

Wireless Sensor Network for Water Quality Monitoring

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Abstract. This book chapter introduces a European Union-backed water quality monitoring and early warning system implemented in the cross border region of Hungary and Slovakia achieved by Hungarian and Slovak partners. The measurement system consists of buoys which carry sensors and send measurement data wirelessly to a gateway on the riverside. The gateway transmits the data to a server, where it is saved and processed. Based on the collected data, alerts can be sent in case of anomalies. Utilizing this solution, an early warning system for water pollution can be deployed, which decreases water quality monitoring costs.

1 Introduction



Wireless Sensor Network for Water Quality monitoring (WSN-Aqua) is a joint research and development project financed by the European Union for creating a water quality monitoring sensor network and early warning system achieved by Hungarian and Slovak partners. The project started in July 2013 and is due to end in June 2015. During the two years of the project, the partners will cooperatively develop and implement all the necessary components to create the water monitoring system. The main output of the project is a test system of 8 buoys placed in the cross border region of Hungary and Slovakia on the River Ipoly.

This book chapter is organized as follows: Section 2 defines the goals of the project; Section 3 introduces the project partners along their responsibilities. Section 4 describes the considered environmental aspects and the selected location of the first demo system. Section 5 presents the details of the implementation and Section 6 discusses research results. Finally, Section 7 concludes this book chapter.

2 Aims and Outcomes of the Project

The overall goal of the joint research project is to foster intensive cooperation between Hungarian and Slovak R&D institutions to increase the economical

competitiveness and capacity of cross-border regions.

The project-specific goal is to develop a sensor network which could be utilized for water quality measurements and contribute to the environmental protection of rivers and lakes and be able to function as an early warning system for the authorities in a cost efficient way. Such a system would be beneficial for both countries.

The project's subject and goals are directly harmonizing with the priorities and goals of the HUSK program, especially with "Cooperation in science, research and innovation" priority (HUSK 1101/1.2.1) and the aim to increase the economical competitiveness of the cross-border region.

The main result of the joint research project is a new product capable of measuring and monitoring water quality. To implement such a system, a radio communication protocol will be developed, a buoy will be designed and a measurement test system will be deployed as a proof of concept.

The project reinforces the social and economical integration of the cross-border region of Hungary and Slovakia, more specifically it builds partnership in the scientific research community.

The outcomes of the project include a new radio communication protocol, hardware board designs, buoy design, measurement test system on Ipoly and documentation.

3 Project Partners and Responsibilities

This chapter introduces the partners and their responsibilities (work packages, WPs) in the WSN-Aqua project.

3.1 BME-Infokom Innovator Nonprofit Ltd.¹



BME-Infokom Innovátor Nonprofit Kft. is a nonprofit organization of technology Research and Development meeting market demands. We take on various technological challenges and carry innovative ideas into execution by utilizing our long-term R&D and project experiences, as well as professional staff. Our company offers outstanding cooperation opportunities and reliable partners, such as the Budapest University of Technology and Economics.

BME-Infokom is responsible for the following work packages:

WP2 Development of an air interface for the environmental monitoring system
Wireless transmission is a critical part of the monitoring system. There will be two different radio technologies applied in the system. The nodes communicate with the central server with GPRS/UMTS data transmission. The nodes use another ISM band

¹ www.bme-infokom.hu

radio solution to provide data transmission. This work package defines the wireless interfaces and their parameters.

WP5 Development of a wireless communication protocol for the environment protecting monitoring system

This working package defines the communication protocol that makes possible to transmit the sensory data via the air interface, defined in WP2. During the design of the protocol energy efficiency was a major factor. It is important that the protocol works as efficiently as possible. This phase specifies the data packet structure, where the different types of sensor data are considered. The various message types during communication are also to be defined.

WP7 Analysis of network topologies and alternative energy sources

The work package has two goals: first, the definition of network topologies, on which the system will operate, second, to develop a module utilizing renewable energy sources, which provides long operating time for the system. The topology largely determines the protocol being developed, so it is connected to the processes defined by WP5. The various situations require very different topological solutions, in order that we have to prepare for more scenarios.

WP8 Establishment of the system monitoring system

The system is placed open terrain, therefore it is exposed to weather effects, ship traffic and possible damage of vandals. The intermittent failure of a device is unavoidable. The aim of this WP is to create a centralized remote monitoring system that collects the status information of the devices. The information should be collected with energy efficiency taken to account. The protocol has to be implemented in a way that it uses as few messages as possible, but also provides satisfactory amount of status information.

3.2 Technical University of Kosice²



Technická Univerzita V Košiciach (TUKE) was founded in 1952 and is currently active in nine scientific fields as a research and educational regional center. Currently there are more than 10000 students at the university. Besides educational activities, TUKE has successfully completed many R&D projects.

TUKE is responsible for the following work packages:

WP1 Analysis and selection of sensors for water quality monitoring in distributed sensor network nodes

During this activity, we analyze and select a set of suitable sensors to be used for cost effective monitoring of water quality in distributed highly embedded network nodes. There is a wide variety of sensors and transducers at the market, which can measure temperature, pH, oxygen ratio, water flow volume, etc. Several key parameters of selected sensors will be optimized during the selection process.

² www.tuke.sk

WP3 Sensor node hardware components, architecture and embedded software development

This activity deals with the selection of suitable hardware components, composition of the sensor node hardware in terms of used embedded devices, such as particular microprocessors, particular radio frequency transceiver chips (RF chips), various sources of energy, and also with efficient energy management.

WP4 Implementation of data confidentiality and integrity algorithms and protocols

During this activity, we analyze and implement a suitable set of cryptographic algorithms and protocols that ensure confidentiality and integrity of transmitted sensors data via the air interface, defined in the second activity and to be compatible with available communication protocol data structures defined in the fifth activity. Confidentiality and integrity of protected data will be based on a suitable combination of symmetric and asymmetric algorithms implemented on an embedded hardware platform defined in the third activity.

WP6 Development of sensor data processing methods for the comprehensive evaluation of the water quality state

The application of the sensor network to be developed within the project is to provide corresponding specialists and authorities with the relevant information on the water quality state within the monitored water flow. The activity is intent on the design of the final content and form of reporting the water quality state based on processing of data provided by the particular nodes of the sensor network.

Both partners are responsible for the following work packages:

WP9 Development and evaluation of the environmental monitoring test system

This WP aims at integrating all the components created in the previous 8 WPs and also tests the whole system in operation in real-word conditions.

WP10 Dissemination of the project results

The project results can be summarized as a contribution to environmental protection (social contribution), the sensor network applied for the water quality monitoring (technical solution), the novel scientific and engineering methods applied for sensor network design and development (research results) and by the excellent example of Hungarian-Slovak cross-border cooperation. Each of these different kinds of the project results will be disseminated by the methods, such as popularization presentations, seminars, papers in journals and conference proceedings, the developed sensor network demonstration and education process.

4 Environmental Aspects

Each unit of the environmental monitoring system implemented within the framework of the project will include sensors capable of measuring 4 parameters, enabling real-time processing and visual display of these data. Thanks to the communication method of the new sensor system, users (authorities, water experts) will be able to locate contaminations, physical and chemical changes or other events, and to monitor or model these in real-time, or to provide estimates and forecasts.

In this project, we examined the temperature, pH, conductivity and the level of dissolved oxygen (mg/l) in a given river sector. The sensors will provide us with five

further parameters: redox potential, dissolved oxygen (%), pressure, salinity, total dissolved salts (kcl). Later on, replacing and extending the sensors can enable us to monitor the locally significant parameters of a chosen area.

The disadvantage of the current monitoring methods (measurement stations or analyzing water samples in a laboratory) is that experts receive the results with a delay, rendering immediate intervention in case of a sudden damage impossible. Another hindrance is that the presence of water experts is constantly required, but – due to the lack of resources – this is impossible to provide.

Using radio communication technology, the data of the wireless sensor network used in the project is sent to other units for processing and evaluation. Thanks to this, if the level of contamination reaches a limit, experts or authorities can be informed immediately. Although the results are of course not as accurate as in a laboratory, after a real-time alert, further analysis can be carried out in order to decide whether immediate intervention is required, which can play an important role in effectively mitigating damages to the environment.

The standalone mode of the sensor network and technology also enables hard-to-reach areas to be monitored. This possibility is available thanks to the energy efficient and renewable energy based operation of the devices.

4.1 Criteria for Choosing the Monitoring Area

Before choosing the monitoring area, we had examined a number of river sectors. As the project is a Hungarian-Slovak joint task, we tried to choose cross-border rivers (Hernád, Sajó) or rivers that are natural borders and their drainage basin and tributaries are present in both countries (Danube, Ipoly)

We wanted to choose a river which lacks shipping routes as ship traffic can damage the buoys, the obligatory illumination of buoys results in higher energy consumption – further increasing the size of the required solar panel –, and the authorization process takes longer.

After installation, the buoy system can be damaged by natural phenomena as well as human factors. We examined the number of police calls and the population density in the areas of the aforementioned rivers, because we wanted to choose the safest, most sparsely populated area.

In terms of natural phenomena, rivers can be most severely affected by floods. The hydrometeorological data of previous years enables us to predict the temporal distribution of floods.

It is also very important to choose a location that is easily accessible.

The aim of the monitoring system is to detect damages and contaminations that negatively affect the condition of the river. This is why we tried to choose an area which has potential water pollution sources nearby.

4.2 Limit Values of Water Quality

The results of river quality analysis have to be compared with the current limit values of water quality. The water quality classes are as follows: I Excellent, II Good, III Acceptable, IV polluted, V severely polluted. In cooperation with the authorities, we

set the alert threshold for the system. Decree 10-2010 lays down the following limit values (listed in Table 1):

Annex II of Decree 10/2010. (VIII. 18.) of the Ministry of Rural Development³

1. LIMIT VALUES OF WATERS

1.1. WATER QUALITY LIMIT VALUES OF RIVERS

Table 1. Water quality limit values of rivers.

		Type of water body based on the relevant legislation
1	Physical and chemical characteristics	Small plain rivers (type 11, 12, 15, 18)
2	pH	6.5-9
3	Conductivity ($\mu\text{S}/\text{cm}$)	<1000
4	Chloride (mg/l)	<60
5	Oxygen saturation (%)	60-130
6	Dissolved oxygen (mg/l)	>6
7	BOI5 (mg/l)	<4
8	KO _{1cr} (mg/l)	<30
9	NH ₄ -N (mg/l)	<0.4
10	NO ₂ -N (mg/l)	<0.06
11	NO ₃ -N (mg/l)	<2
12	Total N (mg/l)	<3
13	PO ₄ -P (mg/m ³)	<200
14	Total P (mg/m ³)	<400

We consulted with our Slovak partner about the water quality limit values set by Slovak authorities. As there is a slight difference between the limits of the two countries, we agreed on creating two different settings in terms of limit values. The first buoy cluster is set according to the Slovak limits, while the second cluster is in harmony with the Hungarian limits.

Based on this, the monitoring system alerts in the cases summarized in Table 2:

Table 2. Alert limits for the monitoring system.

	SK – 1 st buoy cluster (average/moderate status)	HU – 2 nd buoy cluster
pH	<6 and 9<	<6.5 and 9<
conductivity [$\mu\text{S}/\text{cm}$]	>700	>1000
dissolved oxygen [mg/l]	<6.5	<6
T [$^{\circ}\text{C}$]	>24	(>24)

³ http://net.jogtar.hu/jr/gen/hjegy_doc.cgi?docid=A1000010.VM

4.3 Parameters Assessed during the Project

Each buoy of the WSN-AQUA monitoring network will be equipped with 3 Ponsel sensors, which are capable of measuring pH/redox, conductivity, dissolved oxygen (mg/l) and temperature.

pH (pondus Hydrogenii): Chemical characteristic of aqueous solutions which shows the acidity or basicity of the solution. A pH of 7 is neutral. A pH less than 7 is acidic and a pH greater than 7 is basic. The pH is defined as the decimal logarithm of the reciprocal of the hydrogen ion activity. Hydronium is produced by protonation of water, in which giving up a proton results in hydroxide (OH⁻) and hydronium (H₃O⁺) ions.

$$\text{pH} = -\log_{10} [\text{H}_3\text{O}^+] = -\lg [\text{H}_3\text{O}^+]$$

Redox potential: ORP – Oxidation Reduction Potential, a value measured in mV. It is the tendency of a chemical species to acquire electrons and thereby be reduced. The more positive the potential, the greater the species' affinity for electrons and tendency to be reduced.

Dissolved oxygen [mg/l] (OPTOD – Optical Dissolved Oxygen technology): It is an important parameter in assessing water quality because of its influence on the organisms living within a body of water.

Conductivity and temperature: Conductivity is a measure of the ability of water to pass an electrical current. For this, we use a Ponsel sensor to assess electrical current (μS/cm). As conductivity increases by 2% in case of a 1 °C temperature rise, the measurement has to be standardized to 25 °C.

Although all three sensors measure temperature, this factor is very important when measuring conductivity, therefore the conductivity sensor's temperature data will be considered as reference value.

4.4 The Prioritized Area

After preliminary consideration, from the Ipoly, Sajó and Hernád river sections we decided to further examine the Ipoly area. We considered the security of the area, but the distance between possible locations was also a different factor as it greatly influences setup and maintenance costs, and shorter distances mean that the area can be reached faster in case of an alert. The description of the river basin management plan (RBMP) of Ipoly and a debate report for its review from 2014 provide us with useful information about the area.

The Ipoly meets the criteria of our project because it acts as a natural border for almost 100 km and the quality of the water flowing into it from its river basin and tributaries can indicate pollution along the river basin.

Due to river control, the Ipoly is now only 212.5 km long, its river basin is 5151 km², out of which 1502 km² is located in Hungary. The Slovak Ore Mountain, the Selmec Mountains, the Karancs, the Cserhát and the Börzsöny are all located in its river basin.

The valley of the Ipoly is characterized by basins separated by natural formations that hinder erosion. In several areas, it has a gentle gradient with tributaries of steep gradient. The river bed consists of impermeable rocks, but it is not an abundant river

due to little rainfall and small river basin. Its fluctuation is however considerable, any significant amount of rainfall triggers flood waves that last no longer than few hours or 1-2 days maximum. The affected areas are mainly protected by embankments, dams and pumping stations.

4.5 Protected Areas⁴

According to the EU Water Framework Directive, every area receives protected status where any legislation identifies surface waters and groundwater or water dependent species to be protected.

In the Ipoly subunit of the river basin management plan, we can come across the following categories of protected areas:

Protection of drinking water, nutrient or nitrate sensitive areas, natural bathing sites, areas protected due to their natural values.

4.6 Flood Risk

The fluctuation of rivers is another important factor when installing a buoy system. The fluctuation of the Ipoly is fairly wild and there are two flooding periods during the year, one at spring snowmelt and another in summer due to heavy rainfall. The water level is low in August and September. Floods are also possible in winter due to fast snowmelt. According to observation data collected at Nógrádszakál, the lowest water level was 33 cm, while the highest was 362 cm.

The Middle-Danube Valley Water Directorate prepares monthly hydrometeorological reports of its territories. The reports provide an analysis of the meteorological situation of the given month and the temperature changes as well as the connection between these two factors and their effect on river fluctuation. These reports contain water level and discharge parameters of the Ipoly, the Zagyva and the Danube. The reports also provide information regarding groundwater level and the water management situation. The latter includes data about the condition and water level of reservoirs operated by the Directorate. There is also information regarding the level of flood preparedness in certain areas as well as water quality data (dissolved oxygen, ammonia, nitrite, nitrate, minerals and water quality classification).⁵

We examined the river fluctuation data of hydrometeorological reports available on the website (dating back to July 2011). Our aim was to provide an overview of river fluctuation characteristics of the Ipoly, which is a required measure before installing the buoy system.

Installing the monitoring system is due to late April and early May. As earlier observations suggest, we have to be prepared for sudden flood waves, so we intend to install the buoys considering meteorological data and hydrometeorological forecasts of the Directorate. Generally, flood waves are not frequent in the onset of summer.

⁴ http://vizeink.hu/files3/1_8_Ipoly.pdf – available in Hungarian

⁵ <http://www.kdvvizig.hu/Middle-Danube-Valley-Water-Directorate>

Our findings suggested that the Ipoly is the most suitable of the possible areas for our purposes. In order to set the exact location of the monitoring system, further research is required, and circumstances of carrying out the installation and maintenance have to be considered as well.

4.7 Choosing the Monitoring Site, Field Inspection

In order to choose the most suitable site for the monitoring system, we carried out preliminary water quality surveys during our field inspections of the areas that were deemed suitable based on our background research. In the future, the results of these surveys can be used as reference values to compare with results measured by the monitoring system.

Firstly, we inspected three fields on the lower Ipoly section on the river sections along Letkés, Ipolydamásd and Szob. A representative of Aqua-Terra Lab Ltd., the company responsible for designing and manufacturing the buoys, and a colleague of the Institute of Environmental Engineering of Pannon University also participated in the field inspection.

During the field inspection, we assessed the accessibility of the sites as well as the suitability of the river section regarding buoy installation and maintenance. We also tested the Ponsel sensors to be used during the project, and we collected water samples for laboratory measures at Pannon University. We wanted to choose a site where contamination or external impacts that influence water quality are highly possible. This is why we tried to choose confluences of tributaries, areas close to settlements or river sections near arable lands.

After inspecting the lower Ipoly section, we considered the characteristics of all three sites and arrived at the conclusion that the area between Letkés and Salka is the most suitable site to install a monitoring system. The site is easily accessible, there is hourly gauge data available both at Ipolytölgyes and Salka, which can be followed at <http://www.vizugy.hu/>⁶ and the Slovak website, <http://www.shmu.sk/>⁷.

The next step was to consult the experts of the Middle-Danube Valley Directorate. They expressed their support of the monitoring system. Since the project field is located on a river that acts as natural border between two countries, we had to contact the competent Slovak water management authority. The experts of the Directorate also helped us in this case, as they established close cooperation and strong relationship with the Slovak colleagues who are competent in this area.

After prior consultation, we inspected the Letkés section of the river and we discussed our plans regarding the buoy system. The meeting was attended by two experts of the Middle-Danube Valley Directorate, two representatives of the competent Slovak water management directorate, the leader of the river warden service of the section, two river wardens, an expert of Aqua-Terra Lab and of the Institute of Environmental Engineering of Pannon University as well as the engineers of BME-Infokom.

⁶ [//www.vizugy.hu/](http://www.vizugy.hu/)

⁷ <http://www.shmu.sk/>

During the meeting, we presented the aims of the project to the Slovak experts, and they also expressed their support. The Slovak and Hungarian directorates issued written permit to install the monitoring system.

During the field inspection, we also tested whether sufficient radio communication is possible in the area. The data collected from the two gateways and the measuring results show that decent data transmission is possible in the area. This means that the transfer – to gateways – of data collected by the buoy sensors will be perfectly feasible.

The monitoring points are to be installed in two separate chains because, according to the information of the Directorate, the island under the bridge at Letkés is going to be demolished next spring. Since we would like to avoid the river section affected by the earthworks, we intend to install two set of buoys (in an upper and a lower section).

4.8 Devices used for On-the-Spot Measurement

The following sensors were used in the surveyed areas to assess temperature, pH, redox potential, conductivity, dissolved oxygen, oxygen saturation and turbidity:

NOETEK-PONSEL pH/redox measuring instrument: pH, redox potential

NOETEK-PONSEL OPTOD optical dissolved oxygen measuring instrument: dissolved oxygen, oxygen saturation

NOETEK-PONSEL C4E: temperature, conductivity

NOETEK-PONSEL digital nephelometric turbidity measuring instrument: turbidity (NTU)

4.9 Standards and Regulations Followed

MSZ EN ISO 5667-1:2007 Water quality. Sampling. Part 1: Guidance on the design of sampling programmes and sampling techniques

MSZ EN ISO 5667-3:2004 Water quality. Sampling. Part 3: Guidance on the preservation and handling of water samples

MSZ EN ISO 5667-6:1995 Water quality. Sampling. Part 6: Guidance on sampling of rivers and streams (superseded standard)

MSZ 448-2:1967 Drinking water analysis. Determination of temperature, colour, turbidity and limpidity (superseded standard)

MSZ EN ISO 10523:2012 Water quality. Determination of pH (ISO 10523:2008)

MSZ 448-32:1977 Drinking water analysis. Determination of specific electrical conductivity (superseded standard)

MSZ EN 25814:1998 Water quality. Determination of dissolved oxygen. Electrochemical probe method

MSZ EN ISO 7027:2000 Water quality. Determination of turbidity

4.10 Code Table of Colour, Odour and Weather of Surface Waters

Simplified summary (see **Table 3**) of categories and codes used when sampling surface waters (exception: Lake Balaton and its surrounding rivers).

Table 3. Code tables for categories.

Weather

First digit	Precipitation
no precipitation	0
humid	1
foggy	2
rain	3
shower, thunderstorm	4
ice pellets	5
snow	6
snow shower	7
hail	8

Second digit	Level of cloudiness
sunny	1
cirrostratus cloud	2
cloudy	3
very cloudy	4
Third digit	Wind
no wind	0
wind	1
strong wind	2
storm-force wind	3

Colour

First digit	Colour strength
colourless	0
colour intensity	1-7
Second digit	Dominant colour
colourless	0
yellow	1
green	2
blue	3
grey	4
brown	5
black	6
red	7

Third digit	secondary colour
colourless	0
yellowish	1
greenish	2
blueish	3
greyish	4
brownish	5
blackish	6
reddish	7
murky	8

Odour	
odourless	00
chloric odour	01
dirty odour	02
tarry odour	03
oily odour	04
fishy odour	05
decaying, swampy odour	06
odour resembling medicines	07

Ice	
no ice	1
ice along the coastline	2
drift-ice	3
ice cover	4

4.11 Conclusion, Choosing the Area

During the preliminary surveys and field inspections, we examined a number of possible sites that could be suitable for a monitoring system. Based on the criteria described above, we can conclude that the 2 km long river section between Letkés and Salka is the most suitable area for our project, and the local competent water management authorities – both Hungarian and Slovak – support our initiative.

The buoy system to be installed will be able to monitor and detect any possible contamination that gets into the River Ipoly from the Letkés stream as the upper buoy group provides reference values for the lower buoy group – which detects the contamination. Since buoys of the lower buoy group are 200 m away from each other (see Fig. 1), the system can monitor the rate at which the contamination dilutes.



Fig. 1. Location of the buoys and gateway units.

5 Implementation

This chapter presents the implementation of the water quality measurement system. First the network topology and the components necessary to achieve the project goals are introduced. Next, the internals of the network elements (buoys) are demonstrated.

5.1 Network Topology

The sensor network created for the WSN-Aqua project is based on data-gathering sensor-equipped buoys placed on the surface of the water. The buoys send their collected data to a Gateway module located on the shore. In case a buoy is not in the radio range of the Gateway, they can send data in multi-hop fashion as they automatically create a mesh-network.

The radio communication between the buoys and the gateway is conducted on 433 MHz ISM band, therefore the nodes have about 500 m line of sight in case of 10 mW output power. This frequency is free to use in the EU for such radio systems, but the communication protocol has to comply with output power and duty cycle restrictions.

The gateway module sends the data collected from the buoys via a cellular connection (EDGE or 3G depending on coverage) to a server module in an aggregated way. However, in case of an emergency (i.e. thresholds are exceeded), the gateway sends the data to the server immediately upon arrival, so the server can send alert messages (SMS and email) to the corresponding authorities.

The management server communicates with the Business Intelligence (BI) server (via internet), which is responsible for gathering statistics and create multiple views and reports of the measured data.

The BI server can send configuration information and new firmware all the way down to the buoys via the private management interface. The flow of the data in the system is presented in Fig. 2.

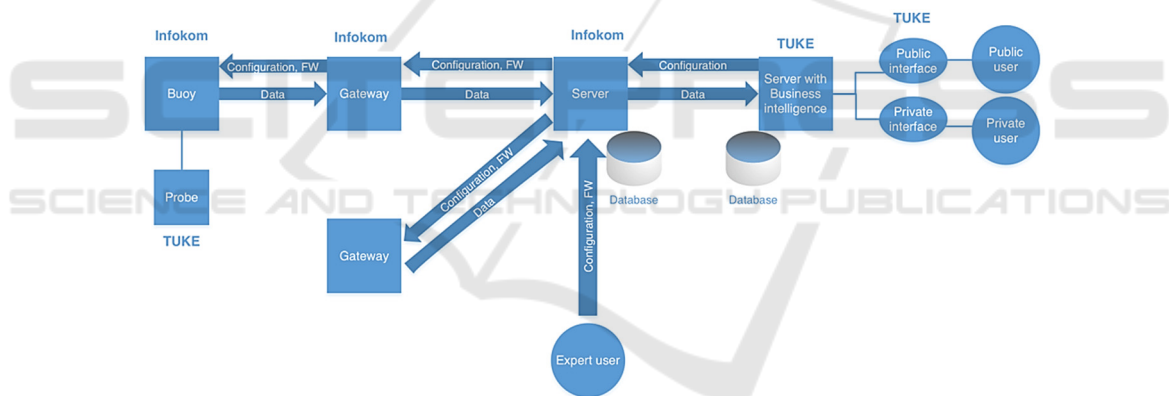


Fig. 2. Data flow diagram of the WSN-AQUA project.

5.2 Buoy and Gateway

The buoy (Fig. 3, Fig. 5, Fig. 6) consists of the following components:

- Buoy body (80 x 90 x 50 cm) with lockable opening made from plastic,
- 3 sensors according to Table 4 to gather data,
- Atmel ATxmega128A3 [1] microcontroller to conduct measurements and control the communication,
- TI CC1101 [2] radio module for data transmission,
- 433 MHz antenna for the radio module placed on top of the buoy body for better

range,

- 5 W solar panel to be able to operate without battery replacement,
- Battery capable of operating for a month without solar power,
- Charge controller board to switch between solar panel and battery power, developed for this project.

Table 4. Sensors used in the WSN-Aqua project.




			
Model ⁸	Ponsel PHEHT	Ponsel OPTOD	Ponsel C4E
Measured Property	pH/redox	dissolved oxygen	conductivity
Protocol	Modbus RS485 via adapter		Modbus RS485
Scope	wastewater, surface water, etc.		
Measuring range	0,00...14,00 pH, 0... 50 °C, -1000...+1000 mV	0,00 – 20,00 mg/l, 0 – 200% saturation	0...200 mS/cm, 0...2000 mS/cm, 0...20 mS/cm, 0...200 mS/cm
Measurement accuracy	± 0,1 pH, ± 0,1 °C, ± 2 mV	± 0,1%	± 0,5%
Compensation	Temperature	Pressure, temperature, salinity	Temperature
Calibration	5 point, it could be manually calibrated		



Fig. 3. Sensor node hardware, embedded into the terminals.

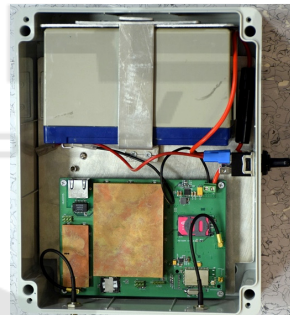


Fig. 4. Gateway node hardware in- into the buoys.

The Gateway module (Fig. 3) consists of the following components:

- Embedded PC for controlling the module,
- Cellular communication module integrated for sending data to the server,
- TI CC1101 [2] radio module for data transmission with the buoys,
- 433 MHz antenna for the radio module placed on top of the buoy body for better range,
- 100 W solar panel to be able to operate without battery replacement,

⁸ www.ponsel-web.com

- Battery capable of operating for a week without solar power,
- Charge controller board to switch between solar panel and battery power, developed for this project.

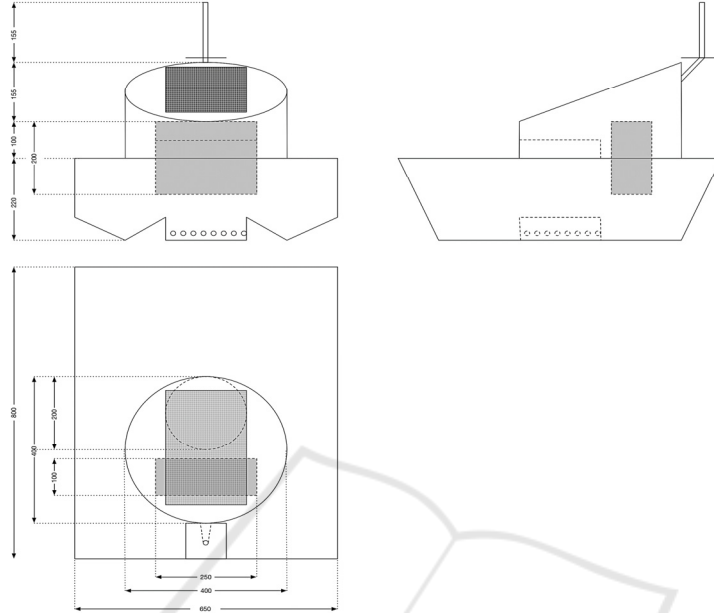


Fig. 5. The buoy was designed and manufactured in association with Aqua-Terra Lab Ltd., Hungary⁹.



Fig. 6. Deployed buoy during testing.

⁹ www.aquaterra.hu

5.3 Business Intelligence

The data gathered from the sensors are sent to a management server via the gateway module. This management server can send alerts in case of an emergency situation (e.g. the thresholds of the measured parameters are exceeded). The data is stored in a database and made available for a data analyzer component. This Business Intelligence server can present the data via a web interface to end users and expert (maintenance) users as well, and is able to collect statistics and generate various reports.

As part of the Business Intelligence, a management system is developed, which is capable of monitoring the status of every node in the network (e.g. battery status, alert configuration, diagnostics, etc.) and initialize firmware upgrade for future requirements. Administrators of the system can monitor and support the system via the management system running on the management server.

6 Research Results

This chapter is an excerpt from [3] and was presented at the Sensornets 2015 conference in Angers, France.

Creating wireless sensor networks requires a different approach than traditional communication networks because energy efficiency plays a key role in sensor networks which consist of devices without external power. The amount of energy used determines the lifetime of these devices. In most cases, data packets are less sensitive to delay, thus can be aggregated, making it possible to gather more useful information reducing the energy required to transmit information.

This chapter discusses the energy efficiency of different Forward Error Correction (FEC) [4] algorithms and presents a method to calculate the optimal amount of aggregation of the data packets in terms of power consumption, while taking into account the Bit Error Rate (BER) characteristics of the wireless channel. In addition, we provide a formula to determine the optimal wakeup signal length, which minimizes the energy consumption.

Fig. 7. shows the gain θ (the ratio of not using aggregation and using it) that can be achieved by using aggregation without FEC. The graph line representing $BER = 4 \cdot 10^{-3}$ is jagged because the number of required retransmissions is growing as the

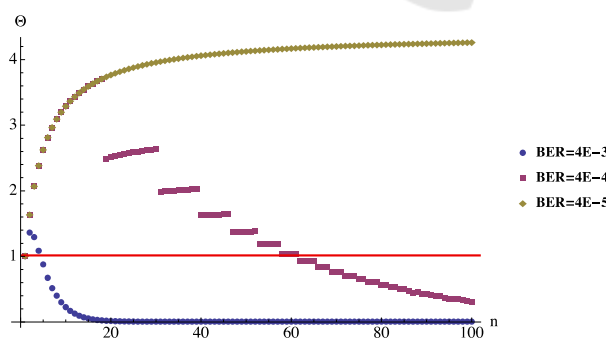


Fig. 7. θ for different BER values without FEC.

aggregation number n is increasing. The number of retransmissions is the same in the neighboring points that follow each other without a jump in their values.

In the figures of this section, the $\theta = 1$ values are marked with a red line to indicate the level above which the use of aggregation is more efficient.

Remark. This phenomena can be observed in case of other BER values, e.g. for $BER = 4 \cdot 10^{-5}$ the first jump is at $n \approx 200$, which is above the data aggregation value we considered worthy to examine.

Fig. 8. has the same setup as Fig. 7., with the only difference that Hamming [5], [6] codes were applied. The graphs show that in case of medium quality channel ($BER = 4 \cdot 10^{-4}$) and good quality ($BER = 4 \cdot 10^{-5}$) channel, there is no difference; the calculated points are perfectly aligned.

Fig. 9 and Fig. 10 show similarity of the values of θ for different BER levels with respect to aggregation number n for Reed-Solomon [7], [8] and BCH [9], [10] FEC codes.

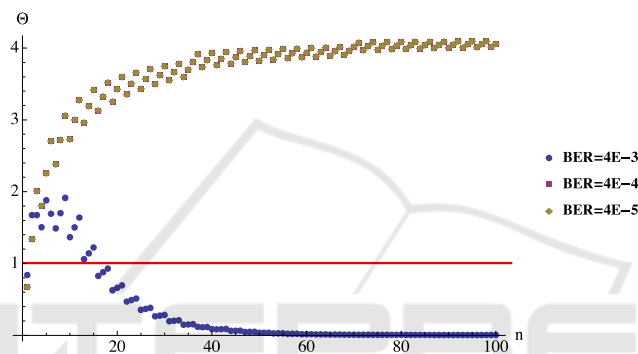


Fig. 8. θ for different BER values with Hamming code.

Analyzing Fig. 9 and Fig. 10 it can be noticed, which in case of a poor quality channel ($BER = 4 \cdot 10^{-3}$) for every aggregation number n we got better gain θ values than in case of better channel. This is because more powerful FEC codes provide more benefits compared to the same aggregation numbers in case of poor quality channels. The better BER channels result in the same gain θ .

Also, the graphs look like stages because the block length of Reed-Solomon codes

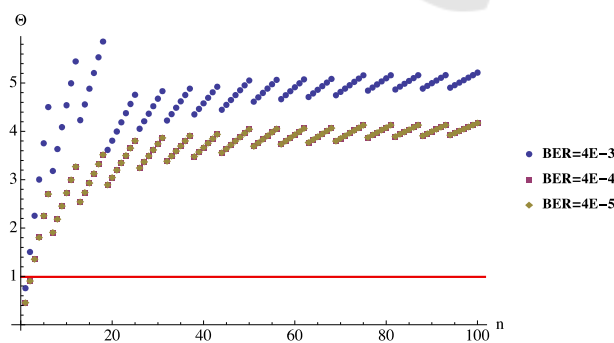


Fig. 9. θ for different BER values with Reed-Solomon code.

is fixed. Therefore, if the payload is not long enough, padding is used to fill the rest of the block, which is inefficient.

In Fig. 10 in case of aggregation number $n < 40$, the poor quality channel gains more using aggregation and BCH code than the better quality channels. Also, at better quality channel, there is significant gain compared to baseline (no aggregation, no FEC) just like in the case of Reed-Solomon codes.

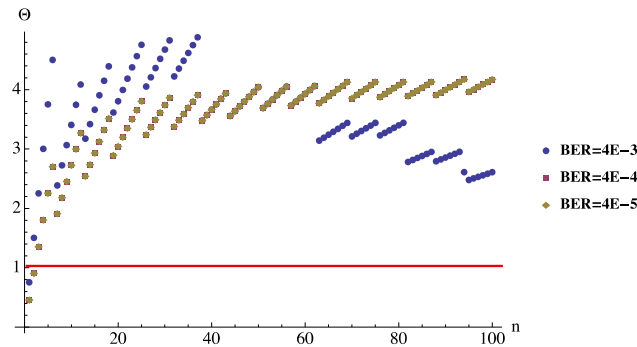


Fig. 10. θ for different BER values with BCH code.

The next three figures (Fig. 11, Fig. 12 and Fig. 13) compare the cases of different FEC codes grouped by channel quality ($BER = 4 \cdot 10^{-3}, 4 \cdot 10^{-4}$ and $4 \cdot 10^{-5}$) in respect to n . For every diagram, a table is included which shows the optimal aggregation number (the highest point of the graphs and the corresponding number of required retransmissions).

Remark. The optimal aggregation number can be much higher in case of BCH and RS codes, but the authors considered $n < 100$ aggregation numbers are worth dealing with because higher aggregation numbers would cause much higher delays. For example, if the aggregation number is $n=100$ and the packets are generated on an hourly base, then the aggregation delay can be as high as 100 hours. For most real-world scenarios, the delay should be within a day.

	No FEC	Hamming	BCH	RS
Opt. aggr. no.	2	9	37	18
No. of reps.	6	8	4	3

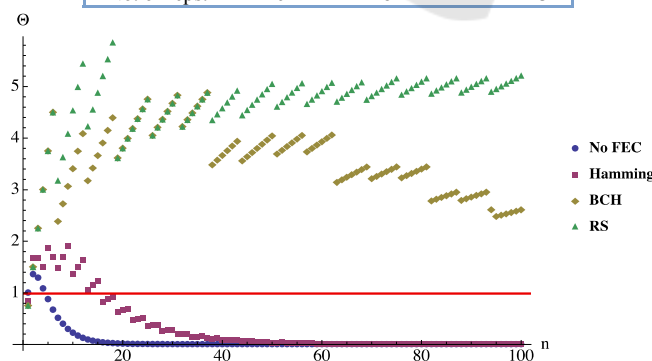


Fig. 11. Comparison of FEC codes at $BER=4E-3$.

Fig. 11 compares FEC codes on the worst quality channel. This scenario shows that the energy cost of different FEC codes is the best. The graph emphasizes that not using any FEC is the worst, and BCH and Reed-Solomon codes perform as the best. It can be seen that in case of lower aggregation numbers ($n < 10$), Reed-Solomon is the best solution, and from $20 < n < 40$ RS and BCH are at the same level. When further increasing the aggregation number, RS code is the most efficient again.

Fig. 12 compares FEC codes on a channel with $BER = 4 \cdot 10^{-4}$. It can be seen that in case of $n > 20$ aggregation numbers, FEC codes provide more energy efficient operation. The FEC codes perform similarly.

	No FEC	Hamming	BCH	RS
Opt. aggr. no.	18	98	94	100
No. of reps.	2	2	2	2

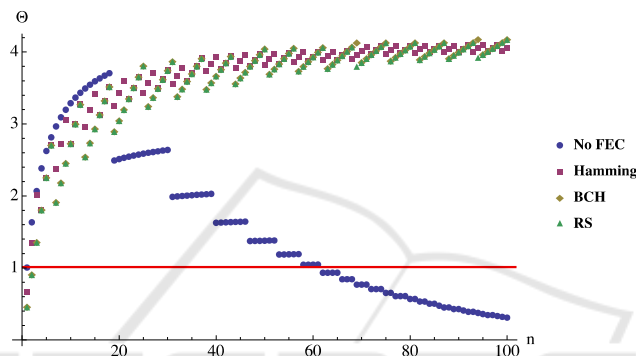


Fig. 12. Comparison of FEC codes at $BER=4E-4$.

According to Fig. 13, in good quality channels there is no benefit of using FEC codes because for every aggregation number, the case without FEC performs the best. The FEC codes just converge to the graph of no FEC case.

	No FEC	Hamming	BCH	RS
Opt. aggr. no.	100	98	94	100
No. of reps.	2	2	2	2

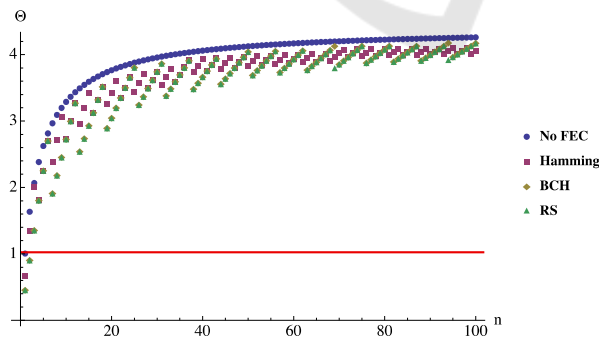


Fig. 13. Comparison of FEC codes at $BER=4E-5$.

7 Conclusions, Future Plans

This book chapter presented the involved partners, implementation details and research results of the WSN-Aqua project. The verification of the proof of concept test system, which is the main output of the project, will be carried out during May to June 2015, therefore the final results cannot be published in this article.

The Middle-Danube Valley Water Directorate is interested in the utilization of the project results with more measured parameters.

Future plans – after the project has been successfully finished – also include further cooperation between the parties involved in new HUSK-CBC tenders.

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