SHORT TERM SCIENTIFIC MISSION (STSM) – SCIENTIFIC REPORT

Action number: CA15127 RECODIS: Resilient communication services protecting end-user applications from disaster-based failures
STSM title: Self-organization in Sensor Networks as a Way to Increase Network Resilience During Disruptions
Grantee: dr. Rasa Bruzgiene, Kaunas University of Technology, Lithuania
Host: Prof. Nadezda Kunicina, Riga Technical University, Latvia
STSM start and end date: 26/11/2017 to 09/12/2017
Working Group: WG2 - Weather-based disruptions

PURPOSE OF THE STSM

Modern communication solutions are already inseparable from the use of Wireless Sensor Networks (WSN), so it application is increasingly spreading across different areas – energy, transport, healthcare and *etc*. Moreover, Wireless Sensor Networks are the basis for such technologies as Internet of Things (IoT), which is in the top of emerging technologies over the world. However, the Internet of Things was created regardless of it resilience to the disruptions. This is because of a high level of the vulnerability in Wireless Sensor Networks – unreliable wireless connections, resource-constrained features as limited transmission power, computing ability, storage space, *etc*., malicious attacks. And since the transmission of data in such networks is carried out wirelessly, the external factors, such as different weather conditions, can cause a serious damage not only to a node, but to the whole transmission process as well. Due to this, the questions, related to topology control, multi-path routing during the weather-based disruptions, should be analyzed with the focus to the correlation between self-organization of sensor nodes and quality monitoring in data delivery levels over Wireless Sensor Networks. That's because it is strongly related to the resilience mechanisms over the Wireless Sensor Networks.

In connection with this, the overall goal of this STSM was to investigate the possible way for self-organization in Wireless Sensor Network including the monitoring of quality parameters in order to increase the resilience of WSN against the weather-based disruptions. In order to achieve this goal, the host prof. Nadezda Kunicina was chosen, since she is investigating the application of Wireless Sensor Networks in the different areas of Critical Infrastructure for upcoming Industry 4.0.

The main objectives were:

- to get familiar with the infrastructure of Wireless Sensor Network for drinking water distribution system in water research laboratory at RTU;
- to identify external factors (as weather conditions), which affect the vulnerability of WSN-based water distribution system;
- to identify the technique for WSN topology control and routing in presence of possible disruptions;
- to include quality monitoring mechanisms in self-organization of WSN considering it impact to increase the resilience of WSN;
- to analyse and summarise the results of STSM for joint publications.

The outputs of this work provided results for the part of the chapter in COST RECODIS final book and will be used for further investigations within the objectives in WG2 group.

DESCRIPTION OF WORK CARRIED OUT DURING THE STSM

During the whole stay in Latvia and work in Institute of Industrial Electronics and Electrical Engineering of Riga Technical University, it was done:

- *regular meetings* with the scientists from the Institute of Industrial Electronics and Electrical Engineering discussing their achievements in investigations of Wireless Sensor Network application over different areas – water or electrical power supply, intelligent transport systems, heating systems, *etc*. Also, it was discussed about such WSN-based systems' resilience on the short time weather-based disruptions;
- *meetings* with the scientists from the Water Research Laboratory and familiarization with the WSN-based drinking water distribution system;
- *meetings* with the scientists from the Faculty of Electronics and Telecommunications, visits to their laboratories for optical communications, sensors in optics, network performance evaluation, sound acoustics and *etc.*
- *visit* to the real working "Baltezers" drinking water pumping station in Baltezers (near Riga city) and meeting with the engineers for a discussion about the monitoring system used at their station, the monitored parameters, sensors, which are used for water supply and the factors, which can impact the vulnerability of water distribution systems in Latvia;
- *identification* of external factors, which affect the vulnerability of WSN-based drinking water distribution system, which is installed not only in Water Research Laboratory, but as well tested till now in Liepaja, Talsi, Jelgava and Ventspils cities of Latvia;
- *identification* of present situation in data delivery over WSN-based drinking water distribution system, if the short time disruptions appear on it;
- *detailed solution* for self-organization over WSN-based drinking water distribution system with focus to quality monitoring in a presence of possible disruptions, which can help to control WSN topology and to continue data delivery by alternate routing;
- *investigations* of the proposed solution, considering it impact to increase the resilience of WSN;
- *summarization and submission* of the results from investigations during this STSM for joint publications.

The main points, that were most important to STSM grantee from investigations carried out during the STSM, are presented in the next section below.

DESCRIPTION OF THE MAIN RESULTS OBTAINED

The main focus of investigations during this STSM was on the developing a solution for self-organization over WSN-based drinking water distribution system with a monitoring of quality-focused parameters in a data delivery over this system in a presence of short-time (mostly caused by external factors) disruptions. The general structure, of the water distribution system with application of Wireless Sensor Network in it is presented in Fig. 1. The WSN-based drinking water distribution system consists of sensors for drinking water quality measurement by main parameters (flow, pressure, consumption, temperature, pH level, free and total chlorine concentrations, turbidity, Red-Ox potential, TOC, electrical conductivity, etc.), gateways – concentrators for metering data reading and transmitting to water utilities, subscribers, servers and databases (MySQL, PostgreSQL) with software for network monitoring, data processing, analysis as well water bookkeeping and billing information systems and reporting to subscribers.

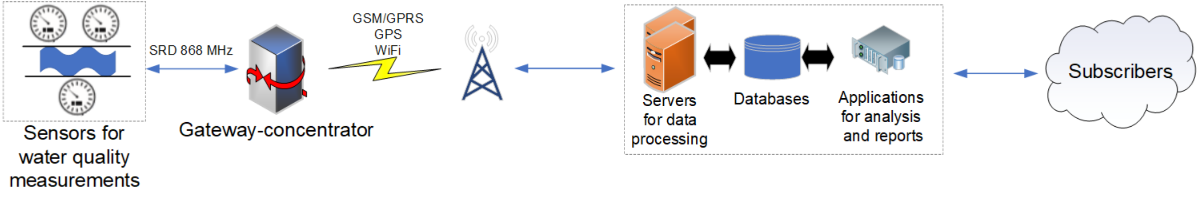

Fig. 1. A general structure of WSN-based water distribution system [1]

The use of Wireless Sensor Network in this system gives a valid way for better monitoring of water quality.

However, this doesn't provide a higher resilience of the system in a case of many possible disruptions, caused by natural, inattentive or malicious factors. More or less, the vulnerability of this system performance highly depends not only on the power supply but on the data transmission quality factors, which affect a sensitive data in all stages of its delivery. The reliability of WSN nodes depends on its sensitivity to changing environmental conditions, especially to different weather conditions. Of course, the impact of weather (changes in temperature, humidity, *etc.*) more or less is related to the wireless sensor nodes, which are located outside [2], [3]. Moreover, if the WSN is applied to drinking water distribution systems, the main factors that impact the placement of sensor nodes are hydraulic and physical parameters of drinking water distribution system [4]. In numerous cases, the locations are not favourable for signal transmission, e.g., manholes of basements. And since the transmission of data in such networks is carried out wirelessly, the external factors in a changing weather conditions (heavy rain, snow, freezing temperature, intensive fog, *etc.*) can cause serious damage to the whole transmission process as well. The effect of different weather factors to a radio signal quality as radio signal strength, signal attenuation over wireless communication links (as WSN) were exploited in several studies [5], [6]. However, there is no achieved an agreed opinion regarding the main dominant factor, which affects mostly the quality of a data transmission over Wireless Sensor Networks in the face of weather-based disruptions. So, the questions, related to the data delivery performance, network topology control, data routing techniques in WSN are still open.

The solution for self-organization of WSN-based drinking water distribution system includes three main factors – a) monitoring of a quality-focused (QoS, QoD and QoE) parameters, b) sensors' hierarchical routing principles and c) data routing method (see Fig. 2).

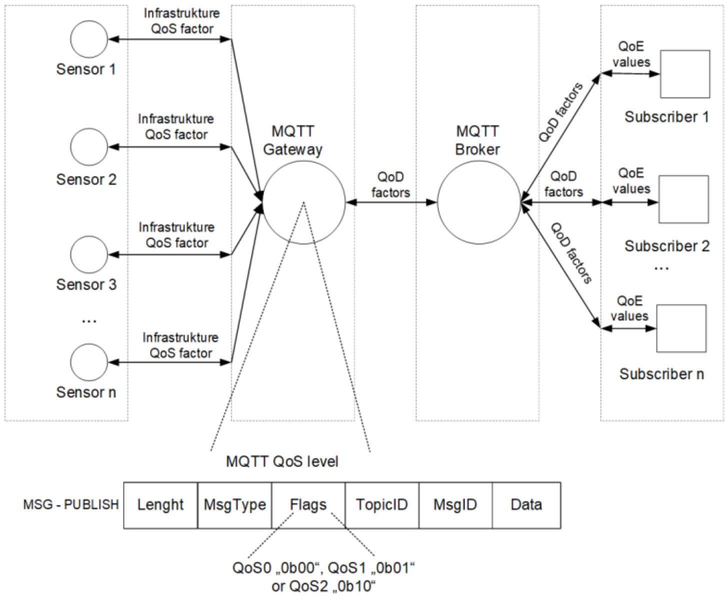

Fig. 2. Structure of proposed model for quality-focused parameters monitoring

Quality of Service (QoS) is influenced by the parameters from water and power supply infrastructures, as well system networking parameters. It has the influence to a quality of data delivered by both the application and the network (Quality of Delivery (QoD)). The factors, which influence QoD are mainly related to the transmission of data from the gateway to the subscriber (user). This means, that all parameters, routing protocols and path or data recovery solutions in the transmission way impact it. The perceptual evaluation (Quality of Experience (QoE)) of overall efficiency of system's performance is made by users of this system. Any negative affect of the factors in QoS or QoD can cause a significant impact on a quality of water, water supply or even a cost of water delivery. So, it means, that each part should operate jointly with others, and quality plays an important role in this. Sensors' hierarchical routing principles are based on the use of LEACH (Low Energy Adaptive Clustering Hierarchy) [7] protocol. Data routing is based on a Message Queue Telemetry Transport (MQTT) protocol [8] in the Latvian drinking water distribution system. In this case, the whole system is divided in to three logical blocks: publishers (sensors, gateways), broker (data processing software systems) and subscribers (users). The present situation of the data delivery over WSN-based drinking water distribution system in a case of disruption and proposed solution for self-organization is presented in Figure 3.

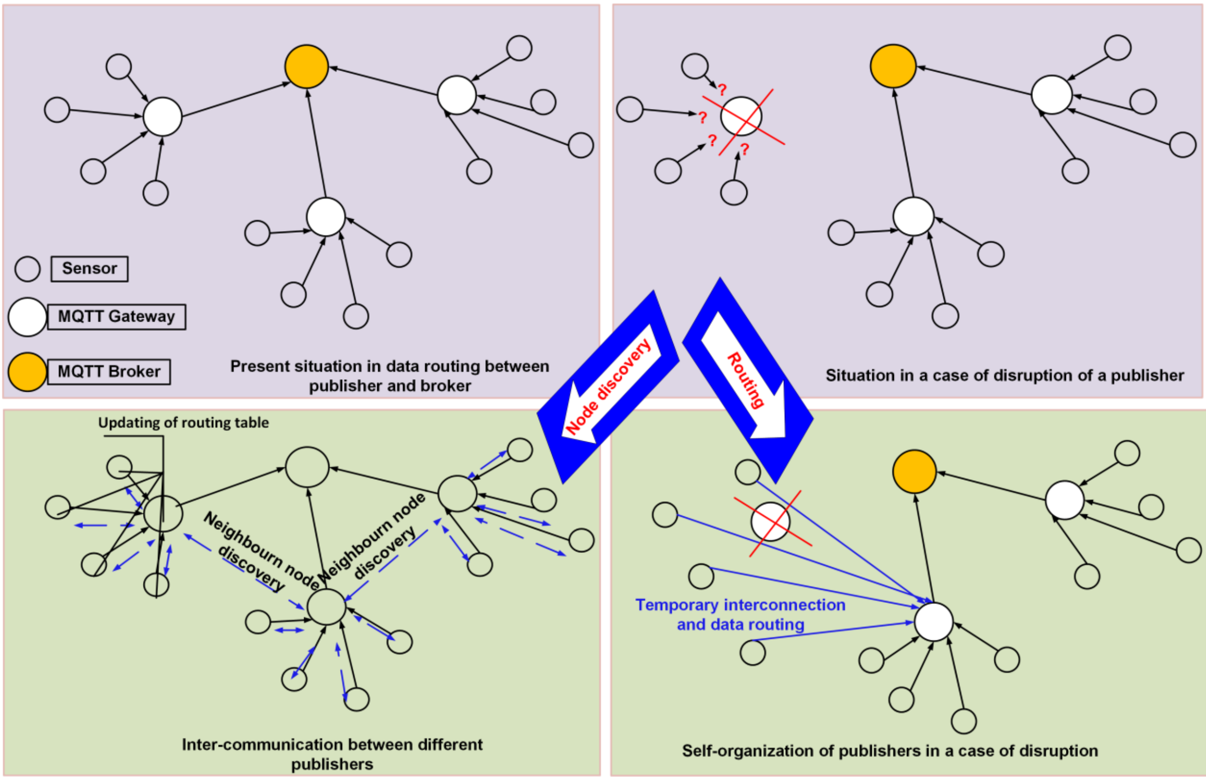

Fig. 3. Present situation and proposed solution for WSN-based water distribution system in a case of disruption

So, the investigations of a data delivery by different data routing MQTT QoS levels with the integration of operating principles of sensors' hierarchical routing into data routing in a case of possible failure on a gateway-controller of a system were carried out. MQTT is suitable to increase the reliability of the data transmission over vulnerable wireless or low bandwidth links. It is built on the top of TCP/IP and for data delivery uses three levels of QoS [9]. However, if the configuration of MQTT QoS means a higher level of the resilience in MQTT broker, it doesn't mean a higher resilience in a publisher or subscriber sides. And that was the main reason for integration of LEACH protocol principles into MQTT routing. The main results of these investigations are presented in Figure 4.

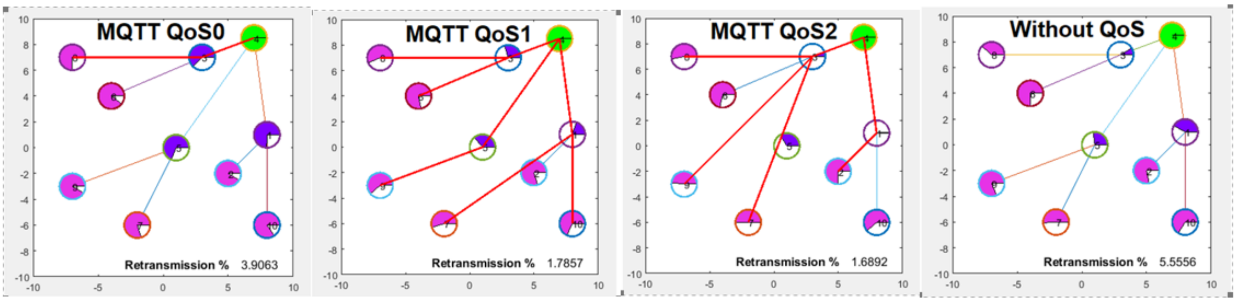

Fig. 4. Data delivery with and without QoS control in publisher side

The results showed, that if there is a quality control in data delivery (QoS1 or QoS2 levels of MQTT) and it is possible to re-organized topology of the sensors, this would help to maintain a stable operation of a system and reduce a percentage of messages from MQTT broker for data retransmission in a failure of any gateway - controller. Moreover, in this case, the relative delay of data delivery stays stable. Also, as a result, it was stated, that the use of MQTT QoS as a single solution in the WSN-based water distribution system doesn't increase the resilience of the system. The integrated solution for self-organization of sensors and data delivery with a selected QoS level would increase both - the overall system's resilience in a case of short-term disruptions and the stable system performance at that time.

FUTURE COLLABORATIONS

Based on the results, that were achieved during the period of this STSM, the host Prof. Nadezda Kunicina and the STSM grantee dr. Rasa Bruzgiene agreed to collaborate in joint investigations, papers and conferences not only on the topics that will arise within COST RECODIS WG2 activities, but on others, which will combine the expertise and knowledge of both sides as well.

Short term collaboration – 1) to investigate more deeply the impact of weather conditions as changes in temperature and humidity to the nodes of WSN-based drinking water distribution system; 2) to investigate the Quality of Protection aspects in Wireless Sensor Networks and it role in the resilience of such networks.

Long term collaboration – 1) to work together in preparation of the chapter in COST RECODIS final book; 2) to extend joint investigations and prepare research proposals.

These plans in host and grantee joint collaborations will enable to submit joint publications, participate in international conferences, visit each other more often, and get useful results for further joint work.

Foreseen publications/articles resulting from the STSM

The summarized results from the investigations during this STSM **were submitted** on 8 of December for:

- presentation in the 22nd International conference "ELECTRONICS 2018", which will be held in Palanga, Lithuania from 18th to 20th June, 2018;
- joint publication in the international journal "Elektronika ir Elektrotechnika", which is indexed in Thomson Reuters (ISI) Web of Knowledge Citation Databases (Science Citation Index Expanded (SCIE), Journal Citation Reports (JCR); IF – 0,859 (2016)), INSPEC, VINITI, EBSCO Publishing.

Also, the further joint investigations and results arising from it will be presented in next COST RECODIS meeting as well as published in scientific conferences and journals.

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