In-line water safety systems based in wireless sensor networks

Mimoza DURRËSI
mimoza.durresi@uet.edu.al

Abstract

Living in the modern times is becoming more challenging every day. Industrial wastes, pesticides, toxins used from the humans are becoming a real threat for their health. In all this closed cycle the most important is to secure the air and water purity. All the wastes go in the water that we drink and this happens every minute and every hour. Public health threats are major incentives encouraging the development of new technologies for in-line monitoring systems that can optimize operation of the large scale supply networks, prolong service life, evaluate performance and improve the security of water supply to customers. The purpose of this paper is to contribute toward improving the water purity, testing and monitoring the resources where we get the water or in other words the in-line monitoring and control of the water systems. In this paper we study, design and test a new protocol of communication between toxin detecting sensors. This system is going to help with monitoring of water sources in order to signal any change in the toxicity threshold. The protocol makes possible the communications between sensors covering a wide area ensuring the quick and efficient communications with the monitoring centers and updating their respective databases. On the other hand the database entries over a threshold value will cause an alarm for stopping filling water from the respective spot, until the parameters become normal as a result of automated systems interventions.In this protocol only few nodes will held the communication within a mini cluster of sensors, giving the possibility for good quality and low cost communications. Those mini clusters can be fixed or moving depending from the kind of the water source.

Key words: Wireless sensors networks, GPS, actuators, wireless sensors protocols, ad-hoc networks, hierarchical schemes, etc.

Introduction

The purity of food, air and water is the biggest concern for everyone in the planet since the more we use the industrial and technological benefits the more conscious we become for their waste's influence in our resources purity. But even knowing the importance of the water safety, the investments from governments are inadequate and mostly go for collecting hydraulic data usually to control the status of pumps, valves and pipes. On the other hand the number of continuous data collections locations is small in number and usually the purpose of their collections is the maintenance or the billing (e.g. data from Automatic Meter Readers, AMR). As for the water quality sampling generally is done through the so called grab samples (single point in time) taken in special locations which are even rare in number.

Wireless Sensors for In-Line Water Monitoring

Many problems and situations raise the need for Real time Water monitoring such as: High water toxicity and pollution throughout the world, communications quality, information delay and security, infrastructure, range of surfaces surveyed and communication cost. These are serious challenges for the research community and raise the need to use new sensing ways and communication control techniques.

There exists a lot of work previously done in this field. In [1] paper the authors consider how to sense the quality of the pipes, monitoring their condition, but they don't consider monitoring the quality of water and further more considering the water quality in the source. Recently monitoring the water quality in the source is taking more attention from the research community.

Usually the drinking water quality measures are determined to respect the World Health Organization (WHO) [7] guidelines for drinking-water qualities. The standards for drinking water quality parameters require that the microbiological, chemical and indicator parameters must be monitored and tested regularly in order to protect the public health. When from the samples received results a contamination problem the contamination warning system (CWS) launches a public warning about the threat. But at this point it might be too late. Maybe the contamination starts at the source and it would be much more effective and less harmful to detect the problems right there. But it would be more economical, safe and manageable if this testing would be in-line, in the rivers and reservoirs.

Previous Research in Water Quality Monitoring

As we mentioned before, the government investments are usually directed toward monitoring the water systems *in the populated areas.*

But most of the problems would be resolved if the water monitoring would happen *at the source*. e earliest detection would cause less harm to humans and the possibility to x it would be higher. Knowing the importance of in-line water monitoring recently it is a lot of work done in this area. Here we can mention the work of researcher group from the Valencia University.

In [2] the group of researchers use sensors network to detect the river pollution. ey focus their work mainly in nitrates water pollution without considering *the heavy metals detection* and moreover the water quality in the sources. ey use *only a few points* and the communication is overlapped which causes delays in information collection.

In [4] the authors consider monitoring the drinking water system by using sensor that detect mostly bacteria (e-coli) and the sensors are placed *in a small area*.

In [5] the authors consider that sensors will be connected to the Internet, but this is not possible always especially in the case of water sources that are found in rural areas. Also there are Safety problems. On the other hand the sensor nodes used to collect data are static. is means that the data will be collected only from few points as a result the conclusions about the water quality in the large area might be wrong. e existence of the large areas makes it costly to cover with sensors. One of the possible solutions to this problem might be the use of moving sensors as we propose in this work. As by our protocol sensors will be organized in groups and they move towards the ow.

SafewaterComm protocol's qualities

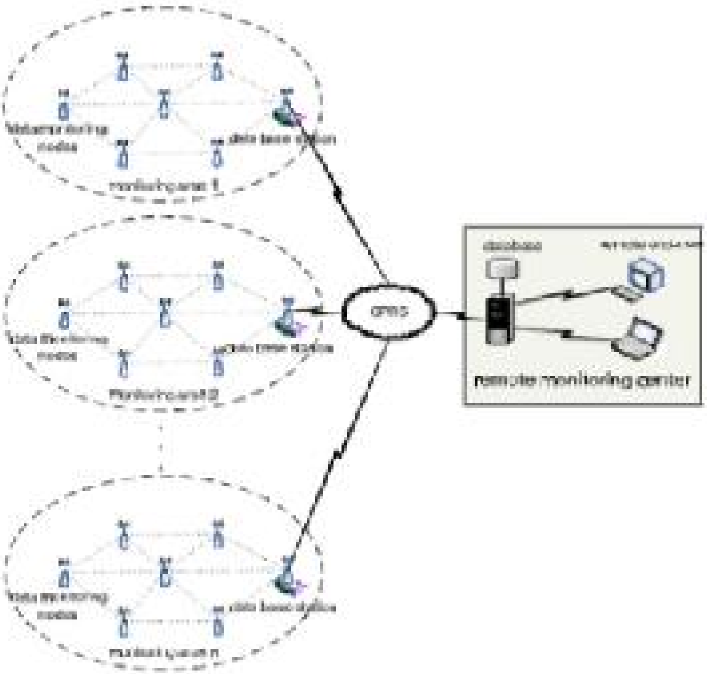
We think that we should monitor the water before it enters the pipes, because is safer and less costly. In this way we prevent the use of toxic water from both water companies and populated areas.

In the other hand we will monitor the water during the ow, creating in this way a detailed view of everything that goes in it. e sensors are organized in groups that move towards the water ow recording data during the tunable time slots. e data will be collected from a certain sensor in each group. A similar scheme is used for sensing air pollution in Dubai area [7]. But in this work they suppose the urban area has communicating infrastructure and each node communicates with a base station. In our protocol the sensors will communicate with the Cell Center creating a wireless ad-hoc communication protocol. eir data will be forwarded to the central data base and be updated according to the data acquisiton rate. is protocol prevents spreading of the problem in the case when a higher toxicity than the threshold will be detected. In a later time the respective services informed by the collected data in the central data server will take care of the problematic area. is will be part of the control and actions decided by the respective companies.

As by this protocol sensors will be organized in groups and they move towards the ow. e hierarchical protocol saves cost in the point of view of the need for more complex sensors only for the centers. e moving clusters of sensors represent nodes of an ad-hoc network with a hierarchical 2 level communication scheme.

Most of the previous papers take in consideration the use of the wireless infrastructure (g.1). SafeWaterComm protocol considers the ad-hoc wireless network created from the wireless sensors that transmit the information between the sensor nodes.

FIGURE 1. Water environment Monitoring System based on WSN

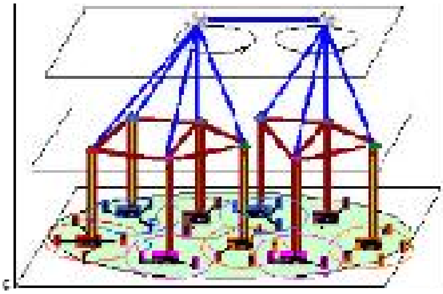


In the case of SafeWaterComm protocol the role of the base station is played by the head group sensor which will have more processing power than the other nodes. Our approach is based in our previous work on intervehicle communication protocols adapted and developed for water safety sensors communications. The river area is divided in virtual cells (fig.2) and their sensor nodes density is changeable. This is related to the area specifics or to a certain critical moment. For example for urban areas or points where the water safety is doubtful, it will be important to have more data, which means more sensor nodes and a fine grained study is needed.

FIGURE 2. Sensor distributed in the river area.

In this protocol we use a virtual infrastructure created from distributed sensors. As we mentioned before the nodes density is tunable and as a result the levels of hierarchy of this infrastructure are tunable, too. We use a hierarchical communication scheme in order to have a low cost approach. This can be explained as in figure 3, where the 3 levels of the hierarchy correspond to the three planes. At the bottom we have the first level. Each sensor represents a simple sensing unit that transmits to the sensing neighbor with a higher scale of hierarchy (called Cell Centers). Then, the second plane is the second level of the hierarchy created from all the Cell Centers. Here each node represents a sensing unit that has a certain number of neighbors (less than a certain number M). Each one of them is a cell center for the first level and is located somewhere in the center of the cluster. The third level of the hierarchy is created from the centers of the previous level.

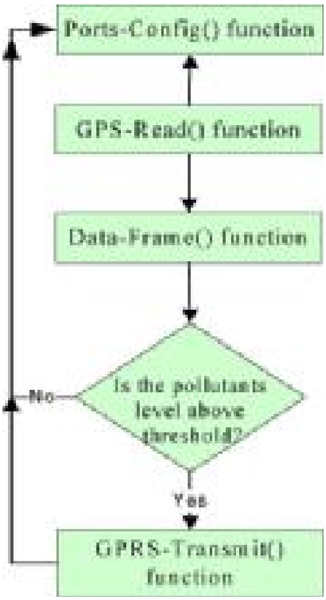
FIGURE 3: Multi-level hierarchical ad hoc sensors network



Data flow and quality control in SafeWaterComm protocol

As we mentioned before the data flow corresponds to the hierarchical scheme of our communication protocol. The data collected from sensors will be transmitted from the GPRS together with the GPS data giving the current node position. The cell center will forward the data set from all the nodes included in its cell to the next hierarchy center till they reach the sink. After that moment the data set will be transmitted to the data center. The traffic in the network will be of a lower load if the nodes transmit with a lower rate. The algorithm that gives more intelligence to the nodes and less traffic load to the network selects the data set and transmits only the data which is above a threshold. (fig.4). The threshold value can be changed or tuned depending on water quality requirements or toxicity situation severity. On the other hand the density of sensors inside the cells is changeable. This can be completed by using the sleep-awake scheme depending on the situation, weather, season etc. The data flow selection algorithm, the sensor sleep-awake scheme and the data collection rate are tunable giving a lot of flexibility to the protocol functioning in order to contribute to a minimal power consumption and network load. A flexible Virtual Infrastructure is created and maintained to enable scalable and effective communications. In each cell we select one node to connect and manage the communications with all the nodes of that cluster which will be considered as Cluster Head or a Cell Center(CC). The hierarchical distribution of cluster Heads will be transferred to the hierarchy of their costs. This structure enables the optimization of the routing process. Depending from the technology used the Cell Center is placed from the designers group or is self-chosen and is located approximately in the geographical center of the cell in order to have same communication distance from the other nodes. At a certain rate each node updates the data from the GPS, which gives the Coordinates (x,y) for each node at a certain moment(fig.4). Then the higher ranked nodes transmit the data along to each-other using them as intermediate communications points and nally transmit the data to the gateway connected to the Internet, toward the Information Management System (IMS), that can be a data center connected to the Water controlling centers that might be of a local or national rank. On the other hand those centers decide about the active nodes distribution modi cations in real-time

FIGURE. 4 Data □ow selection algorithm



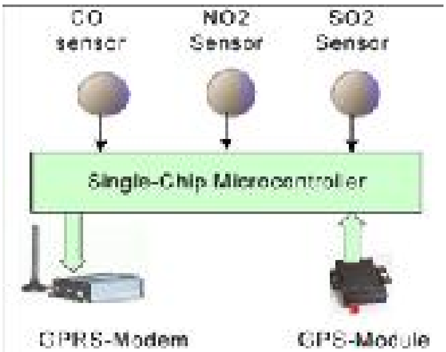
Mixed Sensor-Actuators eet architecture

In the case of SafeWaterComm protocol both strategies might be used, having xed or moveable sensors. Especially for large areas it will be more convenient to have moveable sensors or actuators. e group of sensors to describe a certain area of the water source will be considering as a patrolling group. e cell members choose a center that will behave for a certain time interval as a Base Station. In the case when one node has more processing power than the others, this will behave as a cell center. Every node has its geographical position given by Global Positioning System (GPS). e moving set of sensors moves following the water river natural ow or with a di erent speed if a certain actuator is used. A very similar equipment created by the research team in Michigan State University (MSU) is robotic sh (g.5) and (g.6) can be used as the center of a certain con guration. e bene ts of this architecture is related to the minimum number of sensors used for data collection at a certain moment but having the data from the whole area in a certain time period after the whole sensors' fleet describes it. (Fig 5) The patrolling set can have a different number of sensors or several sets can patrol the river large areas. In (fig6) a more detailed actuator's (robotic fish) scheme is shown and the sensors set can be incorporated in it (fig.7). The sensors nature is related to the analysis and control requirements depending from the guidelines given from the National Water control Center for the certain river area in a certain moment. For this model, we propose a packed Sensing Box to be used in Cell Centers that includes: a microcontroller board with add-on sensors, a peripheral GPS receiver, and a cellular modem. The unit will be connected to the robotic fish that would provide the power supply needed to operate

FIGURE 5. The robotic fish

FIGURE 6. The MSU fish and sensors incorporated

FIGURE. 7 Several sensors incorporated with the robotic fish



Mixed Standarts Benefits

The communication protocols might be IEEE802.11 mixed with Zigbee. It is known that Zigbee can be used for short distances. For this reason we can use Zigbee for all communications inside the cell, or as we can say for all communications in low levels of hierarchy. But for communications between the Cell Centers of different levels of hierarchy we can use IEEE802.11 This way we can save the batteries life. ZigBee represents a high-level communication protocols used to create personal area networks built from small, low-power digital radios. ZigBee is based on an IEEE 802.15.4 standard. Though its low power consumption limits transmission distances to 10–100 meters, depending on power output and environmental characteristics, can be increased by using intermediate nodes or mixed protocols.

ZigBee is typically used in low data rate applications that require long battery life and secure networking (ZigBee networks are secured by 128 bit symmetric encryption keys.) ZigBee has a defined rate of 250 kbit/s, best suited for intermittent data transmissions from a sensor or input device.

Protocols Benefits and future work

SafeWaterComm protocol is an ad-hoc wireless sensors' communication protocol designed to be used for in-line water monitoring and control especially in large areas before that the water gets collected. As we mentioned before this will save the cost of filling toxic water and will increase the water safety. The protocol that we propose is efficient and gives the possibility for studying, monitoring and controlling large areas water surfaces having the possibility for a fine grained data collection. The number of collecting points increase but this doesn't cause increase of communication network load, as we use a hierarchical scheme. The fact of using hierarchical communication scheme brings several bene ts, as: a) low cost for the hardware. Only the Cell Centers need to have more complex design, memory and transmission power, b) Low network load as it will be less communication toward the gateway. ere are few centers that hold most of the communication with the sensor nodes. For the case of several levels of hierarchy there are mostly Center-Member communications, only few of second level of hierarchy communications and even less of the third one, c) Low consumed power and latency. d) More data collected as there are more sampling points, more locations visited from the moving sensors eet. e hierarchical scheme ensures more exibility on data collecting rate, data collection points and less processing power for most of sensors excepting the cell center which can ensure less power consumption.

On the other hand the possibility of using mixed sensors actuators scheme increases the collecting points and also gives the possibility of having a more limited number of sensors by using a moving patrolling set architecture. e cost saving analysis simulations comparison of this architecture will be part of our future work

References

1.A.J.Whittle, M.Allen, A.Preis and M.Iqbal3,"Sensor networks for monitoring and control of water distribution systems", 6th International Conference on Structural Health Monitoring of Intelligent Infrastructure (SHMII 2013), Hong Kong, December 9-11, 2013

2.J.V.Capella, A.Bonastrea, R.Ors,M.Peris, "A step forward in the in-line river monitoring of nitrate by means of a wireless sensor network", Sensors and Actuators, B 195 (2014).

3.R.S´**aez,** S.Climent, R.Mercado, A.Perles, P.Yuste, J.V.Capella, S.Blanc, V.Busquets, J.Serrano, and R.Ors, "Modeling and Simulation of Underwater Wireless Sensor Networks Underwater communication", ITACA-WIICT 2014, Valencia, Spain

4.J.Ramprabu1 and C.Paramesh, "Embedded based real-time monitoring and contamination detection in drinking water distribution system", IJETTCS 2014, Vol.3, Issue 5

5.J.V.Capella, A.Bonastre., R.Ors, M.Peris, "A Wireless Sensor Network approach for distributed in-line chemical analysis of water", Talanta, Volume 80, Issue 5, 15 March 2010, Pages 1789-1798

6. G. Aragay, J. Ponsb and A. Merkoci, "Enhanced electrochemical detection of heavy metals at heated graphite nanoparticle-based screen-printed electrodes", Journal of Materials Chemistry, Issue 12, 2011

7. A. R. Al-Ali, I.Zualkernan, and F. Aloul, "A Mobile GPRS-Sensors Array for Air Pollution Monitoring", IEEE Sensors Journal, vol. 10, no. 10, october 2010

8. Z.Rasin, M.R.Abdullah,"Water Quality Monitoring System Using Zigbee Based Wireless Sensor Network" , IJET Vol: 9 No: 10, 2012

9. Daejung Shin, Seung You Na, Jin Young Kim, Seong-Joon Baek "Fish Robots for Water Pollution Monitoring Using Ubiquitous Sensor Networks with Sonar Localization", *ICCIT '07(ICCIT)*, Gyeongju, 2007, pp. 1298-1303.

10. K. KaurJul, "Robotic Fish Design and Underwater Pollution Control"**,** 20 2012

11. Mimoza Durresi, "Distributed Wireless Sensor Networks for saving the fauna in lakes, DSSH 215, Tirane, UET
12. G.K, Dhakshinamoorthy, "Intelligent Pollution Monitoring Using Wireless Sensor Networks",IJRET: International Journal of Research in Engineering and Technology eISSN: 2319-1163 | pISSN: 2321-7308
13. Corke, P., Wark,T., Jurdak, R., Hu, W., Moore, D., Environmental Wireless Sensor Networks, Proceedings of the IEEE | Vol. 98, No. 11, November 2010
14. Xia. F., QoS Challenges and Opportunities in Wireless Sensor/Actuator Networks, Sensors 2008, 8(2), 1099-1110, www.mdpi.org/sensors.
15. M.Durresi,V.Paruchuri,A.Durresi,L.Barolli,M.Takizawa:"A scalable anonymous protocol for heterogeneous wireless ad hoc networks".J. Embedded Computing 3(1):77-85(2009)
16. M.Durresi,A.Durresi,L.Barolli,"Sensor Inter-Vehicle Communication for Safer Highways".AINA2005:599-604
17. G.M. Solomon, T.R. Campbell, G.R.Feuer, J. Masters, A.Samkian, K.Paul. 2001."No breathing in the aisles, Diesel Exhaust Inside School Buses. Report prepared by the Natural Resources Defense Council and Coalition for Clean Air.
18. M.Durresi, A.Durresi, L.Barolli, Hierarchical Communications for Battle elds, Journal of IEEE Computer Society.
19. N. Alon, A. Bar-Noy, N. Linial, and D. Peleg. A lower bound for radio broadcast. *J. Comput. Syst. Sci.*, 43:290–298, October 1991.