Landslide Monitoring and Assessment System using Low-Cost Wireless Communication

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Landslides are one of the most dangerous natural disasters in Thailand. Areas with landslide hazard can be found in many parts of the country. Accurate rainfall data are required to assess chances of landslide in risky areas. However, most areas rely on rainfall data collected at certain places where equipment can be conveniently installed such as a district office. It is known that rainfall observed closer to a place where landslide is triggered, such as on top of a mountain, can be significantly different, which greatly affects the landslide hazard assessment procedure.

To be able to accurately assess risk and respond in a timely manner, rainfall data should be collected from an area as close to a source of landslide as possible. Hence, any traditional method that require human staff to check and record rainfall data manually from rain gauges are not preferable because it is both risky and time-consuming. In this paper, we present deployment of a wireless communication system for landslide hazard assessment in a village located in District of Khao-Panom, Krabi Province, Southern Thailand. The system is split into two segments: (1) relaying data from a rain gauge installed near a landslide hazard site to the base of the mountain via a multi-hop IEEE802.15.4 network operating at 2.4GHz, and (2) relaying data from the base of the mountain to the center of the village via a single-hop long-range IEEE802.11 link operating at 5GHz. In addition, a debris flow detector is attached to a wireless unit located near a landslide trigger location, so that an alarm will immediately go off when a debris flow is detected. A web-based status monitoring system is also developed to allow villagers to check current battery levels and operational status of wireless nodes. Connectivity statuses such as signal strength between any pair of wireless nodes are continuously recorded for further analysis.

The system has now been collecting rainfall data for several months. Analysis of connectivity data shows many interesting behavior of our wireless communication system in various weather conditions. For example, it is observed that rain can severely disrupt wireless communication operating at 2.4GHz in areas with dense trees. These results allow us to plan our deployment of similar systems in the future.

Acknowledgments

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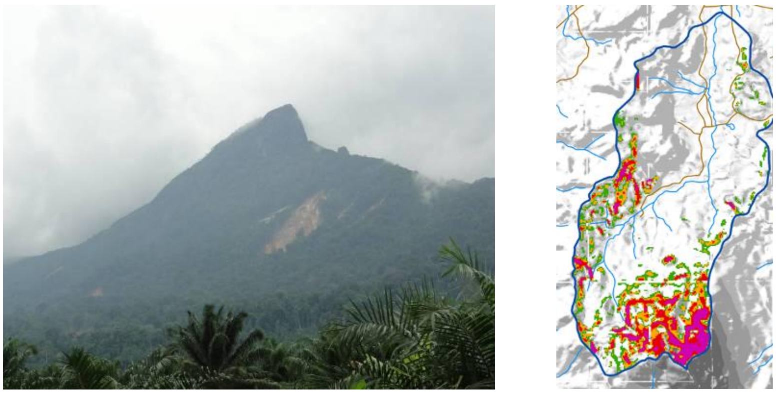
1. Introduction

Landslides are one of the most dangerous natural disasters in Thailand. Areas with landslide hazard can be found in many parts of the country [1]. Accurate rainfall data are required to assess chances of landslide in risky areas. However, most areas rely on rainfall data collected at certain places where equipment can be conveniently installed such as a district office. It is known that rainfall observed closer to a place where landslide is triggered, such as on top of a mountain, can be significantly different, which greatly affects the landslide hazard assessment procedure.

To be able to accurately assess risk and respond in a timely manner, rainfall data should be collected from an area as close to a source of landslide as possible. Hence, any traditional methods that require human staff to check and record rainfall data manually from rain gauges are not preferable because it is both risky and time-consuming. In this paper, we present the deployment of a low-cost wireless communication system for landslide hazard assessment. In addition, a debris flow detector is attached to a wireless unit located near a landslide trigger location, so that an alarm will immediately go off when a debris flow is detected. A web-based status monitoring system is also developed to allow villagers to check current battery levels and operational status of wireless nodes. Connectivity statuses such as signal strength between any pair of wireless nodes are continuously recorded for further analysis.

The system has been initially deployed in the village of Huay Nam Kaew, located in District of Khao-Panom, Krabi Province, Southern Thailand. This area has been damaged by large landslides in 2011, as shown in Figure 1, and has previously been announced by the Department of Mineral Resources (DMR) to be a landslide prone area [2].

The rest of the paper is organized as follows. Section 2 describes our system architecture and components. The initial deployment and preliminary results are covered in Section 3. And Section 4 concludes our work.



(a) (b)

Figure 1 (a) landslide scars on granitic rock at Khao-Panom District, Krabi Province, and
(b) landslide hazard map, where purple and red areas indicate very high risk [2]

2. System Architecture

As shown in Figure 2, our landslide monitor and assessment system consists of four main components: (1) a network of wireless sensor nodes embedded into the observation area for collecting rainfall data and monitor a debris flow in a watershed, (2) a long-range WiFi connection to transfer observed data to the village head, (3) a GPRS connection to provide remote access from the Internet, and (4) a web-based status monitoring system for the wireless sensor network. The following subsections will describe each component in more details.

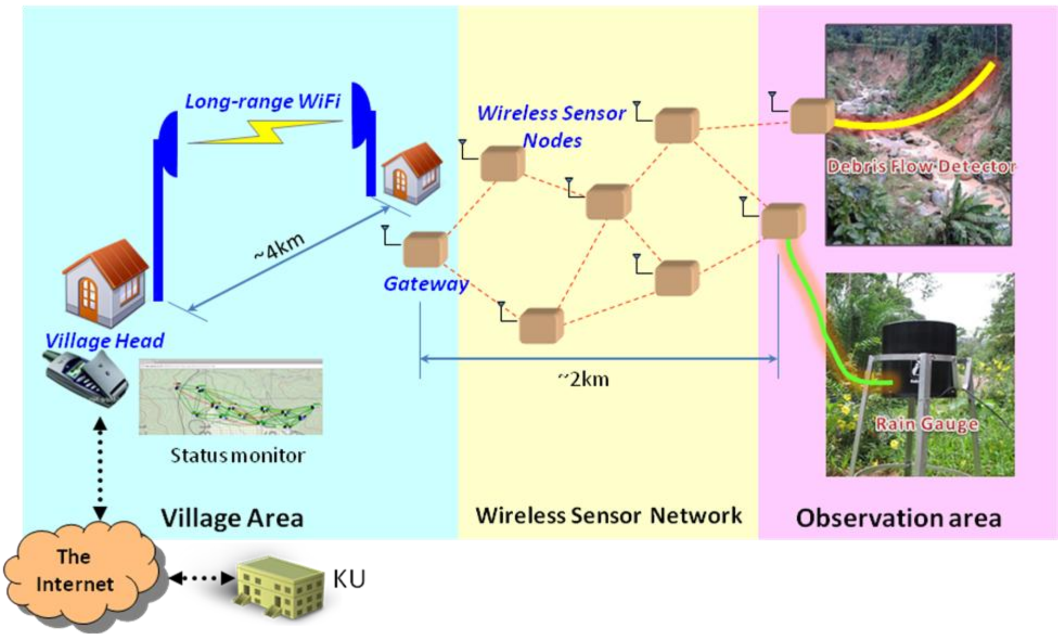


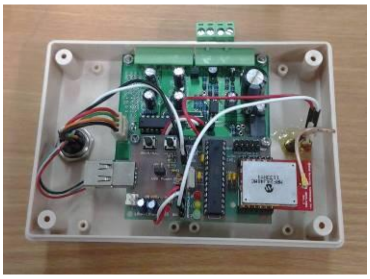
Figure 2 System overview

2.1. *Wireless Sensor Network and Observation Area*

The observation area is located at the lower of the landslide scar where observed conditions include rainfall and debris flows. A tipping-bucket (Figure 3(d)) rain gauge sensor was placed on an open hill to collect and compute accumulated rainfall amount for assessing landslide hazard, while a debris flow detector (Figure 3(c)) was install in a watershed nearby.

Wireless sensor nodes, shown in Figure 3(a), are devices used for collecting and forwarding data from the mentioned sensors to a gateway device. As the installation area is a sparse forest without electricity, these nodes were equipped with communication modules based on IEEE 802.15.4, which was designed to consume very little power compared to typical wireless communication technologies. However, their communication range is rather short, so multiple nodes were perennially installed from the observation area down-to a foothill where the gateway device was installed, with the distance of roughly 2 km. A design of the nodes includes a battery for energy storage, shielded with aluminum housing for dust and humidity protection, as shown in Figure 3(b).

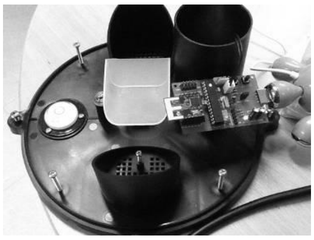
A wireless sensor node comprises of three main electronic parts: (1) ATMega328p microcontroller that processes a data, operates a communication protocol, and controls overall node system; (2) MRF24J40MC radio frequency signal transceiver, used by the microcontroller for accessing communication channel media; and (3) A signal conditioner circuit, interfacing with the sensors for voltage level adjustment and electrical circuit protection.



(a)

(b)

(c)



(d)

Figure 3 Wireless sensor node and sensor devices: (a) inside a unit showing a microcontroller and a high-power RF transceiver, (b) an enclosure with an 18Ah battery and an external antenna, (c) a debris flow detector, and (d) tipping bucket rain gauge

2.2. *Long-range Communication*

The distance from the sensing area at the foothill to the center of the village is around 6 km along the road side where the telephony and electricity poles are not fully covered. Also the cost of new wiring installation and maintenance is not feasible. Hence, the long-range communication used for relaying data has been deployed to connect the sensor gateway at the foothill shown in Figure 4(a) to the center of the village where the village head locates shown in Figure 4(b). The displacement between two end points is around 4 km. The implemented system composes of two 5-GHz WiFi access points with the dish antenna configured as bridge devices. Each WiFi access point is mounted to the top of a pole with the height of 4 meters from the ground. The connection from the access point to the sensor gateway has been linked by the outdoor Ethernet cable. Due to the lack of power system at the foothill, the WiFi access point is powered by the solar cells and UPS. However, at the center of the village, the WiFi access point and monitoring sever are powered by the electricity for system stability. The system can provide the throughput up to 22 Mbps.

(a)

(b)

Figure 4 Long-range WiFi installation located at (a) the foothill (b) the center of the village

2.3. *GPRS Connection*

Observation data such as rainfall amounts and node's battery status are accessible via a web-based monitoring system, installed on a village head server. To provide access the server from another location such as Bangkok, an Internet connection is required. Typical Internet services, such as ADSL, are not available in the area and only GPRS connection can be used. At the village head, a GPRS modem, Wavecom Fastrack© from SIERRA Wireless™, was installed to provide an Internet connection. However, such connection can only allow outgoing requests from the village. To allow requests from outside to the server located inside of the village, an SSH tunneling technique is used

2.4. *Node Status Monitoring*

As the system is intended to be deployed in a remote area without support from technical staff, it must be maintainable by non-technical people. We developed a web-based monitoring tool to check current levels of batteries in wireless sensor nodes, as well as reliability of wireless connection between any pair of nodes.

3. Initial Deployment and Preliminary Results

The system was initially deployed at the Huay Nam Kaew village, Krabi, during the beginning of June 2012. Many villagers gathered at the village center to listen to a briefing of installation procedures, as shown in Figure 5. Cooperation with the villagers was intentionally planned to give them sense of possession, so that they will look after the installed equipment and willingly be part of the system maintenance in the long run. For example, wireless sensor nodes' batteries have been continually monitored and replaced by one of the villagers, using the status monitoring system described in Section 2.4. In the initial deployment, the total of 11 nodes were deployed, with one node equipped with a rain gauge, and another node attached to a debris flow detector. In addition to 18Ah-batteries, both nodes were powered by solar panels. Distances between pairs of adjacent nodes depend on the terrain condition. Nodes communicating across a clear area were installed with the distance around 150-200m, while those communicating across a forest area were installed with the distance around 70-100m.

(a) (b)

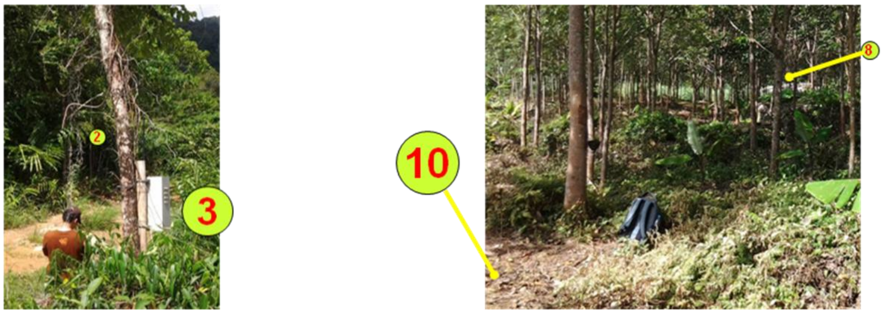
Figure 5 Preparation for deployment: (a) local villagers listening to the plan, and (b) nodes ready to be installed

3.1. *Rainfall Data Collection*

Rainfall amounts are collected from two locations in real-time, on the mountain near the debris flow detector site and the village head. Hourly and daily rainfall reports are generated. In addition, accumulated rainfalls in the last one- and three-day periods are also calculated. These two values also serve as landslide risk assessment, which will activate the warning system when the accumulated amount is greater than 150mm and 300mm within one day and three days, respectively [5]. However, after the initial deployment it was found that a moderate fraction of data collected from the wireless sensor nodes was missing due to packet dropped in communication. During the first week of July 2012, the average data loss rate was around 70%. It was also found that data losses became more severe during rain. For example, 46% of data was lost on July 3, 2012, which was a relatively dry day. On the contrary, 88% of data was lost during heavy rain on July 4, 2012.

3.2. *Impact of Weather Conditions*

Although there have been reports that rain has little impact on short-range, line-of-sight 2.4GHz communication [3], our installation was different in many aspects. As mentioned earlier, some nodes had to be placed inside a dense forest area, while other nodes could be installed on relatively clearer areas; most could not establish line-of-sight communication at all. Due to significant data losses after the initial deployment, we were investigating impacts of weather conditions to wireless signals at two different locations. Figure 6 (a) is a bushy forest area where nodes with IDs 2 and 3 are wirelessly connected over a distance of 70m. Figure 6 (b) is a relatively clear area where nodes with IDs 8 and 10 are located approximately 200m apart.

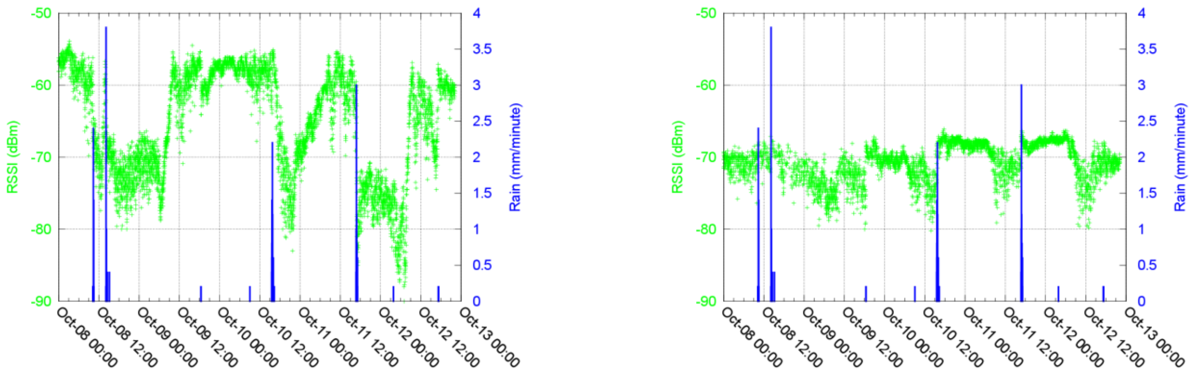


(a) (b)

Figure 6 Terrain characteristics where (a) nodes 2 and 3 are located (bushy area), with approximate distance of 70 m, and (b) nodes 10 and 8 are located (clear area), with approximate distance of 200 m

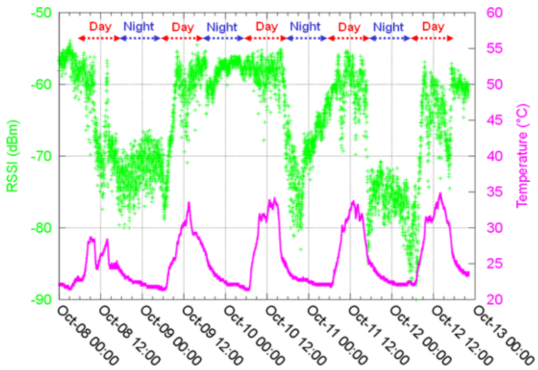
Figure 7 (a) and (b) show signal strengths between pairs of adjacent nodes in both locations, recorded during October 8 – 13, 2012. For the bushy area, signal strengths could drop by as much as 20dB under heavy rain. Moreover, the signal degradation was prolonged even after the rain had stopped for almost a day. This is very likely due to the fact that it was a considerable amount of moisture trapped by the dense trees that disrupted 2.4GHz signals, not rain itself, as these patterns are not observed in the clear area. In fact, effects from rain seem to be the opposite in the clear area, as the signal strength slightly increased after heavy rain on October 10 and October 11. Further investigation was conducted to explain this behavior. Figure 8 (a) and (b) depict signal strengths along with temperatures recorded inside a node directly exposed to sunlight. Obviously in the clear area (the graph on the right), higher temperatures cause drops in signal strengths by up to 10dB, which confirms the results by Boano *et al* [4]. The increase in signal strengths after rain discussed earlier is hence from the corresponding drop of temperature. However, this pattern is not observed from the bushy area (the graph on the left) as effects from trapped moisture due to rain are dominating.

From this observation, it is important to take into account these effects from rain and temperature when deploying 2.4 GHz RF technologies for outdoor telemetry tasks to reduce data losses. If installation of nodes through a forest area is inevitable and line-of-sight communication cannot be achieved, the nodes need to be located close enough to allow at least 20dB drop in signal strength. In addition, nodes installed with direct exposure to sunlight should be provided at least a 10dB margin. In the middle of October, two additional nodes were installed as relay nodes for those nodes whose links are subject to communication disruption. As a result, data loss rate was reduced to 20%-30% even during rainy days.

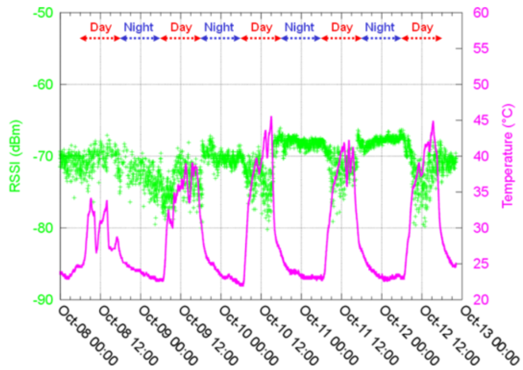


(a) (b)

Figure 7 Records of signal strengths and rainfall data: (a) bushy area, and (b) clear area



(a)



(b)

Figure 8 Records of signal strengths and temperature data: (a) bushy area, and (b) clear area

4. Conclusion and Future Work

Real-time assessment of landslide hazard is challenging as observation data need to be collected from certain places as close to landslide sources as possible, which often are out of range of typical communication infrastructures such as cellular services. We developed a low-cost wireless communication system by combining a low-power wireless sensor network and long-range WiFi technologies for landslide hazard assessment. The pilot system was deployed in a village located in District of Khao-Panom, Krabi Province, Southern Thailand. Preliminary data show that rain can severely disrupt wireless communication operating at 2.4 GHz in areas with dense trees. These results allow us to plan our deployment of similar systems in the future.

Our future plans include implementing low-power communication for the wireless sensor nodes to allow a longer battery replacement cycle. We will also investigate a 433 MHz RF technology which is reported to be more tolerant to moisture and water, compared to 2.4 GHz technologies.

Acknowledgments

This study was partially supported by the Science and Technology Research Partnership for Sustainable Development, JST-JICA, Japan.

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