CHAPTER 1

INTRODUCTION:

Due to the progressive development and utilization of areas endangered by mass movements and changing climatic conditions, the risk for people and public infrastructure like roads, supply lines or facility utilities increases continuously. This increase and the fact that mass movements mostly occur together with other great natural disasters like hurricanes or earth quakes show, how important it is to develop tools to manage landslide hazard adequately. Especially in areas with unfavorable topographic conditions settlements and infrastructures are often located in direct neighborhood to landslide areas. This situation is being complicated by the fact that the dependency of our today’s society on a functioning infrastructure rises.

This development is not only a specific problem to Germany or mountainous regions. It is a global challenge, apparent from an increasing number of national and international programs Just in the USA landslides account for approximated annual losses of about 3.5 bn. USD and 25 to 50 fatalities a year (USGS, 2004). In this context monitoring and early warning systems becomes a reckoned pillar of disaster prevention in natural hazards especially where mitigation strategies are not realizable. Furthermore, internationally the call for multi-hazard early warning systems and improvement of monitoring of natural hazards is steadily growing.

Currently existing monitoring systems for early warning are monolithic in terms of isolated installations, which are very cost-intensive considering installation as well as operational and personal expenses. This results often in a selective monitoring with few measuring stations or observation points in an instable slope or an endangered rock face, instead of a favorable spatial monitoring. In many cases the limited information from single points is not adequate for a reliable interpretation or prediction, especially if the sampling rates are low. In this case the failure of some or even single measuring points leads to a partial or total breakdown of the monitoring system. Limited or missing data may also cause false alarms. Besides the costs of false alarms, the loss of confidence in the system by authorities and people in this case is much worse. Another critical point is the very complex information chain in case of warning, which requires a disciplined adherence to an emergency plan. A failure of single elements or even worse the missing of adequate emergency plans will significantly disturb the flow of information. This may cause in the worst case that a warning massage gets lost. For this reasons it is necessary to improve existing and to develop new monitoring and warning systems to meet the rising requirements to protect people and objects.
THE MAIN ASPECTS ARE:

1. Integration of cost-effective and reliable micro sensors in an ad-hoc multi-hop wireless sensor network to establish an self organizing real-time landslide monitoring and early warning system
2. Enhancement of data quality and reduction of false alarm rates due to sensor and network fusion
3. Development and configuration of a geoservice infrastructure for real-time data management and online geoprocessing with the capability to integrated external data sources to enhance the predictability of landslide processes and warning
4. Fast allocation of user-specific information for all people (actors) involved in a hazard or disaster situation.

1.1 LANDSLIDE

Landslide is a general term used to describe the down-slope movement of soil, rock and organic materials under the influence of gravity. It can be triggered by gradual processes such as weathering, or by external mechanisms including:

- undercutting of a slope by stream erosion, wave action, glaciers, or human activity such as road building,
- Intense or prolonged rainfall, rapid snowmelt, or sharp fluctuations in ground-water levels,
- Shocks or vibrations caused by earthquakes or construction activity,
- Loading on upper slopes, or
- A combination of these and other factors.

Once a landslide is triggered, material is transported by various mechanisms including sliding, flowing and falling.

The types of landslides vary with respect to the:

- **RATE OF MOVEMENT:** This ranges from a very slow creep (millimeters/ year) to extremely rapid (meters/second).
- **TYPE OF MATERIAL:** Landslides are composed of bedrock, unconsolidated sediment and/or organic debris.
- **NATURE OF MOVEMENT:** The moving debris can slide, slump, flow or fall.
1.2 WIRELESS SENSOR NETWORK:

A Wireless Sensor Network (WSN) consists of spatially distributed autonomous sensors to cooperatively monitor physical or environmental conditions, such as temperature, sound, vibration, pressure, motion or pollutants. The development of wireless sensor networks was motivated by military applications such as battlefield surveillance and is now used in many industrial and civilian application areas, including industrial process monitoring and control, machine health monitoring, environment and habitat monitoring, healthcare applications, home automation, and traffic control.

1.2.1 WIRELESS SENSOR NETWORKS SATISFY THESE TECHNOLOGY REQUIREMENTS:

- **CONNECTIVITY:** WSN do not depend on any pre-existing networking infrastructure. They are able to organize automatically in a mesh-type network and they are resistant to partial failures. Because the communication between devices is independent from any external network there is no cost to communicate internally. Wireless sensor networks can also be used in delay-tolerant applications, which are good solutions in countries with poor infrastructures. Data gathered by the sensors can be stored in the memory of a gateway and then transmitted when an external network becomes available. In this way no data is lost, and deployments are possible in rural environments that lack continuous or affordable network connectivity.

- **LOW-COST:** over 100 OEMs or service providers worldwide currently offer or are developing WSN products. Worldwide deployments are expected to grow exponentially for the next 4 years from 2.5 million to 126 billion devices and cost is expected to fall accordingly in the next years. WSN can be easily redeployed with no loss of investment and expanded when more funds become.

- **APPROPRIATE USER Interfaces:** The data gathered from WSN are usually saved in the form of numerical data in a central base station. User interfaces are quickly being developed or already exist, to allow simple access and presentation of these large data sets. Web-based interfaces allow users to monitor or control their WSN through a web browser. The product of the devices, being numerical data, can easily be synthesized into graphs, charts and spreadsheets and translated into local languages.
- **POWER:** WSN can be designed so they require very little energy to operate. Sensor nodes often carry their own power sources (such as AA batteries) and may be equipped with effective power scavenging methods, such as solar cells.

In addition to one or more sensors, each node in a sensor network is typically equipped with a radio transceiver or other wireless communications device, a small microcontroller, and an energy source, usually a battery.

**1.3 SENSOR NODES:** Sensor nodes are essentially small computers with extremely basic functionality. They consist of a processing unit with limited computational power and a limited memory, a radio communication device, a power source and one or more sensors.

**1.3.1 FOLLOWING IS A SHORT DESCRIPTION OF EACH COMPONENT:**

- **PROCESSING UNIT AND MEMORY:** the task of this unit is to process locally sensed information and information sensed by other devices. At present the processors are limited in terms of computational power, but given Moore's law,
future devices will come in smaller sizes, will be more powerful and consume less energy. Memory is used to store both programs (instructions executed by the processor) and data (raw and processed sensor measurements).

- **RADIO COMMUNICATION:** WSN devices include low-rate, short-range radios. Typical rates are 10-100 kbps, and the range is less than 100 meters. Radio communication is often the most power-intensive operation, so the radio must incorporate energy-efficient techniques.

- **POWER:** devices are meant to be deployed in various environments, including remote and hostile regions; consequently, they must use little power. Sensor nodes typically have little energy storage, so networking protocols must emphasize power conservation. They also must have built-in mechanisms that allow the end user the option of prolonging network lifetime at the cost of lower throughput. Sensor nodes may be equipped with effective power salvaging methods, such as solar cells, so they may be left unattended for months, or even years.

- **SENSING DEVICE:** motes may consist of many different types of sensors capable of monitoring a wide variety of physical phenomena. Common applications include the sensing of temperature, humidity, light, pressure, noise levels, acceleration, soil moisture, etc. Some applications require multi-mode sensing, so each device may have several sensors on board.

The gateway (or base station) is made of one or more distinguished elements of the WSN with some more computational, energy and communication resources. It provides the interface between the nodes and the network infrastructure (the internet). A gateway must have enough computing power to be able to run a database, perform local calculation and communicate with an existing net-work (Wi-Fi or LAN), but should be low-power enough to run autonomously in the field. The gateway is normally collocated close to more permanent infrastructure, such as at a telephone pole or on the roof of a building.

A sensor network normally constitutes a wireless ad-hoc network, meaning that each sensor supports a multi-hop routing algorithm where nodes function as forwarders, relaying data packets to a base station. A landslide detection system, make use of a wireless sensor network to detect the slight movements of soil that may occur during a landslide. And through the data gathered it may be possible to know the occurrence of landslides long before it actually happens.
CHAPTER 2

LANDSLIDE MONITORING WITH WIRELESS SENSOR NETWORKS

2.1 SENSORS FOR LANDSLIDE DETECTION:

In order to detect and monitor the different landslide processes (like fall, topple, spreading or sliding) 3D MEMS capacitive sensors made from single silicon crystals and glass were chosen to measure acceleration, tilting and altitude changes. Based on the so-called MEMS (Micro-Electro-Mechanical Systems) technology, the sensors combine very small mechanical and electronic units, sensing elements and transducers on a small microchip.

Three distinct physical events occur during a landslide:

- The initial slope failure,
- The subsequent transport, and
- The final deposition of the slide materials.

The initial slope failure can occur due to the increase in pore pressure and soil moisture content, under heavy rainfall, which necessitates the inclusion of geophysical sensors for detecting the change in pore pressure and moisture content with the warning system developed for landslide detection.

Geophysical sensors such as the 3-axis acceleration sensor (measuring range: +/- 2g), the 2-axis inclination sensor (measuring range: +/- 30°) for measuring tilt and the barometric pressure sensor (measuring range: 30kPa – 120 kPa) for measuring sub-meter height changes (altimeter) are currently integrated into the sensor network and are tested in realistic experiments. In addition sensor nodes with precise potentiometric displacement and linear magnetorestrictive position transducer are used for extension and convergence measurements.

According to the accuracy of the first developed test stations, the results of the experiments showed that the selected sensors meet the requirement profile, as the stability is satisfying and the spreading of the data is quite low. Therefore the jet developed sensor boards can be tested in a larger environment of a sensor network. In order to get more information about accuracy in detail, experiments in a new more precise test bed and tests with different sampling rates will follow.

Another increasingly important aspect for the future is the fusion of sensor data (i.e. combination and comparison) to identify malfunctions and to reduce false alarm rates, while increasing data quality at the same time. The correlation of different (complementary sensor fusion) but also identical sensor-types (redundant sensor fusion) permits a validation of
measuring data. The development of special algorithms allows in a further step to analyze and evaluate the data from all nodes of the network together (sensor node fusion). The sensor fusion contributes to the decision making of alarm and early warning systems and allows a better interpretation of data.

Within the wireless sensor networks domain, simple aggregation techniques such as maximum, minimum, and average, have been developed for reducing the overall data traffic to save energy.

2.2 ENHANCED SENSOR COLUMN DESIGN

Commercially available wireless sensor nodes do not have implanted sensors to measure pore pressure, moisture content, vibration, earth movements, etc. 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 2.1, uses a heterogeneous structure which differs with respect to the terrain conditions and the geological and hydrological parameters of the deployment site. Also, in this sensor column design all the geological sensors (such as geophone and dielectric moisture sensor) are not placed inside the column but are connected to the same wireless sensor node. The sensor column design also includes tilt-meters which can be used for validating the deformation measurements captured using strain gauges.
2.3 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>
<thead>
<tr>
<th>Sensor</th>
<th>Output Type</th>
<th>Signal Processing</th>
</tr>
</thead>
<tbody>
<tr>
<td>Strain gauge piezometer</td>
<td>Dual wire analog</td>
<td>Level shifting, Amplification</td>
</tr>
<tr>
<td>Vibrating wire piezometer</td>
<td>RS-232 from the data logger</td>
<td>None</td>
</tr>
<tr>
<td>Dielectric moisture sensor</td>
<td>Single wire analog</td>
<td>None</td>
</tr>
<tr>
<td>Tiltmeter</td>
<td>Single wire analog</td>
<td>Voltage reduction, Amplification</td>
</tr>
<tr>
<td>Geophone</td>
<td>Dual wire analog</td>
<td>Level shifting, Amplification</td>
</tr>
</tbody>
</table>

2.4 INDIVIDUAL WIRELESS SENSOR NODE ARCHITECTURE

A functional block diagram of a versatile wireless sensing node is provided in Figure 2.2. A modular design approach provides a flexible and versatile platform to address the needs of a wide variety of applications. For example, depending on the sensors to be deployed, the signal conditioning block can be re-programmed or replaced. This allows for a wide variety of different sensors to be used with the wireless sensing node. Similarly, the radio link may be swapped out as required for a given applications’ wireless range requirement and the need for bidirectional communications. The use of flash memory allows the remote nodes to acquire data on command from a base station, or by an event sensed by one or more inputs to the node. Furthermore, the embedded firmware can be upgraded through the wireless network in the field.

The microprocessor has a number of functions including:

- managing data collection from the sensors
- performing power management functions
- interfacing the sensor data to the physical radio layer
- managing the radio network protocol
A key feature of any wireless sensing node is to minimize the power consumed by the system. Generally, the radio subsystem requires the largest amount of power. Therefore, it is advantageous to send data over the radio network only when required. This sensor event-driven data collection model requires an algorithm to be loaded into the node to determine when to send data based on the sensed event. Additionally, it is important to minimize the power consumed by the sensor itself. Therefore, the hardware should be designed to allow the microprocessor to judiciously control power to the radio, sensor, and sensor signal conditioner.

![Wireless sensor node functional block diagram](image)

**FIGURE 2.2:** Wireless sensor node functional block diagram

### 2.5 WIRELESS SENSOR NETWORK ARCHITECTURE

Several sensors that perform only sensing can be deployed. The positions of the sensors and communications topology are carefully engineered. They transmit time series of the sensed phenomenon to the central nodes where computations are performed and data are fused. A sensor network is composed of a large number of sensor nodes, which are densely deployed either inside the phenomenon or very close to it.

The position of sensor nodes need not be engineered or pre-determined. This allows random deployment in inaccessible terrains or disaster relief operations. On the other hand, this also means that sensor network protocols and algorithms must possess self-organizing capabilities. Another unique feature of sensor networks is the cooperative effort of sensor nodes. Sensor nodes are fitted with an on-board processor. Instead of sending the raw data to the nodes responsible for the fusion, sensor nodes use their processing abilities to locally carry out simple computations and transmit only the required and partially processed data. The above described features ensure a wide range of applications for sensor networks. Some of the application areas are health, military, and security.
Realization of these and other sensor network applications require wireless ad hoc networking techniques. Although many protocols and algorithms have been proposed for traditional wireless ad hoc networks, they are not well suited for the unique features and application requirements of sensor networks. To illustrate this point, the differences between sensor networks and ad hoc networks are outlined below:

- The number of sensor nodes in a sensor network can be several orders of magnitude higher than the nodes in an ad hoc network.
- Sensor nodes are densely deployed.
- Sensor nodes are prone to failures.
- The topology of a sensor network changes very frequently.
- Sensor nodes mainly use broadcast communication paradigm whereas most ad hoc networks are based on point-to-point communications.
- Sensor nodes are limited in power, computational capacities, and memory.
- Sensor nodes may not have global identification (ID) because of the large amount of overhead and large number of sensors.

Since large numbers of sensor nodes are densely deployed, neighbor nodes may be very close to each other. Hence, multi-hop communication in sensor networks is expected to consume less power than the traditional single hop communication. Furthermore, the transmission power levels can be kept low, which is highly desired in covert operations. Multi-hop communication can also effectively overcome some of the signal propagation effects experienced in long-distance wireless communication. One of the most important constraints on sensor nodes is the low power consumption requirement. Sensor nodes carry limited, generally irreplaceable, power sources. Therefore, while traditional networks aim to achieve high quality of service (QoS) provisions, sensor network protocols must focus primarily on power conservation. They must have inbuilt trade-off mechanisms that give the end user the option of prolonging network lifetime at the cost of lower throughput or higher transmission delay.

Note: The wireless sensor network at the deployment site 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. The geological and hydrological properties of the whole landslide prone area differ in each location, so it can be divided in two regions having unique properties. Our deployment area is divided into three regions such as crown region, middle region, and toe region as shown in Figure 2.3, and numerous low level nodes attached to homogeneous sensor column are deployed in these regions.
2.6 WIRELESS SENSOR NETWORK ALGORITHM

The wireless sensor network uses four algorithms for implementing clustering, distributed consensus among the data, energy efficient data aggregation and time synchronization, which will contribute for the development of an efficient landslide detection system.

The real-time monitoring networks are constrained by energy consumption, due to the remote location of the deployment site and the non-availability of constant power. Considering these factors, the wireless sensor network at the deployment site implements a totally innovative concept for distributed detection, estimation and consensus to arrive at reliable decisions, more accurate than that of each single sensor and capable to achieve globally optimal decisions. In landslide scenario, the implementation of this algorithm imposes a constraint of handling heterogeneous sensors in each sensor column.

The different methods that can be used for implementing this algorithm, for landslide scenario are:

- Homogeneous sensor columns deployed in each region can be compared and a consensus value can be achieved for all the sensor columns in that region.
- All the sensors deployed in the landslide prone area can be assigned with a weightage with regard to its impact on landslide detection, and a common consensus value can be achieved executing the algorithm at once, for all deployed sensors.
- Decentralized consensus performed for the same type of sensors in all sensor columns in a region.

Decentralized consensus for the same type of sensors has been developed for the deployed network. The decentralized algorithm will be executed for each type of sensors, one by one, for all homogeneous sensor columns deployed at each region. After initial set of sensors achieve its consensus, the next set of sensors will execute the decentralized algorithm.
and so on, as shown in Figure 2.4. The other designs demand apriori knowledge of correlation between different geophysical sensors, whereas this method does not require this apriori knowledge, but the processing delay will be more compared to other methods, due to the multiple execution of same algorithm. Since the study concentrates on the detection of rainfall induced landslides, the most relevant data will be arriving during rainy season. So rainfall based alert levels have been developed which will influence the sampling rate of the geological sensors and the transmission of data to higher layers. This algorithm will help to reduce the energy consumed during the low alert levels and also in collecting and transmitting large amounts of data, only when the environmental and geological conditions demand the same. Other than these methods, state level transitions have been incorporated to 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

![Fig. 2.4: Decentralized Consensus for Same Type of Sensors](image)

**THE NETWORK TOPOLOGIES THAT APPLY TO WIRELESS SENSOR NETWORKS**

- **STAR NETWORK (SINGLE POINT-TO-MULTIPOINT):** A star network is a communications topology where a single base station can send and/or receive a message to a number of remote nodes. The remote nodes can only send or receive a message from the single base station; they are not permitted to send messages to each other.

- **MESH NETWORK:** A mesh network allows for any node in the network to transmit to any other node in the network that is within its radio transmission range. This allows for what is known as multi-hop communications; that is, if a node wants to send a message to another node that is out of radio communications range, it can use an intermediate node to forward the message to the desired node.
HYBRID STAR – MESH NETWORK: A hybrid between the star and mesh network provides for a robust and versatile communications network, while maintaining the ability to keep the wireless sensor nodes power consumption to a minimum. In this network topology, the lowest power sensor nodes are not enabled with the ability to forward messages. This allows for minimal power consumption to be maintained. However, other nodes on the network are enabled with multi-hop capability, allowing them to forward messages from the low power nodes to other nodes on the network. Generally, the nodes with the multi-hop capability are higher power, and if possible, are often plugged into the electrical mains line. This is the topology implemented by the up and coming mesh networking standard known as ZigBee.

Self organization of ad hoc networks includes both communications self-organization and positioning self-organization. Relative positioning or localization requires inter-node communications, and a TDMA message header frame that has both communications and localization fields.

FIGURE 2.5
2.7 RADIO OPTIONS FOR THE PHYSICAL LAYER IN WIRELESS SENSOR NETWORKS:

The physical radio layer defines the operating frequency, modulation scheme, and hardware interface of the radio to the system. There are many low power proprietary low power radio integrated circuits that are appropriate choices for the radio layer in wireless sensor networks, including those from companies such as Atmel, MicroChip, Micrel, Melexis, and ChipCon. If possible, it is advantageous to use a radio interface that is standards based. This allows for interoperability among multiple companies networks.
The 802.15.4 standard was specifically designed for the requirements of wireless sensing applications. The standard is very flexible, as it specifies multiple data rates and multiple transmission frequencies. The power requirements are moderately low; however, the hardware is designed to allow for the radio to be put to sleep, which reduces the power to a minimal amount. Additionally, when the node wakes up from sleep mode, rapid synchronization to the network can be achieved. This capability allows for very low average power supply current when the radio can be periodically turned off.

The standard supports the following characteristics:

1) Transmission frequencies, 868 MHz/902–928 MHz/2.48–2.5 GHz.
2) Data rates of 20 Kbps (868 MHz Band) 40 Kbps (902 MHz band) and 250 Kbps (2.4 GHz band).
3) Supports star and peer-to-peer (mesh) network connections.
4) Standard specifies optional use of AES-128 security for encryption of transmitted data.
5) Link quality indication, which is useful for multi-hop mesh networking algorithms.
6) Uses direct sequence spread spectrum (DSSS) for robust data communications.

The IEEE 802.15.4 will become most widely accepted for wireless sensing applications. The 2.4-GHz band will be widely used, as it is essentially a worldwide license-free band. The high data rates accommodated by the 2.4-GHz specification will allow for lower system power due to the lower amount of radio transmission time to transfer data as compared to the lower frequency bands.

2.7.1 INTRODUCTION TO ZIGBEE (802.15.4) TECHNOLOGY:

ZigBee is a new technology now being deployed for wireless sensor networks. A sensor network is an infrastructure comprised of sensing, computing and communications elements that allows the administrator to instrument, observe and react to events and phenomena in a specified environment. Typical applications include, but are not limited to, data collection, monitoring, surveillance and medical telemetry. The administrator typically is a civil, government, commercial or industrial entity. It is a new wireless network protocol stack of IEEE 802.15.4. Additionally it complies with IEEE802.15.4 protocol, which makes it convenient to communicate with other products that comply with the protocol too.

THE MAINLY ADVANTAGES OF ZIGBEE TECHNOLOGY LIES IN THE FOLLOWING ASPECTS:

(a) Reliable and self-configuration.
(b) Supports large number of nodes.
(c) Easy to deploy.
(d) Very long battery life.
(e) Standards based high security [AES128].
(f) Low cost.
(g) Can be used globally.
(h) Larger network size (65,000 devices vs. 8) and several new topologies (star, mesh, cluster tree)

2.7.2 ZIGBEE DEVICE CLASSES:
- Zigbee Coordinator (ZC)
  - Most capable device
  - Forms the root of the network tree and bridge to other networks
  - Acts as repository for security keys
- Zigbee Router (ZR)
  - Can pass data from one device to another
- Zigbee End Device (ZED)
  - Contains just enough functionality to talk to its parent node either ZC or ZR.

WIRELESS TECHNOLOGY COMPARISON:

<table>
<thead>
<tr>
<th>Standard</th>
<th>Bandwidth</th>
<th>Power Consumption</th>
<th>Protocol Stack Size</th>
<th>Stronghold</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wi-Fi</td>
<td>Up to 54Mbps</td>
<td>400+mA TX Sleep 20mA</td>
<td>100+KB</td>
<td>High Data Rate</td>
</tr>
<tr>
<td>Bluetooth</td>
<td>1Mbps</td>
<td>40mA TX Sleep .2mA</td>
<td>100+KB</td>
<td>Interoperability Cable Replacement</td>
</tr>
<tr>
<td>Zigbee</td>
<td>250kbps</td>
<td>30mA TX Sleep .003mA</td>
<td>32KB</td>
<td>Long Battery Life, Low cost</td>
</tr>
</tbody>
</table>

Table II

2.8 SYSTEM FRAMEWORK FOR LANDSLIDE:
Every site in this system comprises a gateway and some wireless nodes. Gateways and nodes are all embedded with a CC2420 RF transceiver (ZigBee compliant) produced by Chipcon company. Data can be transmitted by transceiver between gateways and nodes, and finally the data from all areas are collected to be transmitted to a server. The sketch of the system is shown in Figure 2.6.
2.8.1 THE FRAMEWORK AND FUNCTIONS OF THE SYSTEM LIES IN THE FOLLOWING:

FUNCTIONS OF GATEWAY:
(1) Communicating with the server via Ethernet;
(2) Communicating with nodes by RF transceiver.

FRAMEWORK AND FUNCTIONS OF WIRELESS NODES:
(1) Atmega128L MCU and TinyOS operating system;
(2) Temperature, humidity, height changes and tilt etc collection periodically;
(3) Transmitting collected data to gateway by using CC2420.


2.8.2 THE FRAMEWORK OF WIRELESS SENSOR NETWORK

The Framework of Wireless Sensor Network is shown in Figure 2.7. Each node can sense, compute and communicate each other. They can either receive message or transmits message, and can transmit messages to a gateway via self-configuration and multi-hop routing. The gateway can use many ways to communicate with remote network, such as Internet, satellite and mobile communication network (in this system we use Ethernet). More than one gateway may be used for large-scale application. Because of its limited communication areas the node must use multi-hop routing to access the nodes out of communication areas.

2.9 COMMERCIALLY AVAILABLE WIRELESS SENSOR SYSTEMS

Crossbow Berkeley Motes may be the most versatile wireless sensor network devices on the market for prototyping purposes. Crossbow (http://www.xbow.com/) makes three Mote processor radio module families– MICA [MPR300] (first generation), MICA2 [MPR400] and MICA2-DOT [MPR500] (second generation). Different sensors can be installed if desired. Low power and small physical size enable placement virtually anywhere. Since all sensor nodes in a network can act as base stations, the network can self configure and has multi-hop routing capabilities. The operating frequency is ISM band, either 916 MHz or 433 MHz, with a data rate of 40 Kbits/sec. and a range of 30 ft to 100 ft. Each node has a low power microcontroller processor with speed of 4MHz, a flash memory with 128 Kbytes, and SRAM and EEPROM of 4K bytes each. The operating system is Tiny-OS; a tiny micro-threading distributed operating system developed by UC Berkeley, with a NES-C (Nested C) source code language (similar to C). Installation of these devices requires a great deal of programming. The MicaZ wireless sensor node connected to the sensor column transmits the digitized data values to the upper layers of the network.
2.9.1 HARDWARE OF WIRELESS NODE

The wireless sensor network nodes use battery power and their power capabilities are limited due to its small size of node. The transmission rate of the network is low and it needs enough power to work steadily for a long time. Therefore low-power design is significant. The system adopts MICAz mote module produced by Crossbow Technology and its sketch of hardware is shown in Figure 2.8. MICAZ is embedded with a ZigBee compliant RF transceiver and it works between 2.4 and 2.4835 GHz, a globally compatible ISM band. Its DDSS radio offers both high speed (250 kbps) and hardware security (AES-128). The MICAz 51-pin expansion connector supports Analog Inputs, Digital I/O, I2C, SPI and UART interfaces. These interfaces make it easy to connect to a wide variety of external peripherals, including a variety of sensor, data acquisition boards and gateway. The RF link has a 30 meter range with a 19200 baud rate. The baud rate on the serial RS-232 link between the Base Station and a terminal PC is 38400.

FIGURE 2.8: HARDWARE FRAMEWORK OF MICAZ.

2.9.2 MICROCONTROLLER

We adopt Atmega128L, a High-performance, and Low-power AVR 8-bit Microcontroller as our processor. The ATmega128 provides the following features: 32 general purpose working registers connected to ALU directly, On-chip 2-cycle Multiplier, 128K bytes of In-System Programmable Flash with Read-While-Write capabilities, 4K bytes EEPROM, 4K bytes SRAM, 2 USARTs, an SPI serial port linked to CC2420, a byte oriented Two-wire Serial Interface, an 8-channel, 10-bit ADC with optional differential input stage with programmable gain, and it design six sleep modes, especially for the restriction of power.
2.9.3 RF TRANSCEIVER

The CC2420 is the industry’s first single-chip 2.4 GHz RF transceiver compliant with the IEEE 802.15.4 standard and already to be used in ZigBee products. In a typical application CC2420 will be used together with a microcontroller and a few external passive components. CC2420 set its work modes by SPI (SI, SO, SCLK, CSn) and achieve its read-while-write operation. The sketch of link between CC2420 and microcontroller is shown in Figure 2.9.

![Diagram of CC2420 and microcontroller link](image)

**FIGURE 2.9:** LINK BETWEEN CC2420 AND MICROCONTROLLER.

2.9.4 GATEWAY

MIB600CA which is one of MICAz mote developer’s kits is adopted as a gateway for TCP/IP-based Ethernet. MIB600CA is used as a bridge to link the wired and wireless network. It connects the MICAz to Ethernet and permit server access data from wireless sensor network by TCP/IP-based Ethernet.

2.9.5 BRIEF INTRODUCTION TO TINYOS

TinyOS is an event-driven operating system designed for sensor network nodes that have very limited resources (the core OS requires 400 bytes of code and data memory, combined). TinyOS supply a series of components which can be used to program conveniently and easily to acquire and process data acquired by sensors. We can regard TinyOS as a API interface interacted with sensors and they can communicate each other. The TinyOS system, libraries, and applications are written in nesC, a new language for programming structured component-based applications. nesC is an extension to C, designed to embody the structuring concepts and execution model of Tiny-OS.
2.9.5.1 THE BASIC CONCEPTS BEHIND nesC ARE:

1. nesC is a “static language”. There is no dynamic memory allocation and the call-graph is fully known at compile-time. These restrictions make whole program analysis and optimization significantly simpler and more accurate.

2. Programs are built out of components, which are assembled (“wired”) to form whole programs. Components can use or provide interface.

3. Interfaces are only point of access to components. The interface specifies a set of named functions, called commands, to be implemented by the interface’s provider and a set of named functions, called events, to be implemented by the interface’s user. Interfaces are bidirectional and the user who uses the command must implement command.

4. There are two types of components in nesC: modules and configurations. Modules provide application code, implementing one or more interfaces. Configurations are used to wire other components together, connecting interfaces used by components to interfaces provided by others.

5. Components are statically linked to each other via their interfaces. This increases runtime efficiency and allows for better static analysis of programs.

2.10 THE DESIGN OF SOFTWARE

The wireless node’s applications are written in nesC. The software’s flow chart is shown in Figure 2.10 shows most components of application. The downward-pointing arrows depict commands and upward-pointing arrows depict events. Timer is an interface to supply a counter to generate an interrupt at a very interval. ReceiveMsg and BareSendMsg are all interfaces to receive messages from network, while SendMsg sends messages to network.

Multi-hop is a module for the judge of multi-hop. It receives messages from application and network and does some necessary sensing and transmitting. For example, if a node A want to communicate to a node B which is not at the range A can communicates, and another node C can communicate with A and B. At the moment the module-Multi-hop let A send message to C and C send the message to B. QuenedSend and GenericComm are communication modules which are responsible for communication in network layer. AM Promiscuous is a module to represent equipments and it can determine whether to send messages to UART or CC2420. RadioCRC Packet and CC2420RadioC which make RF transmitter send or receive messages represent the flow to CC2420.UARTFramedPacke’s flow represents messages to UART (gateway). The gateway’s function is to receive data and send data to server which will do more procession for those data.
2.11 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.

2.12 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/ZigBee 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 2.11. 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 or ZigBee.

![Wireless Sensor Network Architecture for Landslide Detection](image)

**FIGURE 2.11: WIRELESS SENSOR NETWORK ARCHITECTURE FOR LANDSLIDE DETECTION**

2.13 DEPLOYMENT OF SATELLITE NETWORK:

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, 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.
2.13.1 VSAT NETWORKS

A VSAT is a small-sized telecommunications earth station that transmits and receives via satellite. The terminal size is 1.2 to 2.4 meters in diameter. VSAT stands for Very Small Aperture Terminal VSAT systems generally connect a large number of geographically dispersed sites to a central location. VSAT networks may transmit voice, data, fax, or video conferencing. The key point in VSAT networks is that either the transmitter or the receiver antenna on a satellite link must be larger. In order to simplify VSAT design, a lower performance microwave transceiver and lower gain dish antenna (smaller size) is used. Antenna size is restricted to being less than or equal to 3.8 m at Ku band and 7.8 m at C band. They act as bidirectional earths stations that are small, simple and cheap enough to be installed in the end user's premises.

VSAT networks are typically arranged in a star based topology, where each remote user is supported by a VSAT. A star network allows any number of VSAT sites to have two-way communication with a central hub. The Earth hub station acts as the central node and employs a large size dish antenna with a high quality transceiver. The satellite provides a broadcast medium acting as a common connection point for all the remote VSAT earth stations. VSAT networks are ideal for centralized networks with a central host and a number of geographically dispersed terminals.

A more general definition is that a network is a VSAT network if it consists of a large high performance hub earth station (with an antenna of up to 9 m in diameter) and a large number of smaller, lower performance terminals. Being completely general, these small terminals can be receive only, transmit only or transmit/receive.

NOTE: It must always be remembered, however, that as antenna size decreases, the antenna beam widens and that a point is rapidly reached when there is no further advantage in decreasing antenna size because of increased interference with other systems.

2.13.2 THE DIFFERENT VSAT TRANSMISSION METHODS:

There are three basic VSAT transmission types:

- TDMA, time-division multiple access
- DAMA, demand-assigned multiple access
- SPCP/MCPC, single/multiple channels per carrier.

Interactive VSAT systems come in two main network topologies - star and mesh. The former tends to be based either on a shared access scheme (TDM/TDMA), which is designed to support transactional processing applications, or on a dedicated link (the satellite equivalent to a leased line). The latter usually uses links which are set-up and torn-down on request to establish a direct link between two sites on a demand assigned basis. These mesh systems were initially designed to support corporate and public network telephony links, but are being increasingly used to serve high data rate services, such as file downloads, at rates of 64 kbps or greater.
2.13.2.1 THE CHARACTERISTICS OF A TDMA TRANSMISSION TYPE:

TDMA is a form of multiple access in which a single carrier is shared by many users. When signals from earth stations reach the satellite, they are processed in time segments without overlapping. TDMA is typically used in a packet switched environment when small or moderate amounts of data are to be transferred.

2.13.2.2 THE CHARACTERISTICS OF A DAMA TRANSMISSION TYPE:

The DAMA protocol is used to share bandwidth in a time division mode. Typically DAMA transmission is used in a packet-switched environment when large amounts of data are to be transferred. It is a highly efficient means of instantaneously assigning telephony channels in a transponder according to immediate traffic demands. DAMA is also applicable in a circuit-switched environment and is usually characterized by allowing each user a variable slot of time on a demand (or request) basis.

2.13.2.3 THE CHARACTERISTICS OF A SCPC/MCPC TRANSMISSION TYPE:

SCPC/MCPC systems use a dedicated satellite link between a few distinct locations. These links can support either a single telephone line or several telephone or data lines. Such links generally are permanently assigned with no carrier switching or rerouting over the satellite.

2.13.2.4 TDM-TDMA TRANSMISSION:

TDM-TDMA networks are designed for interactive data applications. TDM-TDMA systems feature a large expensive hub that provides basic data communications to very inexpensive remote sites. The architecture supports many remote stations using a small amount of satellite bandwidth. Data rates supported at the remote sites are typically between 1.2 kbps and 9.6 kbps; however, this type of traffic has a very low average data rate. Each station may transmit bursts of 9.6 kbps data, but they generally average less than 100 kbps. Typical applications are transactional in nature.

![V-SAT Architecture](image)
The most common VSAT configuration is the TDM/TDMA star network. This has a high bit rate outbound carrier (TDM) from the hub to the remote earth stations, and one or more low or medium bit rate Time Division Multiple Access (TDMA) inbound carriers.

With its star configuration network architecture, interactive VSAT technology is appropriate for any organization with centralized management and data processing. This configuration has been developed to minimize overall lifetime costs for the complete network including satellite transmission costs. The use of a single high performance hub allows the use of low cost remote VSAT terminals and optimizes use of satellite capacity. Even so, in most VSAT networks, the cost of the VSAT terminals usually far exceeds the cost of the hub (typically a VSAT terminal is 0.1 to 0.2% of the price of the hub).

THE PRINCIPLE CHARACTERISTICS OF AN INTERACTIVE VSAT NETWORK ARE:

- Remote user sites have several low bit rate data terminal equipments (DTEs) operating at 1.2 to 9.6 kb/s. These are connected through the VSAT network to a centralized host processor. The DTEs are connected to the host through an X.25 Packet Assembler/Disassembler (PAD) or through a conventional or statistical multiplexer which concentrates the traffic.
- The amount of data transferred in each transaction is relatively small, typically between 300 and $10^5$ bits. Interactive VSATs are not usually used for batch file transfer ($10^7$ to $10^{11}$ bits per transaction) unless the transmission plan is specifically designed to carry large files.
- Each VSAT terminal only operates with a low duty cycle, i.e. with only a relatively small number of transactions in the peak busy hour compared to the total available capacity.
- A large number of VSAT terminals (10 to 10000) share the same communications link using random access.
- Connections between remote VSAT terminals require a double hop through the hub and are rarely used.

VSAT networks are designed to be flexible and to evolve with user needs. VSAT terminals are controlled by microprocessors and can generally be reprogrammed remotely using downloaded software from the hub. If additional interfaces or capacity are required this can usually be provided by adding or replacing cards in the VSAT terminal.
To make VSAT networks more affordable it is possible to share the hub between several users, thereby spreading the cost. In this case the hub is usually owned by a service provider who retains overall control of the network and who manages the hub itself.

Each user, however, is allocated his own time slots or carriers and can so operate his own private network using the shared hub facility without any loss of privacy. The operation and management of these sub-networks is performed by the users themselves completely independently of the service supplier.

**TABLE III**

<table>
<thead>
<tr>
<th>Supplier</th>
<th>Hardware</th>
<th>Type</th>
<th>Inbound Data Rate (kb/s)</th>
<th>Outbound Data Rate (kb/s)</th>
<th>Modulation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gilat/Spacenet</td>
<td>Skystar</td>
<td>TDM/TDMA</td>
<td>9.6, 13.2, 38.4, 56, 64, 76.8, 120</td>
<td>64, 128, 256, 512, 1024, 2048</td>
<td>DPSK or MSK</td>
</tr>
<tr>
<td>Hughes</td>
<td>ISN/PES</td>
<td>TDM/TDMA</td>
<td>64, 128, 256</td>
<td>128, 512</td>
<td>BPSK</td>
</tr>
<tr>
<td>India Espacio</td>
<td>Arcanet</td>
<td>CDMA</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>NEC</td>
<td>Nexitar V</td>
<td>TDM/TDMA</td>
<td>64, 128, 256</td>
<td>64, 128, 256, 512, 768, 1536, 2348</td>
<td>BPSK/QPSK</td>
</tr>
<tr>
<td>STM</td>
<td>X-Star</td>
<td>TDM/TDMA</td>
<td>96, 192, 384</td>
<td>64, 128, 256, 512, 1024, 1544</td>
<td>BPSK</td>
</tr>
<tr>
<td>TSAT</td>
<td>TSAT 2000</td>
<td>TDM/TDMA</td>
<td>0.3, 0.6, 1.2, 2.4, 4.8</td>
<td>0.3, 0.6, 1.2, 2.4, 4.8</td>
<td>4FSK, 2-4FSK</td>
</tr>
<tr>
<td>TSAT</td>
<td>TSAT 2100</td>
<td>TDM/TDMA</td>
<td>2.4, 3.6, 14.4, 16.8</td>
<td>2.4, 3.6, 14.4, 16.8</td>
<td>QPSK</td>
</tr>
<tr>
<td>ViaSat</td>
<td>Sky Relay</td>
<td>TDM/TDMA</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**FIGURE 2.13 TYPICALINTERACTIVE HUB VSAT FRAME AND PACKET FORMAT**
Each TDM outbound carries a continuously transmitted bit stream which is divided into frames.

The start of a frame is denoted by a framing packet contain a unique word (UW) and a control word (CNTRL) which, together, provide framing, timing and control information.

The rest of the frame is filled by (generally) fixed length data packets which each contain:

- F preamble
- HDR header - giving IDU address and control information
- FCS frame check sequence
- F postamble

Outbound data packets typically contain between 50 and 250 bytes in transactional networks.

Each TDMA inbound contains frames which are synchronized to the outbound frames. Each inbound frame is divided into slots. Individual IDUs transmit in these slots in a manner depending on the access modes available to the particular system and how the network has been set up.

Each inbound packet consists of:

- F preamble
- HDR header - giving IDU address and control information
- FCS frame check sequence
- F postamble

Inbound data packets typically contain between 50 and 250 bytes in transactional networks.

The real-time data collected by FMC from different sites is transferred to the satellite transmit unit. Then this data is processed/ formatted in a high-level data link control (HDLC) frame with CRC for data validity check as well as data delimiter receiver. The formatted data is transmitted DRT transponder of the INSAT satellite by using a suitable channel-access protocol. A satellite transponder is a combination receiver, frequency converter, and transmitter package. It is physically part of a communications satellite. Communications satellites typically have 12 to 24 onboard transponders. The satellite converts the UHF band into C-band and transmits to the 3.8m antenna receive ground (hub) station. The hub station receives real-time data from all the landslide-prone sites and the signal is demodulated to recover the data. The recovered data is fed to the data processing unit of the data processing
centre. This real-time data is then transferred to computers for modeling the analysis of each site. Thus the communication system can be divided into four parts: satellite transmit unit (UHF transmitter), space segment, receive station (hub) and channel access protocol.

**Space segment:** Some of the INSAT series satellites have a UHF transponder specifically designed for meteorological data collection applications. The frequency band available for this application is 402.65 to 402.85 MHz. Presently, two Indian geo-synchronous satellites are operational, having data relay transponders at KALPANA satellite at location 74°E and INSAT 3A at 93°E. Satellite parameters and satellite link calculation are shown in Tables III and IV.

<table>
<thead>
<tr>
<th>Parameters</th>
<th>INSAT 3A</th>
<th>KALPANA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rx frequency range</td>
<td>402.75±100 kHz</td>
<td>402.75±100 kHz</td>
</tr>
<tr>
<td>Polarisation</td>
<td>RHCP</td>
<td>LHCP</td>
</tr>
<tr>
<td>Rx G/T</td>
<td>-19.0 dB/K</td>
<td>-19.0 dB/K</td>
</tr>
<tr>
<td>Downlink frequency</td>
<td>4504.2 MHz</td>
<td>4506.05 MHz</td>
</tr>
<tr>
<td>EIRP</td>
<td>24 dBW</td>
<td>21 dBW</td>
</tr>
</tbody>
</table>

**TABLE IV**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Uplink frequency</td>
<td>402.750 MHz</td>
</tr>
<tr>
<td>Uplink path loss</td>
<td>177 dB</td>
</tr>
<tr>
<td>Transmit power</td>
<td>10 dBW</td>
</tr>
<tr>
<td>Antenna gain (including cable loss)</td>
<td>-3 dBi</td>
</tr>
<tr>
<td>Transmit EIRP</td>
<td>7 dBW</td>
</tr>
<tr>
<td>Satellite G/T</td>
<td>-19 dB/K</td>
</tr>
<tr>
<td>Uplink C/No</td>
<td>EIRP-path loss+G/T+K : 39.0 dBHz</td>
</tr>
</tbody>
</table>

**TABLE V**

### 2.14 DESIGN OF DATA ANALYSIS SOFTWARE

Data received at the DMC is being 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. The software has the capability of real streaming of data and its analysis results, over internet, which will provide greater capability of effective warning issue at minimum delay. 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.

### 2.15 WARNING DATA TO RESPECTIVE AGENCIES:

![Diagram](image)

**FIGURE 2.14: GENERATION OF WARNING BY CONTROL CENTRE**

### 2.16 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.
2.17 EXPERIMENT

An experiment was done in a room which 11 meters in length and 8 meters in width. The application to measure temperature, light intensity, node voltage and parent node is written in Visual C ++6.0 under the Windows 2000 operation. Parent node denotes nodes that receive a message from another node and the 0 parent node represents base node (gateway). The result of experiment is shown in Figure 2.15

From Figure 2.15, we can see that the experiment measure parameters in room perfectly.

Data received from two pore pressure transducers and a rain gauge is shown in Figure 2.16.

FIGURE 2.16: REAL-TIME FIELD DATA

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.
2.18 PREVENTIVE MEASURES FOR LANDSLIDE:

The preventive measures can be deduced directly from the causes.

1. The first cause listed is gravity. Since we cannot alter gravity, what we can do, is alter geometry of the man-made slope so that the gravity effects are not detrimental. If the landslide is surficial (not too deep), the easiest way to prevent the fall of rocks and soil over the slope – is to vegetate it! However, vegetation can help only if the movement hasn’t already begun or if the landslide is deep!

2. Groundwater table changes are the most common cause of landslides. Heavy rains, leaking pipes, melting of snow in warm weather, floods, etc can cause changes in the groundwater table, thus inducing a landslide. Although natural phenomena such as heavy rains, melting snow, etc cannot be modified, its effect on the groundwater table can be controlled by applying the principles of hydrology and geotechnical engineering. Rain water or snow melt can be directed far away from the slopes by building drainage channels or swales that convey the water where it shall not be detrimental to the stability of the slope. Leaking pipes or leaking swimming pools can be easily fixed, once the location of the leak is determined.

3. Earthquakes cause ground shaking which may directly lead to a landslide. Or, the ground shaking may cause the soil to loosen and become weak, leading to a landslide. To prevent earthquake induced landslides, the ideal solution is to design the geometry of the slope such that it has an adequate factor of safety even for seismic cases.

4. To prevent landslides triggered due to construction on top of the slope, a setback distance should be maintained between the top of slope and construction. The distance will depend on the type of construction and geology and geometry of the slope.

5. Another cause of landslides, is undercutting of the toe of slope. The toe of the slope plays a major role in keeping the upper portion in a stable condition. In fact, if a slope seems unstable, soil berms (counterweight fills) are placed at the toe of the slope to provide additional resistance to the potential movement of the upper part of the slope. Another aspect with similar principles would involve removing soil from the top of the slope, thus reducing the forces driving the movement.

6. Benching, constructing retaining walls, shotcreting, putting up steel nets, etc are some other methods of preventing or controlling landslides.
CHAPTER 3

CONCLUSION AND FUTURE DEVELOPMENTS

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. The most general and versatile deployments of wireless sensing networks demand that batteries be deployed. Future work is being performed on systems that exploit piezoelectric materials to harvest ambient strain energy for energy storage in capacitors and/or rechargeable batteries. By combining smart, energy saving electronics with advanced thin film battery chemistries that permit infinite recharge cycles, these systems could provide a long term, maintenance free, wireless monitoring solution.