Simulation of Wireless Sensor Network for Flood Monitoring System

Manal Abdullah

Faculty of Computing and Information Technology FCIT,
King Abdulaziz University KAU, Saudi Arabia
maaabdullah@kau.edu.sa

Abstract. Monitoring environmental disaster such as flooding is highly improved using ICT. Deployment of sensor networks to monitor physical environment is one of the most important applications for Wireless Sensor Networks (WSNs). In this paper, we model and simulate flood monitor case in Jeddah, Saudi Arabia. Using OMNET++ simulator , we employ Direct Diffusion DD routing protocol to operate flood case.. We first have developed one of the well-known sensor network protocols which is DD. Then, we evaluate the performance of our simulated case by computing several statistics including power consumption, end-to-end delay, throughput to measure the availability and scalability of the network and decide the best possible configuration that well monitor our case. Our results determined that the best sensor network configuration for flood monitor system in the area of interest is 135 sensors with memory capacity of 80 to 120 message entries.

Keywords: WSN, Flood control, Direct Diffusion, Discrete Event Simulation, OMNET++.

1 Introduction

Flooding is a growing problem in the world. In Jeddah, Kingdome of Saudi Arabia (KSA), we have a special interest with the flooding problem because this disaster happened twice in the few recent years. It has a significant effect on residents, businesses and commuters in flood areas. The cost of damage caused by flooding correlates closely with the warning time given before a flood event, and this makes flood monitoring and prediction critical to minimizing the cost of flood damage. Wireless Sensor Networks (WSN) has proven its worth in monitoring physical quantities and environmental disasters. That is because this technology has the capability of quick capturing, processing, and transmission of critical data in real-time with high resolution. Environmental disasters are one of the major applications of wireless sensor networks. Jeddah in KSA has faced flood disasters that could have less harm on citizens with an advanced networking monitoring and alarming system.

WSNs consist of individual nodes that are able to interact with their environment by sensing or controlling physical parameters; these nodes have to collaborate to fulfill their tasks as, usually, a single node is incapable of doing so; and they use wireless

A. Marcus (Ed.): DUXU 2014, Part III, LNCS 8519, pp. 255–264, 2014.

communication to enable this collaboration. Sensor is the object used to gather information about a physical object or process, including the occurrence of events (i.e., changes in state such as a drop in temperature or pressure). These are called remote sensors. From a technical perspective, a sensor is a device that translates parameters or events in the physical world into signals that can be measured and analyzed [1]. In most cases, it is very difficult and even impossible to change or recharge batteries for these sensor nodes. For this reason, energy efficiency is of primary importance for the operational lifetime of a sensor network. [2],[3]

The focus of this work is to simulate a wireless sensor network flooding monitoring system. The system will be responsible for water level monitoring during the flooding periods.

OMNeT++ [4] is a discrete-event simulation platform that is trusted to model and simulate variety of networking systems. As a first step, we have developed one of the well-known sensor network routing protocols which is Directed Diffusion. We evaluate the performance of our simulator by computing several statistics including many performance parameters to measure the availability and scalability of the network and decide the best possible configuration. Some previous work has proven its worth using same type of monitoring. It shows how to benefit from WSN and solve this problem.

Hughes, et. al.[5] introduced two main classes of flood prediction models. The first is referred to as spatial models, and the second class is referred to as point prediction models. Traditional flood monitoring approaches impose a rigid separation between the on-site WSNs that are used to collect data, and the off-site computational grid which is used to analyze this data.

Castillo, et. al. [6] presented the ongoing effort in providing the population of the Andean region of Venezuela with a flashflood alerting system by making use of wireless communications and information technologies. A key component is a WSN that is used for monitoring the environment and tracking the disaster. The main objective of the system is to gather environmental information and, based on the collected data, to alert the authorities and the population at risk autonomously.

Price, et.al.[7] developed an environmental sensor network deployed in the Great Crowden Brook catchment area of the Peak District, United Kingdom. The main aim was to assess the deployment methodology for “multi hop” networks and assess the sensor node technology choices from an operational perspective. The area of interest is deep within a steep sided valley where there is no GSM coverage, and thus the only cost effective way to transmit real-time sensor readings to a remote lab is via multi-hop networking. The design strategy has been to minimize the duration and frequency of communications, and limit such communications to the transmission of summary data (from node to node) and alarms from base-station to end user.

2 Sensor Network Architecture

Wireless Sensor Network (WSN) is a type of networks that consists of individual nodes and are able to interact with their environment by sensing physical parameters.

There are two types of node: Source which is the sensor that provide sensed information, Sink which is the base station that acts as the destination where the information should be delivered.

Sensor networks are usually related to real-time computing. Despite the differences in purposes of sensor networks they all share the need for distributed form of organization[8]. The following subsections detail the WSN components.

- **Sources:** they are the entities which provide information that is the actual nodes which sense data. [8]
- **Sinks:** They can be called the destination where the information should be delivered to. They could be in 3 types: just sensor/actuator node – entity outside the network e.g. *Personal Digital Assistants* (PDA) or handheld – gateway to another larger network such as Internet [8].
- **Base Station (BS):** It is a single powerful node, usually a sink node, which is used to connect a WSN to a wired network. BS is supported with powerful resources and extra capabilities in communication and processing compared to a normal wireless sensor node [9].

2.1 Sensor Node Hardware Overview

A basic sensor node comprises five main components [8] as shown in Figure 1

- **Controller**: The controller is the core of a wireless sensor node. It collects data from the sensors and processes this data. It is the *Central Processing Unit* (CPU) of the node.
- **Memory** Some memory to store programs and intermediate data is required.
- **Sensors and actuators:** The actual interface to the physical world; devices that can observe or control physical parameters of the environment.
- **Communication devices:** It is used to exchange data between individual nodes.
- **Power Supply:** As usually no tied power supply is available, some forms of batteries are necessary to provide energy.

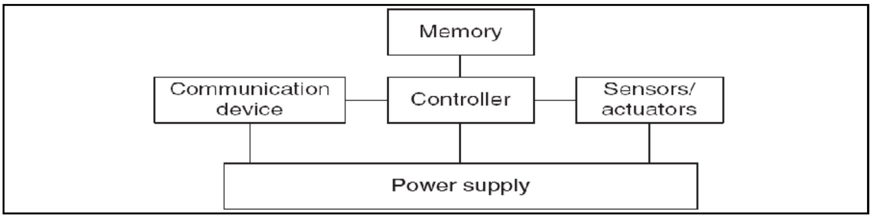


Fig. 1. Overview of main sensor node hardware components [8]

2.2 Water Level Sensors

Liquid level sensors as its name indicates are used to detect the level of the liquid and the interfaces on the liquids, where the liquid in the intended network is water. Three level sensors types, that are Ultrasonic, submersible and bubbler. These sensors are considered to be used for water level monitoring in the case of floods. Comparing between them, submersible sensor seems to be the most suitable. Ultrasonic sensor has the disadvantage of being damaged by floods. This is critical since our network will deal with floods caused by rains so the reliability of the sensor is not guaranteed. Bubbler sensor has the disadvantage in terms of maintainability which will require continuous visits to refill the tanks. In addition, the power consumption is large in this type of sensor that besides the cost [10][11]. In contrast, submersible sensor is waterproof, using power moderately, requires little maintenance and easy to install. For those reasons it will be the choice for the network. [10]

2.3 Routing Protocols

Recent advances in wireless sensor networks have led to many new protocols specifically designed for sensor networks where energy awareness is an essential consideration. The four main categories explored for WSN are data-centric, hierarchical, location-based and Network Flow and QoS-aware protocols [12].

Direct Diffusion is a data dissemination and aggregation protocol, which is data centric and application aware. It has several key elements as follows:[13][14]

- *Data naming:* sensing tasks are sent by the sink in attribute-value pairs.
- *Interests and gradients:* Each named task description constitutes an *interest* that has a timestamp field and several *gradients* fields. As *interest* propagate through the network it, and the *gradient* from source back to sink is setting up.
- *Reinforcement:* at the beginning the sink sets low data rate for all the incoming events. Then it can reinforce one particular sensor to send the events with a higher data rate by resending the original interest message into a smaller interval.

This protocol meets the main requirements of WSNs such as energy efficiency, scalability, and robustness. However, it has some limitations such as; the implementation of data aggregation requires some synchronization techniques that are not realizable yet in WSNs. Also, DD can't be applied in applications that require continuous data delivery to the BS [13],[14],[15]. For these limitations, we developed DD protocol for our flood monitoring system by modifying the original DD in application and network layers.

3 Problem Formulation

Many agencies over the world are taking care of the weather and environmental phenomena. In Kingdom of Saudi Arabia (KSA), we have the Center of Excellence in Environmental Studies (CEES), as one of the excellence centers affiliated to King Abdulaziz University (KAU). Also, the General Directorate of Civil Defense (GDCD) and Presidency of Meteorology and Environment (PME) in KSA who warn people by sending warning reports to media and GDCD. The scenario of operation is illustrated in figure 2 .

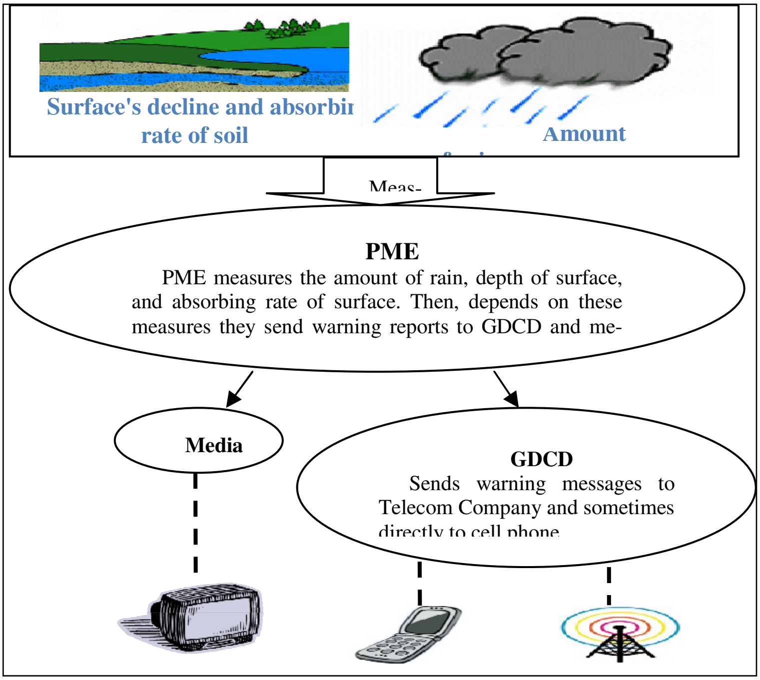


Fig. 2. The scenario of flood alert

3.1 Simulation Setup

The following information is used for model setup

- **The Monitored Area:** Bani Malek St. 4896.27m [from Google Earth]. This street was the most street that have been affected by floods in 2011.
- **Number of Base Stations (sinks):** one placed in the middle of the street.
- **Number of Sensors (sources):** Obstructions assumed to be presented, so the radio frequency for the sensor is almost 305m. This leads to 16 sensors to cover one side of the street. For self-healing purposes we will add another sensor in the opposite side of the street which form zigzag shape, as shown in figure 3 .The total number of sensors are 32.

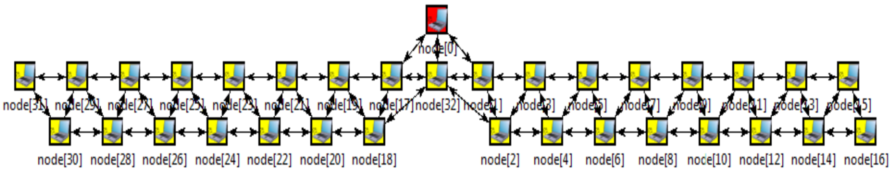


Fig. 3. WSN Configuration in OMNet++

- **Sensor Installation:** 1 meter altitude from the surface of the street. Thus the ground height is the zero level of the sensor.
- **Interest:** According to *Federal Emergency Management Agency* (FEMA), six inches of moving water could breakdown most of cars and make the walker fall [16].

For energy saving, all sensors are off and wake up when tasked by the sink. The sink sends a task or interest at specific periods. The sensor which measures an event will send back the response to the same gradients. Once the sink received event, it resends an interest with higher data to Reinforce specific path. The flood monitoring system work flow is illustrated in figure 4.

The above information has been used to setup the simulation model using OMNET++ [4]. The parameters adopted during simulation test along with their respective values are summarized in Table 1.

Table 1. Simulation Parameters Configuration

Values	Simulation Parameter
17400	**Network size (m2)**
135	**Number of sensors**
100	**Broadcasted message entries**
62	**Packet size (byte)**
6	**Threshold (inch)**
1.9	**Interval (s)**

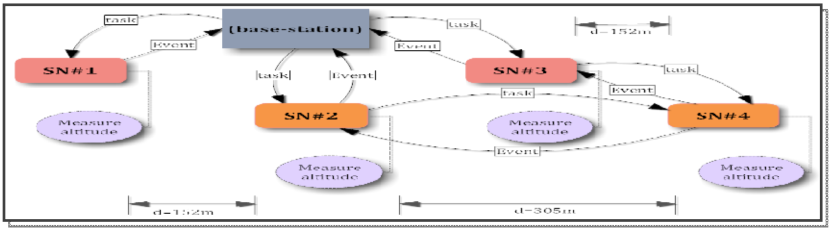
4 Results and Discussion

4.1 Performance Metrics

The high growth of WSN research has opened challenging issues about their performance evaluation. Performance is affected by several issues. In this section we review performance based on the scalability and availability which we have used in our research.

In scalability, WSN consists of hundreds of sensor nodes, densely deployed in a regional area[17]. Protocols must thus scale well with the number of nodes. This is often achieved by using distributed and localized algorithms, where sensor nodes only communicate with nodes in their neighborhood [18]. In availability, as most sensor nodes will be restricted concerning their energy capacity, all protocols and algorithms must be energy-efficient and save as much energy as possible. Since the most energy is consumed during the wireless communication, the radio must be turned off most of the time. But also the transmission of data should be energy-efficient in order to minimize the number of sent and received packets [18].

(a) System Model: Events which satisfy task requirements will arrive to the base station. Sensors in the same side of the street has same color.



(b) Reinforcement Illustration: If sensor#4 has measured an altitude for the water that exceeds the threshold, the base station will reinforce its path to be updated regularly with the situation.

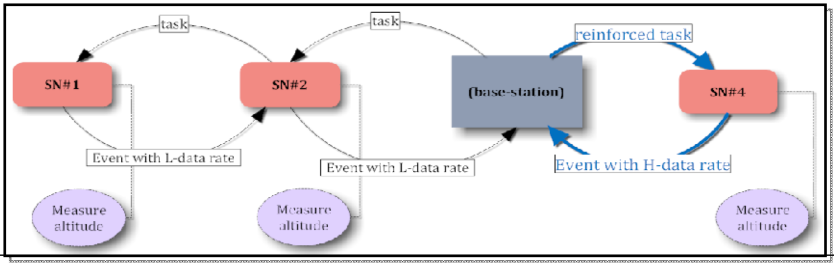


Fig. 4. Flood Monitoring System workflow

Our research is evaluated against availability and scalability. Availability is determined by two metrics: average energy cost and storage capacity. While scalability is measured by throughput and delay.

4.2 Availability

Availability is the property of the system being in function. In our research , we have measured the availability using two metrics: average power consumption and throughput. Figure 5 shows the average energy consumption of the network while the number of nodes varies from 18 to 264. Energy consumption is increased with increasing the number of nodes in the network due to routing process.

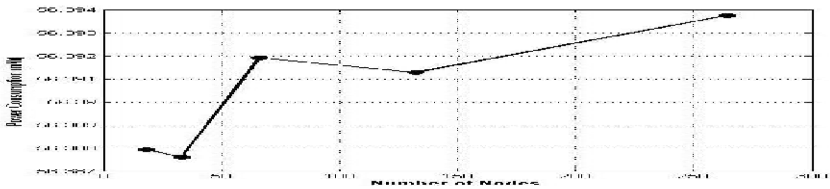


Fig. 5. Average energy cost per node versus number of sources

Storage affects on routing process since it is based on how many packets will be sent/forwarded via the network. The factors used in this metric are the number of data packet forwarded versus the max number of entries in the network. Figure 6 shows relationship between number of entries in the network and number of packets forwarded. The importance of increasing storage has benefit in conserve the network traffic by decreasing the number of packets forwarded through nodes.

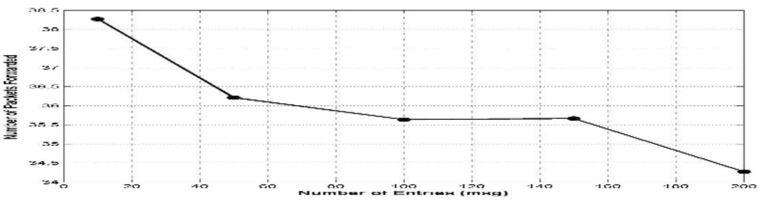


Fig. 6. Cost of storage (Packet forwarded versus network entries)

4.3 Scalability

The number of nodes in WSN has an impact on network scalability. Scalability could be measured with the following metrics: End-to-end delay and throughput. A higher latency when network workload is high due to increasing sources and the network contention caused by path sharing between different sources. From figure 7, the max end to end delay exists at 132 network nodes after which we have very small decrease of latency.

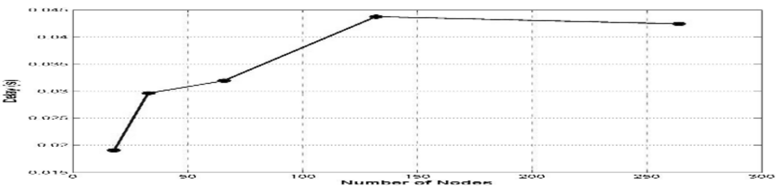


Fig. 7. End-to-End transmission delay versus number of sources

Throughput is a measure of network performance that is the average rate of bit per second (bps) that has successfully deliver over a communication channel. Figure 8 shows that throughput decreases with the increase of number of nodes. This is because the network is not sufficiently loaded and the required transmission messages are less than the network capability. At nearly 70 nodes, the throughput starts increasing.

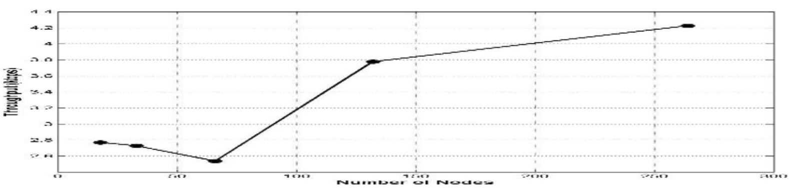


Fig. 8. Throughput versus number of nodes

5 Conclusions

The wireless sensor network used in our simulation scenario consists of 32 stationary sensors and a base station. The nodes are supposed to be aligned in the monitored area of 17400 m2. At each simulation test, the nodes transmit sensed data during their corresponding time slots, only when an incident is detected. This happens whenever the current value of the sensed attribute is greater than the threshold value which is set to 6 inches according to FEMA [16].

In order to experiment the performance for our simulated network, we review the performance based on the scalability and availability . In addition, the results of analysis to check that the results conform to the rules defined by the requirements. We have reached the optimum configuration of WSN Flooding System in the assigned area as:

The number of sources must be more than 132 node to operate with minimum delay. Using 132 nodes, the longest delay between two nodes is less than 0.04 s. The number of nodes between 70 to 150 nodes would also optimizes the network power consumption.

The importance of increasing the storage has benefit in conserve the network traffic. However, because memory capacity is limited, between 80 and 120 message entries are quite enough and result in a reasonable number of forwarded packets.

Acknowledgement. I would appreciate the support and help of the computer science department at Faculty of Computing and Information Technology FCIT, King Abdulaziz University KAU.

References

1. Ahmed, A., et al.: Wired Vs Wireless Deployment Support for Wireless Sensor
2. Oh, E.: Study of Network Design Factors That Influence Industrial Fieldbus Network-Based System Integration. In: Industrial and Systems Engineering. The Ohio State University (2009)
3. Dargie, W., Poellabauer, C.: Sensor Classifications. In: Fundamentals of Wireless Sensor Networks: Theory and Practice, p. 336. John Wiley & Sons, United Kingdom (2010)
4. OMNet++, User Manual Version 4.3, `http://www.omnetpp.org/doc/omnetpp/manual/usman.html` (last retrieved at December 2012)
5. Hughes, D., Greenwood, P., et al.: An intelligent and adaptable grid-based flood monitoring and warning system. Citeseer (2006)
6. Castillo-Effer, M., Quintela, D.H., et al.: Wireless sensor networks for flash-flood alerting. In: Proceedings of the Fifth IEEE International Caracas Conference on Devices, Circuits and Systems (2004)
7. Price, M.C., et al.: Development & Demonstration of the Utility of Wireless Environmental Sensors Incorporating a Multi-hop Protocol. IEEE (2008)
8. Karl, H., Willig, A.: Protocols and Architectures for Wireless Sensor Networks, p. 526. John Wiley & Sons, England (2005)

9. Irrigation Training and Research Center. Water Level Sensor Testing Summary. ITRC, California Polytechnic State University, San Luis Obispo, California, USA (2004)
10. Andreas, T.G., et al.: Comparative Simulations of WSN (2008)
11. Jevti, M., Zogovi, N., Dimi, G.: Evaluation of Wireless Sensor Network Simulators (2009)
12. Noury, N., Herve, T., Rialle, V., Virone, G., Mercier, E., Morey, G., Moro, A., Porcheron, T.: Monitoring behavior in home using a smart fall sensor. In: IEEE-EMBS Special Topic Conference on Microtechnologies in Medicine and Biology, pp. 607–610 (October 2000)
13. Rabaey, J.M., Ammer, M.J., da Silva Jr., J.L., Patel, D., Roundy, S.: Picoradio supports ad hoc ultra-low power Wireless Networking 38, 333 (2002), IEEE Computer Magazine
14. Petriu, E.M., Georganas, N.D., Petriu, D.C., Makrakis, D., Groza, V.Z.: Sensor-based information appliances. IEEE Instrumentation and Measurement Magazine, 31–35 (December 2000)
15. Montresor, A., Caro, G.D., Heegaard, P.E.: Architecture of the Simulation Environment (2003)
16. FEMA. During a Flood (August 11, 2010), http://www.fema.gov/hazard/flood/fl_during.shtm (retrieved June 7, 2012)
17. Busse, M.: Wireless Sensor Networks, http://pi4.informatik.uni-mannheim.de/pi4.data/content/projects/wsn/
18. Chipara, O., et al.: Real-time power-aware routing in sensor networks. IEEE (2006)
19. Lee, J., et al.: RFMS: Real-time Flood Monitoring System with wireless sensor networks. IEEE (2008)
20. Standard Emergency Warning Signal (SEWS), http://www.emergency.nsw.gov.au/content.php/491.html (retrieved June 6, 2011)
21. Khadari, F.: Weather Index, http://www.pme.gov.sa/WeaIndex.asp (retrieved June 9, 2011)