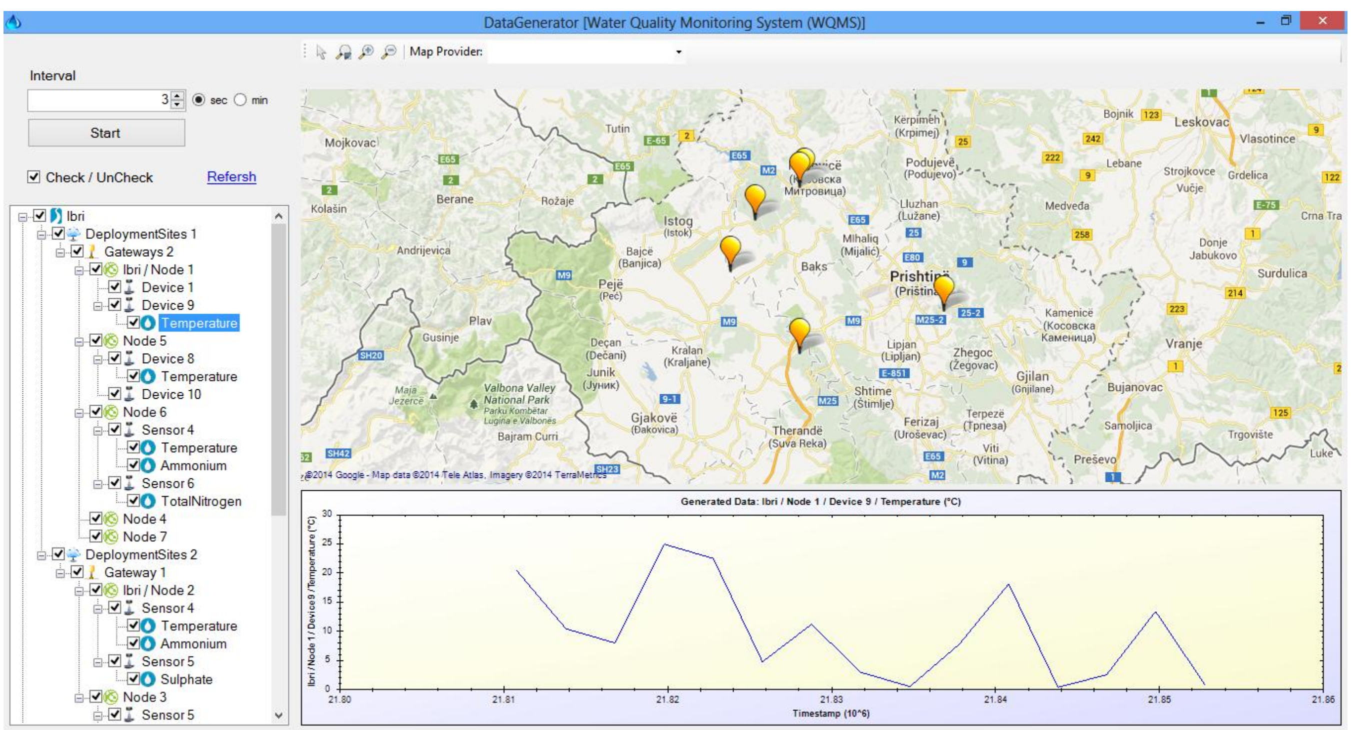

Figure 10. Simulator

CONCLUSION AND FUTURE WORK

Building Web portals to support real-time monitoring of water quality through wireless sensors is not a novelty. However, the Web portal introduced in this paper is distinguished for its multifaceted contribution compared to the existing portals discussed in the related work, namely:

- The diversity of data types it covers: The observational stream data on water quality coming from wireless sensors – dynamic data; The data describing the wireless sensor network itself, its devices and the corresponding site allocation data – static data; The experts' data, like are different local and international regulators and the quality standards they define; The expert's rules, like are the inferred conclusions given certain limits in values are achieved by the observed values through sensors, or different statistics derived for water parameters given a certain number of measured water samples.

- The wide range of individuals that may benefit from accessing the portal: Water experts – who need data for real-time monitoring and further investigation, who may be potentially interested not merely in accessing the data, but also in deriving reports and statistics about certain water parameters. This may also facilitate researchers in analyzing and gathering scientific facts, without the need to go in the field, making thus the whole system more efficient and reducing the costs; General public, i.e., individuals that want to have a clear overview about the quality of water in their environment; WSN engineers who might be interested in having a continuous control over the system, whether it works properly, and configure it appropriately, e.g., add a new measuring node also visualized in the portal's map.

- The intelligent behavior of the portal to support water quality classification based on different regulation authorities such as WFD UNECE standards, or any other classification regulatory provided by experts.

- The level of scalability in favor of future extensions of the portal as might be deemed necessary by a certain individual and / or institution: It allows adding with ease new components/functionalities, e.g., add certain new regulatory documents for water quality, and directly compare through the portal the data measured by sensors with the quality standard values as defined by those corresponding regulations.

- Its flexibility in supporting the export of measured data into several formats for use by individuals or institutions interested on water quality and WSN-related data.

- The extensibility of the portal by means of web services made available to support third party developers to leverage the portal system.

The portal has practical value, and is already in use. The authorities in the water sector may easily adopt the portal for their use by configuring it to integrate their sensing platforms and the observation data and rules of interest. The data may then be smoothly shared among stakeholders at different levels (researchers, policy-makers, engineers, citizens) in favor of healthy water and for research purposes.

There is previous work presented in (InWaterSense, 2012) on modeling portal's data with semantics, and also work introducing reasoning over such semantically-enriched data (Jajaga, 2015). The aim is to incorporate them, the semantically-enriched data and the reasoning capability over such data, into the existing portal introduced here, to then finalize with a semantically-enabled future model for water monitoring portals through wireless sensor networks.

Challenges currently addressed relate to issues which commonly occur in the era of Big Data due to speed and amount of sensor data and how they are to be stored and analyzed by new intelligent solutions (Chen, 2014; Dimitriyev, 2015), similar to our intelligent portal introduced in this paper.

Acknowledgements. The work described in this paper is supported by "InWaterSense: Intelligent Wireless Sensor Networks for Monitoring Surface Water Quality", an EU funded project managed by European Union Office in Kosovo, implemented by University of Prishtina.

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