8-1-2014

A Wireless Mesh Sensor Network Framework For River Flood Detection And Emergency Communications In Case Of Disaster

Mynor Vinicio Anthone Andrade

Satoru Oishi

11th International Conference on Hydroinformatics
HIC 2014, New York City, USA

A WIRELESS MESH SENSOR NETWORK FRAMEWORK FOR RIVER FLOOD DETECTION WHICH CAN BE USED AS AN EMERGENCY COMMUNICATIONS NETWORK IN CASE OF DISASTER

VINICIO ANTHONE (1), SATORU OISHI (2)
(1): Graduate School of Engineering, Kobe university, 1-1 Rokkodaicho, Kobe, 657-8501, Japan
(2): Research Center for Urban Safety and Security, Kobe university, 1-1 Rokkodaicho, Kobe, 657-8501, Japan

This study proposes an alternative network relatively simple and inexpensive that can be used for maintaining communications capabilities during major natural disasters and other emergency situations by introducing a system that utilizes Short Message Service (SMS) over Wireless Mesh Sensor Networks (WMSNs). To create this WMSN we propose a system using the water level sensors.

INTRODUCTION

Nowadays, most of the communication systems and their applications require a network infrastructure like cellular network or the Internet for communications between users. This communication links can become unavailable during a major disaster due to damaged infrastructure and power outages. These disadvantages raise the following problem; how can people communicate during a major natural disaster? It is imperative to find an alternative system that is capable and resilient enough for communications during a major natural disaster that also can be used in developing countries. Therefore we propose a system using the water level sensors widely used for river flood detection along with wireless technologies for creating a Wireless Sensor Network (WSN) that provides an alternative communication system that is independent from the mobile network infrastructure for sending SMS during emergency situations like natural disasters.

There are approximately 178 river level sensors in Hyogo Prefecture Japan, see the website of MLIT [1]. Also the distance between sensors is relatively short. Figure 1 shows a map of the river level sensors in the Hanshin area.

Figure 1. River level sensors in the Hanshin area.

WIRELESS COMMUNICATION SYSTEMS

Wireless Sensor Networks (WSNs)

WSNs consist of small devices, so called sensor nodes equipped with a number of sensors and a wireless communication unit. Sensor nodes are either battery-powered, or gather their energy through solar panels, hence do not need wires and may be deeply embedded into the environment.

Wireless Mesh Networks (WMNs)

WMNs are composed of mains-powered so called mesh nodes, or wireless mesh routers. WMNs are very similar to the “traditional”, well known wireless local area networks (WLANs). In contrast to the WLAN Access Points (APs), mesh routers cooperate in providing a wireless multi-hop backbone and thereby covering a larger geographical area where client devices may exchange data, and access the Internet.

Characteristics

Using the Ad hoc On-Demand Distance Vector routing protocol the system provides High robustness, which means that if one node drops out of the network due to hardware failure or any other reasons, its neighbors simply find another route. More, extra capacity can be installed by simply adding more nodes. The integration of these two non-cellular wireless networks is referred as Wireless Mesh Sensor Networks (WMSNs).

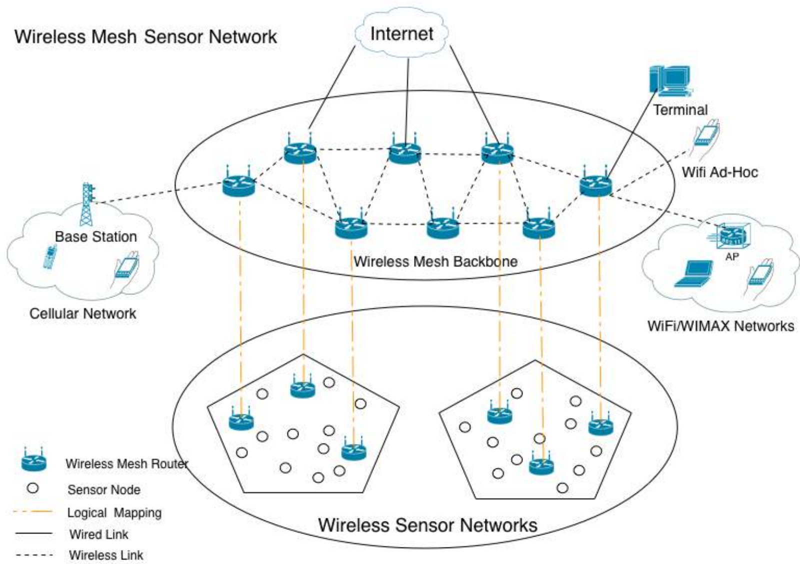

Figure 2. Network architecture of a Wireless Mesh Network with several access modes.

MOBILE TELECOMMUNICATIONS AND CHALLENGES

In recent years cellular wireless networking technologies like GSM, UMTS, or LTE enable high data rates, and high degree of coverage. However, if this infrastructure were to fail in the case of a major natural disaster for example in the aftermath of the March 11, 2011 Great East Japan Earthquake and Tsunami (GEJET), were up to 95% of the usage was restricted for mobile phones for a period of several days due to damaged base stations and power outages, see Tomioka [2]. In this situation, the communications for users inside the disaster zone would be almost to impossible. According to Tomioka [2], after the GEJET there was a network congestion due to an enormous surge in the number of voice calls resulting in the usage restrictions. To alleviate congestion for the people in the disaster zone is more feasible to communicate via text messages (SMS) rather than a phone call. SMS length can be up to 160 characters where each character represents 7bits. A workaround to the traffic congestion is to codify alert messages into one character embedded into the mobile phone of the user. This is achieved by using an ad-hoc application for sending the codified messages to the SMS central through WMSNs.

EMERGENCY COMMUNICATIONS

First we separate the topology in two zones; the disaster zone and the safe zone as shown in Figure 3. The aim is to establish the interconnections between the WSN inside the disaster area and the mobile network infrastructure in the safe zone. SMSG and SMSC are acronyms for Short Message Service Gateway and its Center respectively. We codify alert messages into one 7 bit character embedded into the mobile phone of the user. The procedure is described below:
1) When a user initiates communication from the disaster zone, the user connects to the most nearby sensor inside a WSN using the ad-hoc application through WiFi directly to the sensor;

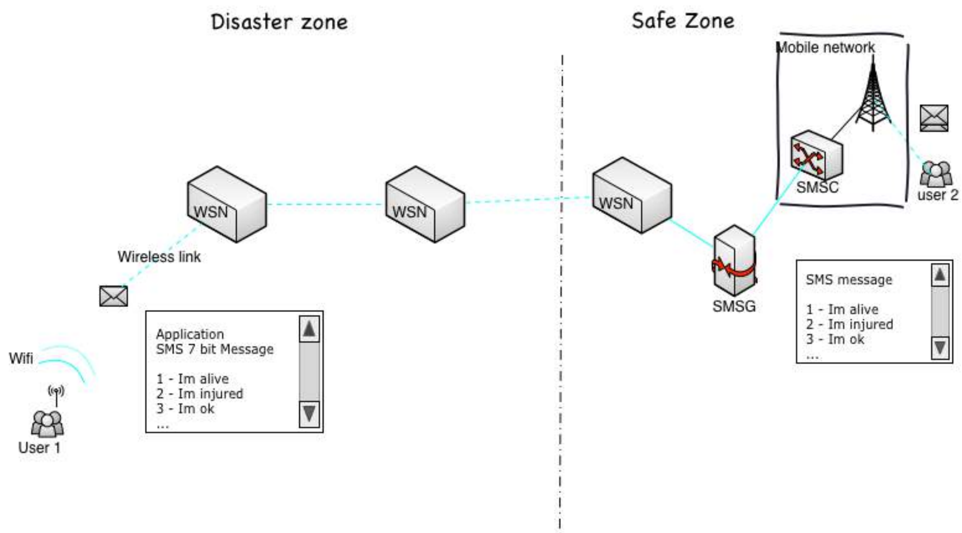

Figure 3. System topology and communications from the disaster zone to the safe zone.

2) The WSN becomes a medium in which devices communicate resiliently and independent of infrastructure (e.g. The internet or mobile network) in order to exchange data between networked objects and users in the disaster zone; 3) The data is relayed from the WSNs in the disaster zone until it reaches the safe zone WSN and then the SMSG; then it interconnects with the mobile network infrastructure SMSC; 4) The SMSC relays the message to the user in the safe zone.

TRAFFIC ANALYSIS AND MODELING IN WSN

Instant messaging doesn't consume much bandwidth, but should be fast and reliable. In many application scenarios of wireless sensor networks, sensor data must be delivered to the base station within time constraints so that appropriate actions can be made. Hence, it is crucial to evaluate the performance limits, such as end-to-end delay of WSNs in all conditions.

WSNs performance analysis method

One traffic analysis performance method is presented for WSN. The Deterministic network calculus model; Network calculus is a min-plus system theory for deterministic queuing systems. It is based on cluster topologies, which is the proposed topology for this paper.

System model

We consider a static wireless sensor network consisting of multiple sensor nodes, relaying nodes called cluster heads (CH) and a sink node.

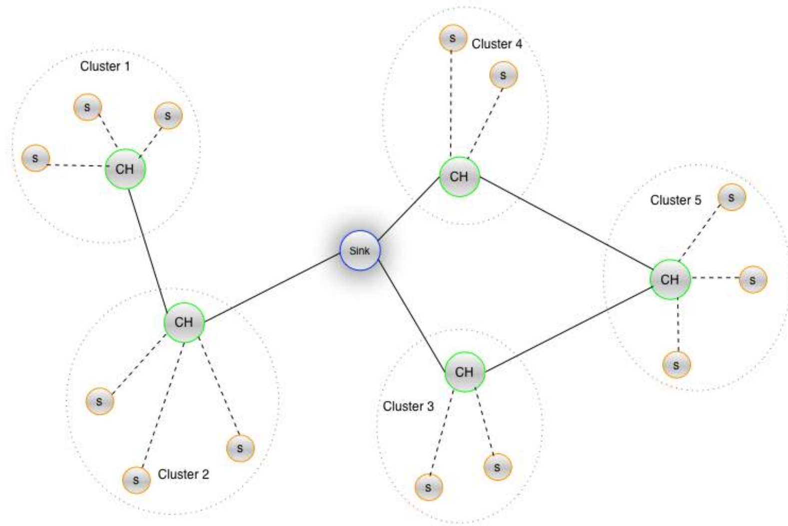

Figure 4. Example of a cluster based wireless sensor network.

The basic equations by She [3], are described as:

Theorem 1: Delay bond;

$$D(t) \leq \inf_{\tau \geqslant 0} \{\alpha(t) \leq \beta(t+\tau)\}. \tag{1}$$

Theorem 2: Backlog bound;

$$B(t) = \sup_{t \geqslant 0} \{\alpha(t) - \beta(t)\}. \tag{2}$$

Theorem 3: Output flow: The output flow *R*(t)* is constrained by the arrival curve,

$$\alpha^*(t) = \sup_{s \geqslant 0} \{\alpha(t+s) - \beta(s)\}, \tag{3}$$

where sup is the least upper bound (LUB).

Analysis procedure

In order to model the traffic scenarios in a generalized way, we introduce three types of traffic flow operators, which are traffic passing operator, traffic merging operator and traffic splitting operator, see Figure 5.

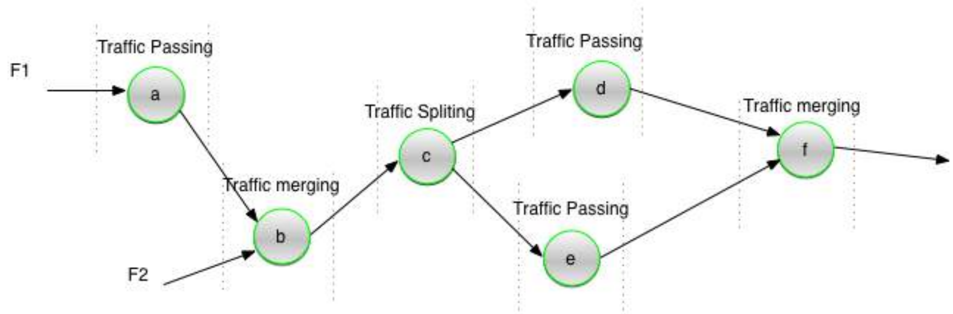

Figure 5. Traffic Flow Operators. (a) Traffic passing: one input flow and one output flow; (b) Traffic merging: multiple input flows and one output flow; (c) Traffic splitting: one input flow and multiple output flows.

Based on the theorems from Eqs. (1), (2) and (3), the delay bound for the traffic operators can be derived as in She[3]:

For the passing operator, the delay is expressed as,

$$D_{pa} = \frac{\sigma T_s}{SC} + (T_s - S). \quad (4)$$

For the traffic merging operator, the delay is expressed as,

$$D_{me}^{i} = \frac{\sigma_i}{C_i} + (T_s - S). \quad (5)$$

For the traffic splitting operator, the delay is expressed as,

$$D_{sp}^{j} = \frac{\gamma_j \sigma T_s}{SC} + (T_s - S). \quad (6)$$

The Deterministic analysis method

Step 1. According to the topology of the sensor network and the routing algorithm, obtain the routing paths of each traffic flow.

Step 2. Construct traffic flow scenarios based on the three traffic flow operators.

Step 3. Compute the output flow, delay bound and backlog bound for each node starting from the source node.

Step 4. Calculate the end-to-end delay bound. To compute the end-to-end delay bound. The method is summing up the per-hop delay together.

Analysis example and results

As shown in Figure 5, first we proceed to obtain the routing paths of each traffic flow as described by the algorithm in step 1. For constructing the traffic flow scenario we established a method on which we can combine the three traffic operators using equations (4), (5) and (6) for calculating the end-to-end delay bound, this method can define every single traffic operator by just changing the values of *N* and *M*, number of inputs flows and output flows respectively. And hence we found a general equation D_g,

$$D_g = \gamma_j \sum_{j=1}^{N} \rho_j \sigma_1 / \rho_1 \cdot T_s / (SC) + (T_s - S), \quad (7)$$

where γj ($j = 1 \cdot \cdot \cdot M$) is the number of outputs M and $\sum_{j=1}^{N} \rho_j$ is the number of inputs N, σ is the traffic burstiness and ρ is the traffic rate. T_s is the work period and S is the active duration of the nodes. C is the link capacity.

Numerical experiment

We established the deterministic Analysis method step by step using MATLAB. For obtaining the end-to-end delay. The parameters used are as follows:

1. We use the same sensor network in Figure 5.
2. The parameters are according to the XBee RF 900MHz.
3. The link capacity C is 10 kbps for urban range·
4. The duty cycle of this module is 10% averaged over the period of 1 s. (i.e., T = 1s and S = 0.10s).
5. We assume that the average traffic rate ρ=25 bits/s and the burstiness σ = 50 bits/s.

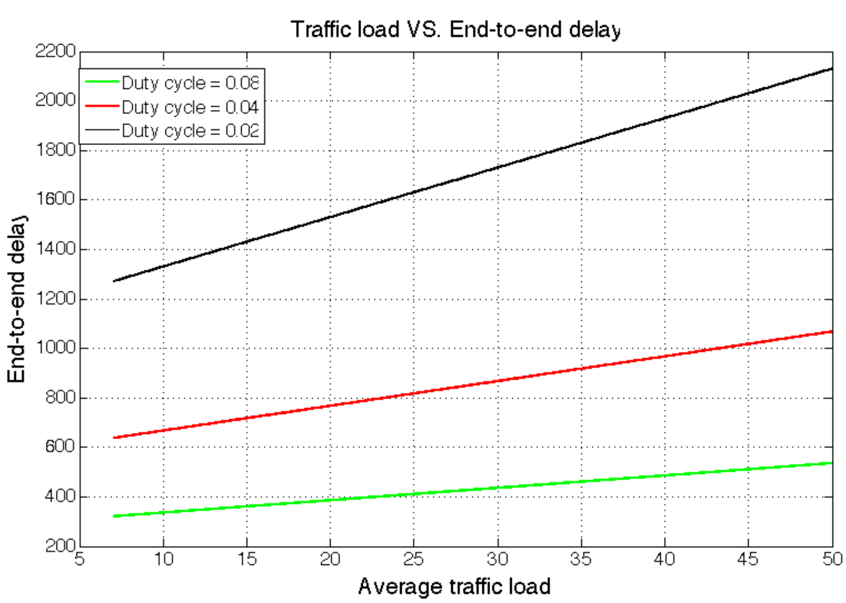

Figure 6. End-to-end delays with various duty cycles.

For this analysis we chose three different values of duty cycles. 0.8, 0.4 and 0.2. In Figure 6, the end-to-end delay increases when the traffic load increases. With the same traffic load, the delay decreases as duty cycle increases. The duty cycle is the percentage of time that the sensor node is active in a period. Lower duty cycle represents higher sleep time and therefore less battery consumption.

CONCLUSIONS

By providing an alternative network that is independent of the Mobile network infrastructure for sending SMS during emergency situations like natural disasters we can provide the users in the disaster zone an alternative means of communications. The proposed method is based on sending SMS directly to the Short Message Service Center (SMSC) using the SMS communications protocols over Wireless Mesh Sensor Networks (WMSNs).

The reliability of WSNs is a major concern when designing such networks. Hence, we proposed an operator-based deterministic performance analysis method for traffic analysis integrating variable duty cycle for WSNs. The results show that increasing the duty cycle of sensors can improve data delivery ratio and reduce the packet transmission delay.

REFERENCES

[1] Ministry of land, infrastructure, transport and tourism (MLIT), http://www.river.go.jp/, 2013.
[2] Tomioka, H. "Maintaining Communications Capabilities during Major Natural Disasters and other Emergency Situations” *Ministry of internal affairs and communications*, Japan, 2011.
[3] She, H. “*Network-Calculus-based Performance Analysis for Wireless Sensor Networks*”. Ph.D Diss. of KTH Royal Institute of Technology, 2009.