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Application of wireless sensor networks in flood detection and river pollution monitoring

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Abstract

In this paper, we propose a system for river monitoring based on wireless sensor network (WSN) technology. This system consists of sensor nodes that periodically measure several environmental parameters such as flow rate, water level, rainfall and pollution level. Each type of sensor node has two threshold values and measured data is compared with them at the end of the reporting interval.
Based on the current situation in WSN and measured data velocity sensors can use three different frequencies of reporting. Simulation of river monitoring system is done using Matlab software tool and the results of river maintenance during one WSN life cycle are presented. Two possible hierarchical system architectures are considered and their performance is compared. The optimal system architecture for this WSN application is discussed based on the obtained results.

Keywords: *environmental management, flood detection, river pollution, wireless sensor networks*

Rezumat. Utilizarea rețelelor de senzori wireless în detectarea inundațiilor și monitorizarea poluării fluviale

În această lucrare propunem un sistem de monitorizare a râurilor pe baza rețelelor de senzori wireless (tehnologiei WSN). Sistemul constă din noduri de senzori care măsoară periodic mai mulți parametri, cum ar fi debitul, nivelul apei, precipitațiile și nivelul de poluare. Fiecare tip de nod are două valori de prag și datele măsurate sunt comparate cu acestea la sfârșitul intervalului de raportare.
Pe baza situației actuale din WSN și a vitezei de măsurare, senzorii pot utiliza trei frecvențe diferite de raportare. Simularea sistemului de monitorizare a râurilor este realizată folosind un instrument software Matlab și sunt prezentate rezultatele analizei pe parcursul unui ciclu de viață WSN. Sunt luate în considerare două posibile arhitecturi ierarhice de sistem, iar performanța acestora este comparată. Arhitectura optimă a sistemului pentru această aplicație WSN este discutată pe baza rezultatelor obținute.

Cuvinte-cheie: *managementul mediului, detectarea inundațiilor, poluarea râurilor, rețelele de senzori wireless*

Introduction

In many industrial, scientific and medical applications, there is a need for intense and extensive data collection from the physical environment for monitoring purposes. In Serbia, about 13% of the territory (1.6 million ha) is endangered by floods and more than 2.08 million ha must be protected from floods of external and internal waters. It is necessary to drain the existing 2.67 million ha (Gavrilović, 1975; Serbian Ministry of Agriculture, Forestry and Water Management, 2001; Dragićević et al., 2009; Đorđević, 2009). Although significant protection systems have been built from the decades-long flood struggle, some of the erosion and torrential types can endanger about 90% of the territory.

Significant improvements regarding the sustainable use, protection and development of water resources in the Republic of Serbia have been made with the establishment of Water Management Information System of Serbia. The synchronization with relevant EU documents has been made, in particular with Directive 2007/60/EC of the European Parliament and the Council of the European Union from 23rd October 2007 on the assessment and management of flood risks (EFD 2007/60/EC) and with SOFPAS (*Study of Flood Prone Areas in Serbia*) project (*Indikativna mapa područja rizika od poplava*, 2016; Đorđević, 2017).

However, legacy systems for river monitoring based on complex sensor devices that use point-to-point communication for sending data did not provide the necessary flexibility, scalability and they required high operational and maintenance cost. Further development of communication technologies has enabled the application of wireless sensor networks (WSN) (Dargie & Poellabauer, 2011).

WSN applications are based on usage of small, low-cost and multi-functional sensor platforms. These platforms have the ability to form ad-hoc wireless networks in the area of interest, communicate with each other and deliver collected data to the end user. A river monitoring schemes based on WSN technology have been already studied in (Morias et al., 2005; Seal et al., 2012; Ahmad et al., 2013; Pasi & Bhave, 2015).

The rest of the paper is organized as follows. In the second section, the WSN architecture and its principles of work are defined. The third section contains description of the proposed simulated model for river monitoring. The main part of this paper is explained in the fourth section, where the simulation results are presented. Based on the obtained results, conclusions are pointed out in the fifth section.

Wireless Sensor Networks

For the needs of collecting and transmitting data in WSN, a multifunctional platform called sensor node (SN) is used. By placing a large number of SNs within the area under the observation, a sensor field is formed. In general, SNs are scattered within the sensor field in order to perform local measurements of the observed phenomenon. The collected information is transmitted through mutual communication between SNs to the Sink. Sink represents the destination of all packets that transmit data from SNs and enables two-way communication between the end user of WSN with all SNs. Sink is considerably more complex than SN, it has larger size and greater possibilities for data processing. Communication with the end user of WSN is realized using the available network infrastructure in the area of interest. In most cases, Sink is a Base Station of the corresponding mobile network that transmit data collected from SNs to external network (Internet) (Buratti & Verdone, 2008). One possible WSN communication architecture with two sensor fields is shown in Fig. 1.

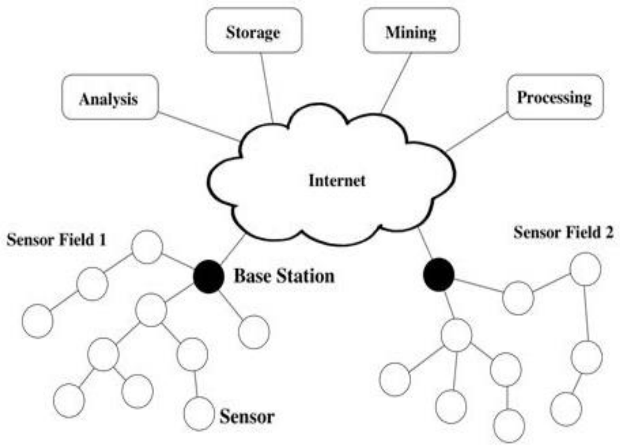

Figure 1: WSN communication architecture

Data collected by SN is forwarded to Sink over a large number of SNs and routed through the ad-hoc multi-hop WSN architecture. In many applications, it is not necessary that all SNs in the network deliver data to Sink. In order to reduce the amount of traffic and energy consumption in WSN, the combined information obtained by combining the data of more SNs is delivered. Successful data aggregation can be achieved by the formation of mutually separated groups of SN clusters (Duan & Yuan, 2006). The cluster consists of several SNs, one of which has the role of a cluster coordinator - cluster head (CH). Other SNs in cluster communicate only with CH while CH coordinates the process of communication and collection of sensor data and performs data aggregation. A set of all CHs in WSN that communicate with each other and perform routing of data and packets from and to Sink represents a higher layer of two-layer WSN hierarchical architecture. The lower layer consists of SNs within a single cluster without the possibility of mutual communication. The choice of CH is done according to the criterion of the lowest energy consumption possible, as well as in accordance with the application of WSN, traffic requirements of the network and data routing needs (Yadav et al., 2007; Cengiz & Dag, 2017).

Simulation Model

We consider the use of WSN for monitoring the parameters of the river basin in each cell (cluster) that covers the area shown in Fig. 2 (Marković & Drajić, 2015; Lukić & Lukić, 2017). Simulation environment supports two Sink positions: in the centre of the sensor field and at the centre of the lower edge of the sensor field. WSN consists of two cell types: RMC (River Monitoring Cells) and RFC (Rain Fall Cells). RMC cells includes five RMSN (River Monitoring Sensor Node) with sensors for tracking the river flow rate FRS (Flow Rate Sensors), current water level WLS (Water Level Sensors) and river pollution level PLS (Pollution Level Sensors). In addition, there are four RFSN (Rain Fall Sensor Node) with rainfall sensors RFS (Rain Fall Sensors) in each RMC cell on the ground by the river. Each cell has one SN that performs the calculations, it is called computational node (CN), and at the same time represents a permanent CH for that cell. To track the river basin for possible rise in water level - Flood Detection Monitoring (FDM) function and pollution level - River Pollution Monitoring (RPM) function, it is necessary to send the information collected by each CH to the Sink located at some distance. For this reason, additional RFC cells are formed, through which the data from the RMC cells are routed to the Sink. Since these nodes would not only be used for transmission, they also contain RFSN sensors and thus measure the amount of rain fall on a much wider surface. Each RFC cell includes nine RFS sensors and one of them is CH located in the middle of the cell.

For all parameters measured by FRS, WLS, RFS and PLS sensors two values are defined: actual value and the measured value with the given accuracy of the measurement. FRS, WLS and RFS sensors perform measurements every 15 minutes and PLS sensors every 30 minutes and they process the received data in the given observation interval. Depending on the situation in WSN the length of observation period can be 15 minutes (alarm for FDM function), 1h (increased alertness for FDM function), 6h (normal operation for FDM function), 2h (alarm for RPM function), 6h (increased alertness for RPM) and 12h (normal operation for RPM function). At given time intervals, SNs send data with reports that contain a minimum, maximum and medium value for the collected measurement result.

SNs for each measured parameter value have defined two thresholds so they can have three states: below the lower threshold, between two thresholds and above the upper threshold.

Depending on the current state and the change in measured values it is possible to define the status of the sensor for FDM and RPM function, according to which SN can independently decide to send reports more often to its CH. Depending on the results collected during the current observation period CH can independently change the status of reporting in the cell. In that way, for each FDM and RPM function three cell states can be defined: normal operation (very rare reporting), increased alertness (slightly more frequent reporting) and alarm (frequent reporting).

Two hierarchical WSN architectures are examined: single-hop and multi-hop. In a single-hop architecture CH sends data collected from cluster members directly to the Sink. In a multi-hop architecture CHs form a higher network layer and through multiple jumps by mutual communication send data from their cluster to the Sink. Simulation of the river monitoring system is performed with Matlab software tool. Fig. 2 contains a graphical representation of WSN model simulated in Matlab.

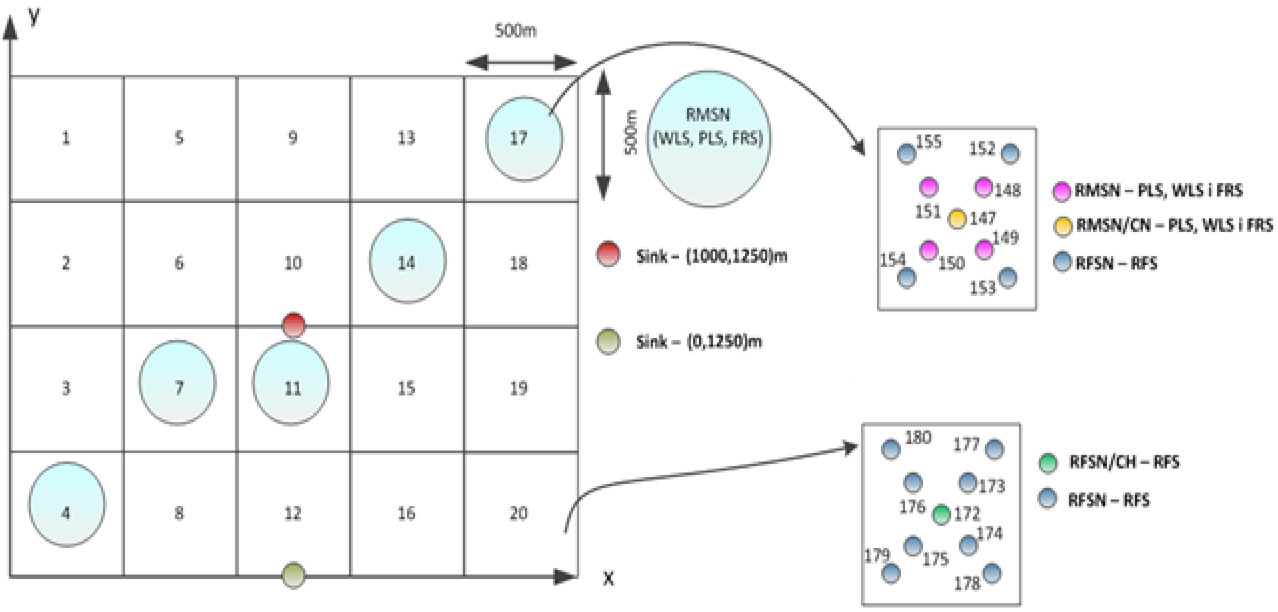

Figure 2: Simulated WSN model with RMC and RFC cells

Results

The WSN work is designed in 15-minute time frames. Observation lasts one month so there are 2880 time frames during the network life cycle. At the beginning of each time period, the output variables obtained in the previous reporting interval are set as initial values for the current period.

During the specific reporting interval, identical procedures for both FDM and RPM function are executed and they include the following: calculating the minimum, maximum and mean data values collected from the corresponding sensor type, defining of the SN state and cell state based on measured data and counting the number of packets sent from SN to CH and the number of aggregated packets sent from CH to the Sink.

Simulation model is implemented in a way that makes SN change its state to increased alertness or alarm state if at least one sensor type within the FDM and RPM function exceeds the lower or upper threshold, respectively. It has also been assumed that the cell state changes if the state of at least half of the SNs in that cell has changed. In order to examine the reliability of the event detection, the root-mean-squared error (RMSE) of the measured values is calculated for each sensor type.

At the end of the simulation the number of packets sent by each SN during the network life cycle is stored in vector SN_sent. The number of aggregated packages sent by each CH to the rest of the network is stored in the corresponding vector CH_sent. The residual energy of SNs can be found in vector SN_E_new. The values of these vectors during the WSN work is graphically represented in Fig. 3 in case of a single-hop WSN architecture.

The same procedure is performed on a multi-hop WSN architecture. Corresponding vector values are calculated and presented in Fig. 4. The number of packets sents from SN to CH and the number of aggregated packets sent from CH to the Sink is decreased in relation to the single-hop case.

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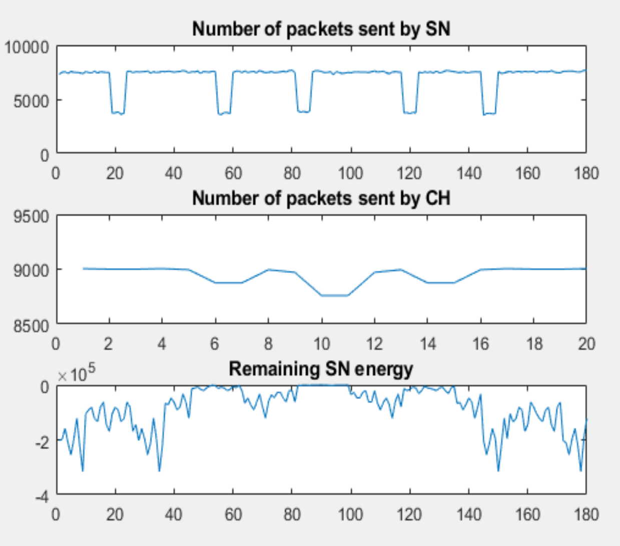

Figure 3: Content of *SN_sent*, *CH_sent* and *SN_E_new* in case of a single-hop WSN architecture

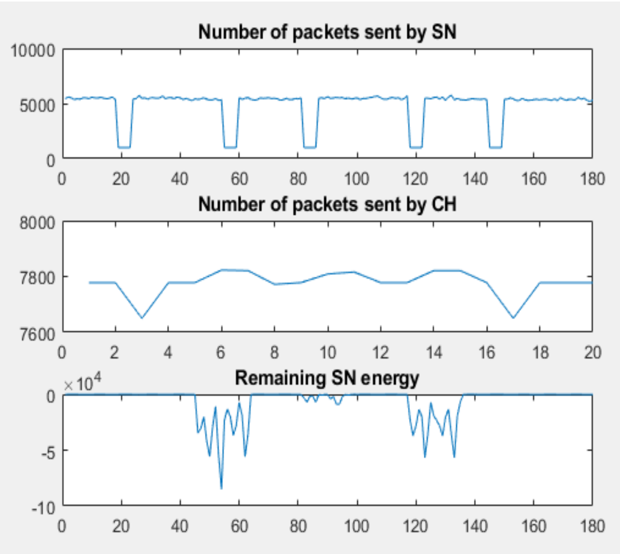

Figure 4: Content of *SN_sent*, *CH_sent* and *SN_E_new* in case of a multi-hop WSN architecture

In a multi-hop scenario CHs are communicating with each other so the total number of aggregated packets is distributed among CHs in WSN which results in the lower average number of packets sent by CH to the Sink. Also, the remaining energy of SNs is much higher compared to a single-hop WSN architecture due to the very nature of a multi-hop communication in WSN.

For both hierarchical system architectures the RMSE of data collected by each sensor type is obtained. These values are shown in Fig. 5 and 6 for a single-hop and a multi-hop WSN architecture, respectively. Results are very similar although deviation between values predicted by simulation model and observed values is slightly higher in a single-hop case.

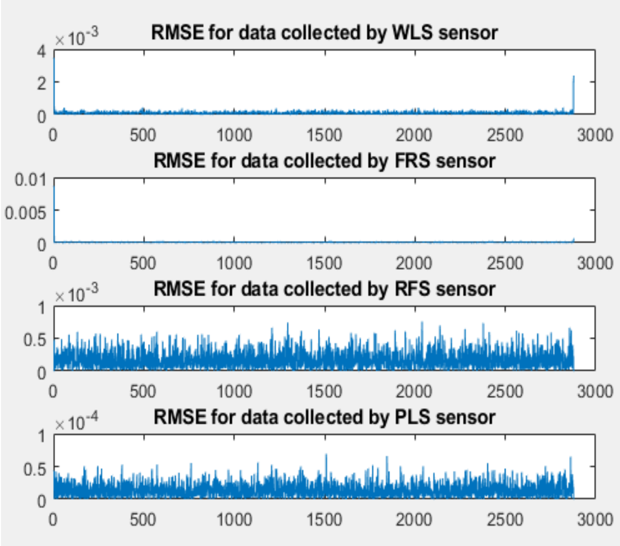

Figure 5: RMSE values for data measured by SNs in case of single-hop WSN architecture

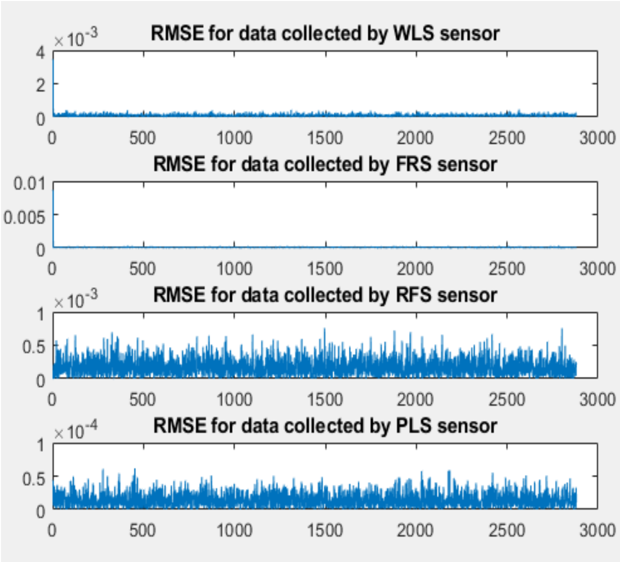

Figure 6: RMSE values for data measured by SNs in case of multi-hop WSN architecture

Conclusion

This paper considers usage of WSN technology in the river maintenance. Proposed simulation model gives very precise results and it shows that environmental parameters were accurately measured during the observation period.

Moreover, it was concluded that a multi-hop architecture is more efficient in terms of energy consumption compared to the single-hop architecture and that it increases overall network life span. Based on the obtained results the multi-hop hierarchical architecture represents the optimal system architecture for this WSN application.

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