Real-time Wireless Sensor Network for Landslide Detection

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Abstract—**Wireless sensor networks are one of the emerging areas which have equipped scientists with the capability of developing real-time monitoring systems. This paper discusses the development of a wireless sensor network(WSN) to detect landslides, which includes the design, development and implementation of a WSN for real time monitoring, the development of the algorithms needed that will enable efficient data collection and data aggregation, and the network requirements of the deployed landslide detection system. The actual deployment of the testbed is in the Idukki district of the Southern state of Kerala, India, a region known for its heavy rainfall, steep slopes, and frequent landslides.**

Keywords- wireless sensor network, distributed algorithms, heterogeneous networks, landslide

I. INTRODUCTION

Environmental disasters are largely unpredictable and occur within very short spans of time. Therefore technology has to be developed to capture relevant signals with minimum monitoring delay. Wireless sensors are one of the cutting edge technologies that can quickly respond to rapid changes of data and send the sensed data to a data analysis center in areas where cabling is inappropriate.

Wireless sensor network(WSN) technology has the capability of quick capturing, processing, and transmission of critical data in real-time with high resolution. However, it has its own limitations such as relatively low amounts of battery power and low memory availability compared to many existing technologies. It does, though, have the advantage of deploying sensors in hostile environments with a bare minimum of maintenance. This fulfills a very important need for any real time monitoring, especially in hazardous or remote scenarios.

We aim to use the wireless sensor networks in the landslide scenario[1] for estimating the chance occurrence of landslides. India faces landslides every year with a large threat to human life causing annual loss of US $400 million [1]. The main goal of this effort is to detect rainfall induced landslides which occur commonly in India.

This paper discusses the design and deployment of a landslide detection system using a WSN system at Anthoniar Colony, Munnar, Idukki (Dist), Kerala (State), India. The deployment site has historically experienced several landslides, with the latest one occurring in the year 2005, which caused a death toll of 10 (people).

The remainder of the paper is organized as follows. Section II describes related work in WSN systems, and other methods for landslide prediction. In Section III, we describe the sensors for landslide detection. Section IV details the different wireless sensor network algorithms implemented in the landslide detection network. Section V presents our wireless sensor test bed. Field deployment, its design concerns, and experiences are described in Section VI. Finally we conclude in Section VII and discuss the future work also in the same section.

II. RELATED WORK

Wireless sensor technology has generated enthusiasm in computer scientists to learn and understand other domain areas which have helped them to propose or develop real-time deployments. One of the major areas of focus is environmental monitoring, detection and prediction.

The Drought Forecast and Alert System (DFAS) has been proposed and developed in [2]; it uses mobile communication to alert the users, whereas the deployed system uses real time data collection and transmission using the wireless sensor nodes, WiFi, satellite network and also through internet. The real streaming of data through broadband connectivity provides connectivity to wider audience.

An experimental soil monitoring network using a WSN is presented in reference [3], which explores real-time measurements at temporal and spatial granularities. Paper [4] describes a state-of-the-art system that combines multiple sensor types to provide measurements to perform deformation monitoring. Reference [5] discusses the topic of slip surface localization in wireless sensor networks, which can be used for landslide prediction. A durable wireless sensor node has been developed [6], which can be employed in expandable wireless sensor networks for remote monitoring of soil conditions in areas conducive to slope stability failures.

In this paper, real time deployment of a heterogeneous network in India for landslide detection has been discussed. This study incorporates both theoretical and practical

knowledge from diverse domains such as landslides and geomechanics, wireless sensor, Wi-Fi, and satellite networks, power saving solutions, and electronic interface and design, among others, which paved the design, development and deployment of a real-time landslide detection system using a wireless sensor network.

III. SENSORS FOR LANDSLIDE DETECTION

Under heavy rainfall conditions, rain infiltration on the slope causes instability, a reduction in the factor of safety; transient pore pressure responses, changes in water table height, a reduction in shear strength which holds the soil or rock, an increase in soil weight and a reduction in the angle of repose. When the rainfall intensity is larger than the slope saturated hydraulic conductivity, runoff occurs [7].

The geophysical sensors selected for the in-situ measurements are pore pressure transducers, soil moisture sensors, geophones, stain gauges and tiltmeters, based on their relevance in finding the causative geological factors for inducing landslides under heavy rainfall conditions. However, commercially available wireless sensor nodes do not have implanted geophysical sensors and this constraint has lead us to implement data acquisition boards to connect the external sensors to the wireless sensor nodes. The geological sensors were placed inside a sensor column and they were connected to the wireless sensor node via a data acquisition board as shown in Figure 1.
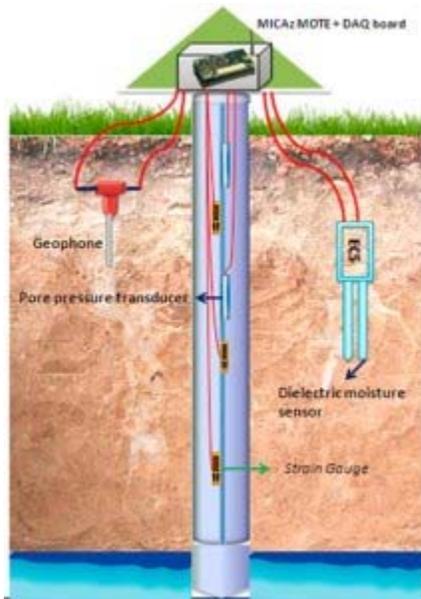

Figure 1: Sensor Column [8]

IV. WIRELESS SENSOR NETWORK ALGORITHMS

The WINSOC project has developed a totally innovative design methodology, where the high accuracy and reliability of the whole sensor network is achieved through a proper interaction among nearby, low cost, sensors. This local interaction provides more accurate distributed detection than that of each single sensor as discussed in research papers [9][10][11]. Therefore, the wireless sensor network at the deployment site uses the same concept for distributed detection, estimation and consensus to arrive at reliable decisions.

Our study concentrates on the detection of rainfall induced landslides, and so, the most relevant data has to be collected during rainy season. Therefore, we have developed a threshold based algorithm [8] that will influence the sampling rate of the geological sensors and the transmission of data to higher layers using rainfall and pore pressure based alert levels. Along with these methods, state level transitions have also been incorporated in the wireless sensor nodes. Both methods reduce the energy consumption per node which will also contribute to reduced energy consumption throughout the network. These requirements, however, lead to the need of time synchronization, and the algorithm planned for implementation in our network is discussed in the research paper [12].

V. WIRELESS SENSOR TESTBED

The wireless sensor network follows a two-layer hierarchy, with lower layer wireless sensor nodes, sample and collect the heterogeneous data from the sensor column and the data packets are transmitted to the upper layer. The upper layer aggregates the data and forwards it to the sink node (gateway) kept at the deployment site.

Data received at the gateway has to be transmitted to the Field Management Center (FMC) which is approximately 500m away from the gateway. A Wi-Fi network is used between the gateway and FMC to establish the connection. The FMC incorporates facilities such as a VSAT (Very Small Aperture Terminal) satellite earth station and a broadband network for long distant data transmission. The VSAT satellite earth station is used for data transmission from the field deployment site at Munnar, Kerala, South India to the Data Management Center (DMC), situated at our university campus 300 km away.

The DMC consists of the database server and an analysis station, which performs data analysis and landslide modeling and simulation on the field data to determine the landslide probability. The wireless sensor network architecture for landslide detection is as shown in Figure 2.

The Munnar region experiences frequent landslides and has several landslide prone areas within every 1 sq km, which can be utilized as future extension sites for landslide detection systems. The different deployment sites can connect to the FMC via a Wi-Fi network.
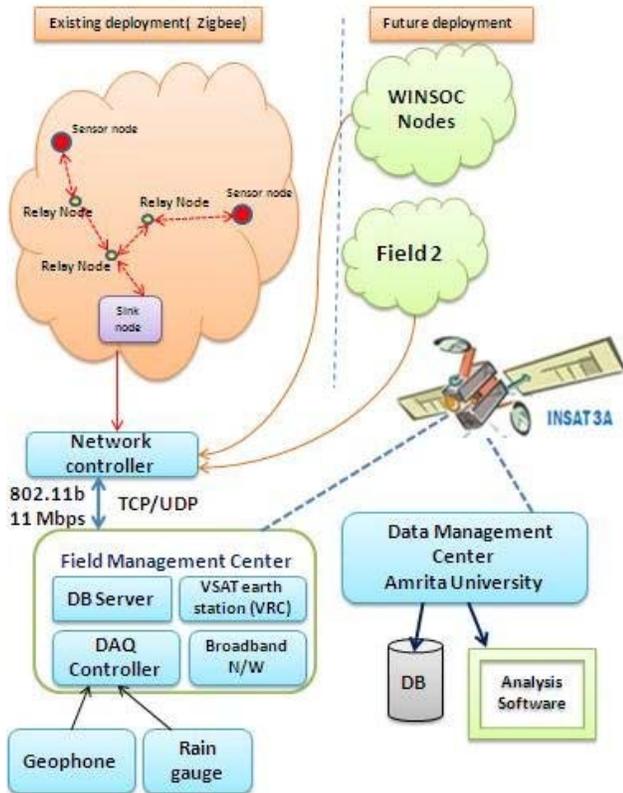
Figure 2. Wireless Sensor Network Architecture for Landslide Detection

VI. FIELD DEPLOYMENT

Extensive field investigations were conducted for identifying the possible locations for sensor column deployment. At the deployment site, Anthoniar Colony, an initial twenty sensor column locations consisting of 150 sensors total, were identified with respect to their geological relevance.

The pilot deployment consists of two sensor columns, with ten sensors, are deployed in the field along with six wireless sensor nodes. One of the sensor columns is deployed at the toe region where various water seepage lines converge. This fact lead to the installation of pore pressure transducers at different depths (2m, 5m) and a dielectric moisture sensor, both sampled at every five minutes. Geophone is also deployed at sensor column 1 and sampled at the rate of 10 samples/second. The MicaZ wireless sensor node connected to the sensor column transmits the digitized data values to the upper layers of the network.

The other sensor column is attached with movement sensors since the location of it is in an unstable region. This sensor column has three tilt meters (1m, 2m, 3.5m), and three strain gauges (1.5m, 2.5m, 4m) to capture the earth movement from the sensor column bending. A dielectric moisture sensor is also connected to the sensor column at 1 feet depth. The wireless sensor nodes sample these sensors at

every five minutes and sent the data to upper level sensor nodes in the network.

A. Design of Interfacing Circuits

Indigenous interfacing circuits have been developed for data acquisition from the geophysical sensors by the wireless sensor nodes. The analog signals from the geophysical sensors are amplified; level is shifted; the signal conditioning has been performed according to each sensors requirement. The details are shown in Table I.

TABLE I. Interfacing Circuit Requirements

Sensor	Output Type	Signal Pre-Processing
Strain gauge piezometer	Dual wire analog	Level shifting, Amplification
Vibrating wire piezometer	RS-232 from the data logger	None
Dielectric moisture sensor	Single wire analog	None
Tiltmeter	Single wire analog	Voltage reduction, Amplification
Geophone	Dual wire analog	Level shifting, Amplification

B. Design of Power Solutions

Power circuits have been developed that provide constant power for the excitation of the geophysical sensors and also for powering the interfacing circuits. The power circuits consists of voltage regulator and negative voltage converter IC'S and provide different voltages from a lead acid battery to the geophysical sensors and their interfacing circuits. The lead acid batteries are automatically recharged by the solar recharging unit.

C. Design of Heterogeneous Networks

The sensor column is physically attached to a wireless sensor node which is integrated with a data acquisition board. The distance between current sensor columns is approximately 50 meters, at a slope of about 70°. Due to the terrain structure and vegetation, the data from the sensor columns are not able to reach the gateway. The major reason for this is no line of sight path between the columns, between the first sensor column and the gateway, and between second sensor column and the gateway. The above observations, along with experimental tests, have led us to employ three relay nodes in between the sensor columns themselves and the gateway. One of the relay nodes is a cluster head for the first and second sensor column. The data from the cluster head is transmitted to the gateway in the form of packets. At the gateway the received packets are time stamped and stored.

The wireless senor nodes used for the test deployment are 2.4 GHz MicaZ motes from Crossbow. The gateway is a single board computer which has 64 MB RAM, 32 MB flash

and a fixed base mote that is used to send and receive the messages through the transceiver.

The Wi-Fi Network is used to transfer the data from the gateway to the FMC and it uses an external antenna and an access point for the same. The Wi-Fi network allows us to install the gateway in any scalable distance from the FMC. The Network has been tested with WLAN standards 802.11a/b/g.

The basic satellite communication network in the landslide scenario is based on VSAT. The geological data collected at the landslide deployment site is transmitted from the FMC at the deployment site to the DMC at Amrita University's Amritapuri campus, using the VSAT earth station. The data is transmitted using UDP Protocol which includes recovery of lost packets, corrupted packets, secure transmission, route via broadband during unavailability of VSAT, buffering the data to disk in case both networks are unavailable and sending the data as soon as the network is connected, etc.

D. Design of Data Analysis Software

Data received at the DMC is being been analyzed using the integrated landslide modeling software and the in-house designed data visualization software, which has the capability to determine factor of safety of the mountain and probability of landslide occurrence with respect to the signals received from the deployed sensors. It also has the capability to compare and analyze data from different sensor columns, different sensors, selective comparison, etc. Data is successfully received from the deployment site with minimal data packet loss and analysis of data has been performed. Data received from two pore pressure transducers and a rain gauge is shown in Figure 3.

During 2008 monsoon season, the sensors were able to capture the expansion and contraction of soil mass during and after heavy rainfall. The data analysis software showed respective variations in each of the deployed sensors.

The data analysis software has been integrated with the capability of real streaming of data over internet. This facility has been tested and will be uploaded soon in the webpage www.winsoc.org. The scientists around the world can analyze the data with very minimal delay and effective warning can be issued on time.
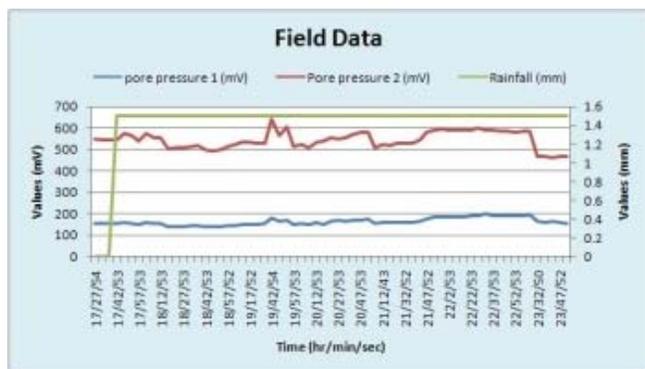

Figure 3. Real-time Field Data

E. Design of Feedback System

A feedback loop is incorporated for remotely administering the sampling rate of the geological sensors with respect to real-time climatic variations, monitor the level of battery charges, monitor the level of solar charging rate, indicate faulty wireless sensor nodes or geological sensors etc.

VII. CONCLUSION AND FUTURE WORK

Real time monitoring of landslides is one of the challenging research areas available today in the field of geophysical research. This paper discusses the development of an actual field deployment of a wireless sensor network based landslide detection system. This system uses a heterogeneous network composed of wireless sensor nodes, Wi-Fi, and satellite terminals for efficient delivery of real time data to the data management center, to enable sophisticated analysis of the data and to provide landslide warnings and risk assessments to the inhabitants of the region. A test setup of this design has been already deployed at Anthoniar Colony, Munnar, Idukki, Kerala, India. In the future, this work will be extended to a full deployment by using the lessons learned from the existing network. This network will be used for understanding the capability and usability of wireless sensor network for critical and emergency application.

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