Factors and Approaches towards Energy Optimized Wireless Sensor Networks to Detect Rainfall Induced Landslides

Maneesha V. Ramesh, Rehna Raj, Joshua Udar Freeman, Sangeeth Kumar, P. Venkat Rangan
Amrita School of Engineering,
Amrita University,
Amritapuri, Kerala, India

Abstract - *Real time wireless sensor networks are primarily constrained by the availability of energy for a long monitoring period. Either new methodologies for acquiring energy or new methodologies for efficient energy utilization have to be adopted. This paper analyzes the energy consumed by the entire network and discusses the factors and approaches used towards deriving an optimal topology which minimizes the energy consumption for the whole wireless sensor network. One application of this network, which we discuss in this paper, is detecting rainfall induced landslides. However, this can be extended to larger networks concerning almost any area of monitoring, from critical and emergency applications to long term environmental monitoring. Thus the approaches discussed here are suitable for a wide variety of environmental applications such as avalanche detection, forest fire detection, gas leakage etc.*

Keywords: Wireless Sensor Networks, Topology, Energy Efficient, Landslide, Environment Monitoring.

1 Introduction

Wireless Sensor Networks (WSN) are most applicable in areas that are difficult to access and where real time monitoring is very essential. Real time monitoring requires a larger number of sensors to be deployed for a long amount of time. Deploying and maintaining traditional wired sensors in these scenarios is very difficult and expensive. In addition, WSN can be made self configurable and remotely administered. As the network size grows, the cost involved in deploying wireless sensor networks is drastically reduced compared to wired networks. The work described here is a part of the WINSOC[1] project (www.winsoc.org).

A primary constraint in deploying large scale wireless sensor networks is the amount of power required to maintain the efficient working of the network for a long duration of time. Energy consumption has to be minimized for optimal up-time and coverage of the network. Otherwise new or more efficient methods have to be developed for providing external power sources. This requires longer period of research and development, which in turn drives up the cost.

This paper takes a different approach to use the available power more efficiently for a prolonged network lifetime. It also discusses the effect of network topologies [1] on the energy consumption of the whole network. For a fixed number of low level (sensor) nodes to be deployed, we discuss a way to find the required number of hierarchy levels and the number of child nodes that can be effectively used under each cluster head, so that the available energy can be efficiently utilized. Thus an optimal topology with minimum energy consumption is devised for any situation with a predetermined number of low level nodes. The steps involved in this process will be dealt with in detail in later sections.

2 Landslide Scenario

Landslides are one of the major catastrophic disasters happening around the world, which can happen due to several causes, including geological, morphological, physical and human [2]. Landslides are the down-slope movement of soil, rock and organic materials due to the influence of gravity. These movements are short-lived and suddenly occurring phenomena, which cause extraordinary landscape changes and destruction of life and property. In the Indian Scenario, [3] the main landslide triggers are intense rainfall and earthquakes. Some of the factors

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that aggravate the incidence of landslides are environmental degradation on account of the heavy pressure of population, decline in forest cover, change in agricultural practices, and industrial and infrastructural development on unstable hill slopes, among others.

We are implementing the sensor networks designed in this paper for landslides in India, where the annual loss due to landslides is estimated to be US $400 million [3]. The principal parameters for monitoring rainfall induced landslides are pore water pressure of the soil and the slope movement [2, 4]. The primary geotechnical sensors being used are pore pressure transducers, tilt meters, strain gauges, accelerometers and geophones. One or more of these geological sensors are connected with a wireless sensor node to form a sensor column. The sensor column will be buried underneath the earth for monitoring the various parameters like soil pore water pressure, earth movements, in situ stresses and strains, etc.

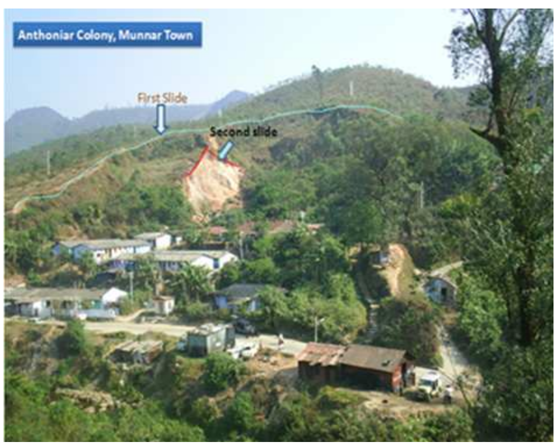

Figure 1 - Landslide Field Testing in the Idukki District of Kerala, India

The initial field testing for landslides scenarios in the WINSOC project will take place in the tea-growing hillsides of the Idukki district of the southern state of Kerala, India. Figure 1 shows a high risk landslide prone area that has been identified for the deployment site.

3 Wireless Sensor Network Architecture for Landslides

In general, the wireless sensor network has two types of nodes: the low level sensor nodes and the cluster head nodes which are connected to the control center. All of the low level nodes are each connected to a sensor column. These low level nodes under each cluster head communicate and come to a local consensus about the sensor data, and then transmit it to the cluster heads.

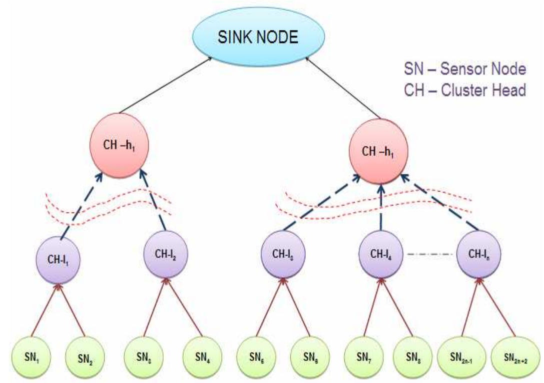

Figure 2 – Wireless Sensor Network Architecture

Figure 2 shows the wireless sensor network architecture. The complete network architecture is shown below in Figure 3.

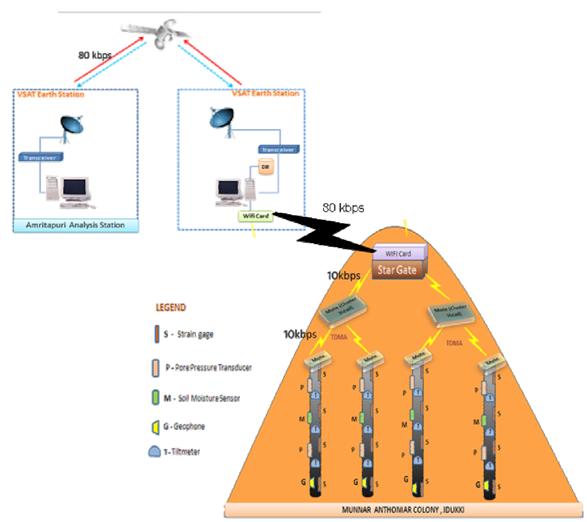

Figure 3 - Network Architecture for Landslides

The cluster heads transmit the data to the sink node, which will then further forward the data via TCP/IP to a local analysis computer. From there, it is transmitted via a satellite link to a more sophisticated landslide data processing and modeling center located at Amrita University.

4 Energy Consumption in WSN

Data generation, transmission, reception and aggregation consumes the majority of the energy in the whole wireless sensor network. Since the energy consumed for the data transmission, reception and aggregation are proportional to the number of bits transmitted, received or aggregated, the energy consumption can be optimized by: optimizing the energy consumption in the whole wireless sensor network; optimizing the energy consumption in each hierarchical level; or optimizing the energy consumption in each node in the whole network.

The network used in this paper tries to optimize the energy consumption [5] in each node and each hierarchical level by using various state transitions [6] and by adjusting the number of child nodes on each cluster head respectively.

4.1 Energy Consumption by a Single Wireless Sensor Node

The wireless sensor network used in the landslide scenario has three types of nodes: low level nodes, cluster heads, and the sink node (the gateway node). The lower level wireless nodes are connected to the sensor column comprising of the geological sensors. These low level nodes coming under each cluster head are allowed to communicate each other and arrive at a consensus on the parameter values. The consensus value will then be forwarded to the cluster head and no processing is done in any of the cluster heads. All the higher level nodes will be receiving the data from the lower nodes and transmitting it to the successive higher level nodes.

The maximum energy consumed by any node is

$$E_{node} = E_t + E_r + E_p \quad (1)$$

$$t_t + t_r + t_p = 1 \quad (2)$$

where E_t, E_r, E_p are the total energies consumed for transmitting, receiving, and processing respectively; t_t,t_r,t_p are the fractions of time taken for each.

If the nodes are always allowed to be active, the radio transceiver will always be in the listening state and the processor will also be running, thus consuming large amounts of energy. Different approaches are available to reduce the energy consumption in each node. State transition methodology is one among them. In Figure 5, four states are introduced: *Off* - The nodes are initially in off state. In this state it consumes no energy. *Sleep* - In this state the nodes will consume very little energy. *Monitor* - Nodes will be allowed to gather the data from the geological sensors and compare them with the available threshold values. The nodes use low power to listen to the channel. *Active* - Nodes can transmit and receive data in this state. The nodes will talk each other to reach a consensus on the data. This is the state in which maximum power is consumed.

In each of the states, each node will consume different amount of energy due to the state transition as shown in Figure 4. In general, the total energy a senor node can consume is:

$$E_{node} = t_s E_s + t_m E_m + t_a E_a + t_{off} E_{off} \quad (3)$$

$$t_s + t_m + t_a + t_{off} = 1 \quad (4)$$

where E_s, E_m, E_a, and E_{off} are the energies consumed in respectively the sleep state, monitor state, active state and off state, and t_s , t_m, t_a, t_{off} are the accompanying fractions of time for each.

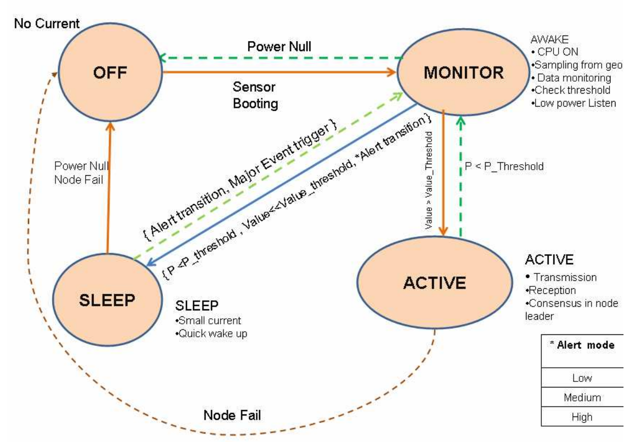

Figure 4 - State Transition Diagram

Once the network is booted up, the nodes go into the monitor state, in which the entire time is utilized for data collection. The energy consumed is,

$$E_m = E_{dc} + E_p \quad (5)$$

where E_{dc} is the energy used for data collection from the sensor column, and E_p is the processing energy used.

The data is sampled from the geological sensors and it is compared with the threshold values. Once the threshold is reached, the node will transition to active, and the data will be transmitted to its neighbors in the group. The node that has crossed the threshold can send a digital signal, activating the rest of the group members. The group will then try to reach a consensus on the data received from all the members. The consensus value will be compared to the threshold, and if that is reached, the alert state of the network will be changed.

The energy consumed in the active state is,

$$E_a = E_t + E_r + E_p \quad (6)$$

where E_t, E_r, E_p are as given in Formula (1).

4.2 Energy Consumption by the Entire Network

The number of lowest level nodes is fixed as previously described. It is assumed that the wireless sensor network is not restricted on the size of the hierarchical levels or on the size of the child nodes under each cluster head, as in Figure 3. A further assumption is that the groups of sub nodes under a node are all equally sized within any given hierarchical level. In this scenario, the sink node is connected to an outside network, therefore its energy usage is different and it is not considered.

The total energy consumed by the whole network (without the sink node) can be written as,

$$E_{total} = \sum_{i=1}^{h} c_i E_{node} \quad (7)$$

where h is the number of hierarchical levels in the wireless sensor network, and c_i is the number of child nodes underneath each hierarchical level.

5 Factors and Approaches for Energy Optimized Topology

In the landslide scenario, the low level nodes sample data from the geological sensors and transmit it to the higher levels after consensus among the group members has been achieved. All nodes in each hierarchical level other than the lower level will simply receive the data and transmit it to successively higher levels. Thus, the maximum energy consumption and delay will be in the lower level nodes. This is a primary factor in determining the topology. Aspects affecting the energy consumption are transmission range of the nodes, number of child nodes, number of hierarchical levels, and number of bits transmitted.

Optimal topology can be reached by minimizing Equation (7) for each level of the hierarchy with respect to the constraints:

- The total number of nodes in the whole network will be equal to the sum of the number of nodes in the lowest level, which is a fixed number, and all of the nodes in upper hierarchical levels;
- The product of the number of hierarchical levels with the range of transmission should be greater than or equal to the maximum distance between the lowest level nodes and the sink node;
- The sum of the times taken for transmission from each child node in a group at each hierarchical level should be less than or equal to the time delay threshold.

Simulators will be used to simulate the situation and the optimal number of child nodes for each level. Therefore the proposed method is also applicable to find the bounds of fan out of intermediate nodes in hierarchical networks that meet the aforementioned conditions.

6 Conclusion and Future Work

This paper discusses a methodology for optimizing the energy consumption in a wireless sensor network that is specific to landslide scenarios. Using a combination of the number of low level nodes, the allowable delay in groups of low level nodes, and the distance between the low level nodes and the sink nodes, an optimal topology can be generated for the specified application. This work can be extended for finding the bounds of fan out in hierarchical networks. The method will be simulated and the network design will be implemented in a test network setup, and then field deployed at the landslide site.

7 References

[1] S. Ramanathan, P. Venkat Rangan, H. M. Vin, T. Kaeppner. ”Optimal Communication Architectures for Multimedia Conferencing in Distributed Systems”; IEEE, 1992.

[2] A. Keith Turner. “Landslides: Investigation and Mitigation”, United States Transportation Research Board, National Research Council, 1996.

[3] Dr. P. K .Thampi, John Mathai, G. Sankar and S. Sidharthan. “Landslides: Causes, Control and Mitigation” (based on the investigations carried out by the Centre for Earth Science Studies, Trivandrum)

[4] A. Terzis, A. Anandarajah, K. Moore, I. Jeng Wang. “Slip Surface Localization in Wireless Sensor Networks for Landslide Prediction; IPSN’06, April, 2006.

[5] Y. Jia, T. Dong, J. Shi. ”Analysis on Energy Cost for Wireless Sensor Networks”; Proceedings of the Second International Conference on Embedded Software and Systems (ICESS’05), IEEE, 2005.

[6] R. Jurdak, P. Baldi, C. V. Lopes. “State-Driven Energy Optimization in Wireless Sensor Networks”; Proceedings of the 2005 Systems Communications (ICW’05), IEEE, 2005.