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Design of Low Cost Wireless Sensor Networks-Based Environmental Monitoring System for Developing Country

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***Abstract*-One of the principal problems faced by countries in tropical region is the high risk of natural related disaster due to the high precipitation level, which can cause floods and provoke landslide. The damaging impact on human beings and public facilities is often worsened in developing countries by the lack appropriate infrastructure for flood control and landslide protection, unchecked deforestation, and high dense of population in urban areas. In this paper we describe the design of environmental monitoring system by using wireless sensor networks (WSN) as platform, as well as the implementation of a prototype system, which could be beneficial to a developing country like Indonesia.**

***Index Terms* - wireless sensor network, environmental monitoring, water level monitoring, floods detection, developing country**

I. INTRODUCTION

A large portion of population of countries in tropical region face potential risk to various hazards related to high rain rate characteristics of the equatorial zone. Two of the common hazards are floods and landslides, which almost occur on regular basis in certain developing countries, like Indonesia. Although the governments of these countries are aware of this constant risk to the population, the construction of adequate infrastructure to protect populated areas from floods and landslides are too costly and the available funds are spent for more immediate needs. Moreover other factors often come into play to worsen the situation, for example unchecked and rampant deforestation in the mountainous regions, riverbed shallowing, and high dense of population in urban areas.

A case of example is East Java Province of Java Island, shown in Figure 1. Inhabited by more than 37 millions people, the province with an area of 47.922 km2 boasts a population density of 787 per square km. As can be seen in Figure 1, which illustrates natural hazard risk map related to floods and landslides, a significant portion of populated areas in the lowland areas are exposed to risk of floods while in certain mountainous regions the danger is due to landslides [1]. Both of these hazards are caused mainly by heavy rains. A recent study to measure the annual statistics of rain rate in Surabaya area, the capital of the East Java Province, shows that 125 mm/hr is exceeded for 1% of time, while similar measurement conducted in 1999 reached only 120 mm/hr for the same percentage of time [2]. The latest major flood occurred during the period between the end of 2007 and the early of 2008 when Bengawan Solo, the longest river in Java Island, which inundated tens of towns and hundreds of villages in rural areas for more than two weeks, and as a result thousands of rice fields were damaged.

While the construction of required infrastructure to protect human beings from hazards on country scale could not be expected in the near future, there are other means more feasible and within the reach of the governments of developing countries, which allow to minimize risk to the population. In recent years, rapid progress in electronic miniaturization and wireless communication technology have open the way for the naissance of a new generation of sensor networks. Its most important characteristics are its small size, integrated sensing and computation capabilities, as well as low-power communication by using wireless link, hence the name wireless sensor networks (WSN).

The distributed WSN are capable of sensing the physical world, processing the data, and transporting the measured data to the base station for further analysis or even to be used in making decisions and performing appropriate actions [3]. The deployment of WSN on wide range of applications have been reported or envisaged, for example: transportation, logistics, environmental and habitat monitoring, security and surveillance, industrial automation, military, precision agriculture and healthcare.

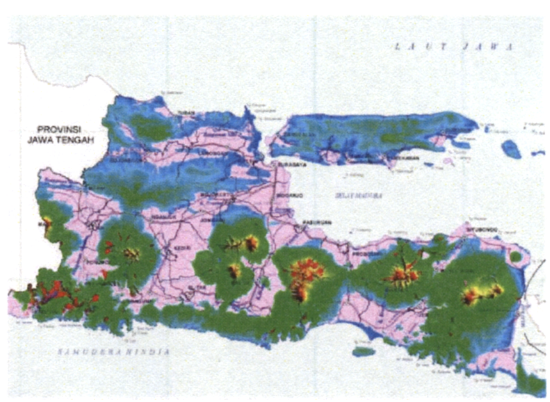

Figure 1. Natural related hazard risk map of East Java Province [1]. Pink areas shows regions with flood risk and red ones are due to landslides. The whole figure covers an area of 405 km by 236 km.

For environmental and habitat monitoring in particular, the monitoring of volcanic activities by using WSN has been reported in [4], while in [5] the authors described the deployment of WSN in uninhabited island to monitor the ecological parameters as a support for biologists. Other potential applications that could be beneficial for developing countries have been discussed and proposed in [6], and no system implementation has been reported. Recently, during the paper revision we are aware of a work similar to ours, where early warning flood detection system has been installed along a river in Honduras [7].

This paper describes the design, prototype development and field test trial of a WSN based environmental monitoring system with water level monitoring for floods detection as a focus. This paper makes the following contribution. We designed and developed low-cost environmental monitoring system which could be integrated to early warning system for floods and tsunami suitable to developing countries with high risk of these hazards like in Indonesia. While water level monitoring system for hydrological purpose and early warning systems for floods are common and already in place in various part of the country, their high cost and usually bulky size of the equipments hamper its deployment in large number over vast area as required. Moreover, most of the existing equipments rely on wired network to relay observation data from measuring stations to the base station, or when wireless communications is employed it uses satellite link.

The rest of the paper is organized as follows. In section II we describe floods and landslides basic characteristics encountered in East Java Province. Section III presents the system design principles and followed by Section IV where we discuss system integration. Section V describes field trial conducted in our campus. Finally, in Section VI we give conclusion and further works in the future.

II. FLOODS AND LANDSLIDES

The occurrence of floods caused by rainfall in Indonesia can be classified in general into two categories, the first is when high rainfall rate is sustained for sufficient period in a given small region and when the drainage system could not cope with rapid increased of water volume, the floods will occur in that region, and the second is when the prolonged rainfall takes place in a large area surrounding the upstream of a big river which will feed the stream. The first is usually short lived event and covers a relatively small area, while the latter could last for days, even weeks, and affects much larger area and population. Accordingly, a water level monitoring system is needed to be deployed in the various locations along the upstream part of big rivers to address the second type of flood and it should be capable to detect reliably the events leading to floods. Since the upstream part of a river is invariably located in mountainous and rural areas, the communication and electricity infrastructure are not available in most cases to support a conventional environmental monitoring system.

Landslides occur due to the weakening process soil's structure, which could take place either relatively abrupt when the rainfall rate is unusually high or slowly in a long period affecting hilly terrains or areas with steep slopes. The resulting landslide is very dangerous for the population living along the track of the landslide because other materials are combined with flowing mud and sometimes take a large toll on human lives. In some cases floods and landslide can occur simultaneously and the impact is much more damaging. The increased risk of hazards, such as floods and landslides, during rainy season, motivates us to develop environmental monitoring system for various precipitation related phenomena.

III. SYSTEM DESIGN

In designing the WSN based environmental monitoring system for floods detection, we must not only take into consideration the physical processes involved and its sensing requirements or the system architecture suitable with specific geographic condition of the region to be covered, but we must also consider that the equipments required to build the system should be easily acquired with relatively low cost without sacrificing too much the performance of the whole system. Although WSN devices are widely available in the developed countries, it is not the case in most developing countries, and the cost of importation limits the number of devices that could be procured. This suggests the combination of the WSN devices with custom built equipments by using off the shelf components.

A. System architecture

Figure 2 illustrates the typical system architecture of the WSN based monitoring system we use in our work. On the left part we can see the deployment of the sensor nodes in an area where physical phenomenon/phenomena are desired to be measured. By using single hop or multi hops, the data measured by individual sensors are collected and aggregated by an aggregator node, which subsequently transports the observation data to the base station or fusion center by using backbone links. In typical application, the sensor nodes are located in remote area far from the base station, where the data will be stored and be used for further analysis.

B. Ultrasonic-based water level measurement

In flood detection system, the most important sensor is the one which measures water level. In choosing the sensor for our water level monitoring purpose, we are guided by the following requirements: low cost, reliable, and easy to deploy.

Ultrasonic sensor that we design fits to the above requirements because the components are easily acquired with low cost, so that it can be made in large quantity for large scale deployment or for replacement. The sensor can measure distance from 2 cm up to 3 m with and programmable sampling rate with the maximum value of 40 Hz. The observed data is read by through serial connection by using standard RS232 interface.

C. Motes

The network that we develop is based in part on Mica2 and Micaz mote platform, with the characteristics detailed in Table 1. They can be easily configured as sensor nodes by connecting with sensor devices or as a relay node in multihop connection of mobile ad-hoc network.

TABLE I
MOTES MAIN CHARACTERISTICS [8]

	MICA 2	MICAz
Radio access	868/916 MHz	2.4 GHz IEEE 802.15.4
Data rate	38.4 kbaud	250 kbps
Processor	Atmel ATmega128L	Atmel ATmega128L

There are various sensors that can be attached to the motes, for example: temperature, humidity, luminance, etc.

D. Wireless link

To account for various geographic conditions that will dictate the network topology of a given application, we consider several alternatives for wireless link, as illustrated in Figure 3, in order to give more freedom and flexibility in the design process. For the short range link, one can use either 802.15.4 based radio link or 802.11 based radio link, while for long range one it is more suitable to employ 802.11 based outdoor transceivers combined with high gain directional antennas. Another option is to make use of GPRS connection of a cellular network, on the condition that the sensor deployment area is covered by cellular network.

IV. SYSTEM INTEGRATION

Once the basic components of the network have been decided and procured, we integrated them into operational system. The first set of network elements are sensor nodes, which consist of ultrasonic sensor for water level, luminance sensors, and temperature sensors. The second set is an aggregator node, with the assemblage as shown in Figure 4 and the corresponding circuitry diagram in Figure 5. The aggregator node consists of an MIB 600 Gateway node which collects sensed data from motes, an RS232 to Ethernet converter which is connected to ultrasonic sensor, an 802.11 access point and power supply. The third set is the base station which consists of a PC server equipped with various communication link and network interfaces, namely: 802.11 access points for short range and long range connections, GPRS modem and Internet connection through campus LAN. The additional advantage of using IP-based network is that addressing of each sensor node poses no problem, because each node is allocated with a unique IP address.

Before and after assemblage each component is calibrated individually. The design of aggregator node requires that it should be easily transportable, well protected in not too harsh field condition and independent power source. We design a customized power supply from a battery and a regulator.

V. FIELD TRIAL

Figure 6 depicts the deployment of the equipment during the field trial within our campus. We set up the sensors and the aggregator node on the bank of canal surrounding the campus. Aside from water level measurement, we also observed the ambient luminance and temperature. To add functionality to the remote measuring equipment we also installed wireless IP camera, which serves for two purposes: as a visual monitoring system and as a traffic generator to test the capacity of 802.11 link as a backbone connecting the aggregator node to the base station in our laboratory, located about 70 m from the measurement field. For much larger distance of backbone link, we will employ also 802.11 link but equipped with high gain directional antennas and transceivers for outdoor or alternatively a GPRS connection of cellular network.

To test completely the system it is necessary to deploy the system in real setting in the field for an extended period of time. However, the installation in the field, e.g. riverbank, requires coordination with communities on site as well as the government offices in charge of disaster management, which we plan for our future activities. The work reported in [7] took place in the span of three years. Moreover we developed and tested the system during the dry season of the country, where rain is scarce and virtually no risk to floods or landslide is encountered.

VI. CONCLUSION AND PERSPECTIVES

We have presented the design and implementation of WSN-based environmental monitoring system with specific purpose for floods detection. Although our current works is focused on floods detection, the monitoring system is easily adapted for other specific applications, such as landslide detection and habitat monitoring. In the future we will conduct long term measurement in rural areas. Moreover a web-based monitoring system will be also developed such that the information can be accessed by general public and scientific community through Internet.

ACKNOWLEDGMENT

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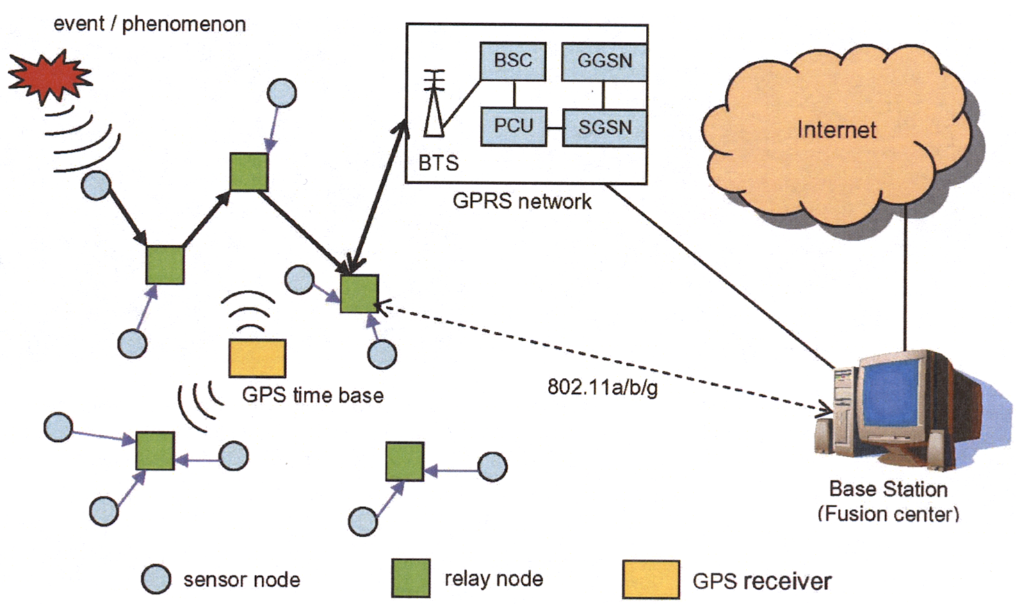

Figure 2. System architecture of WSN

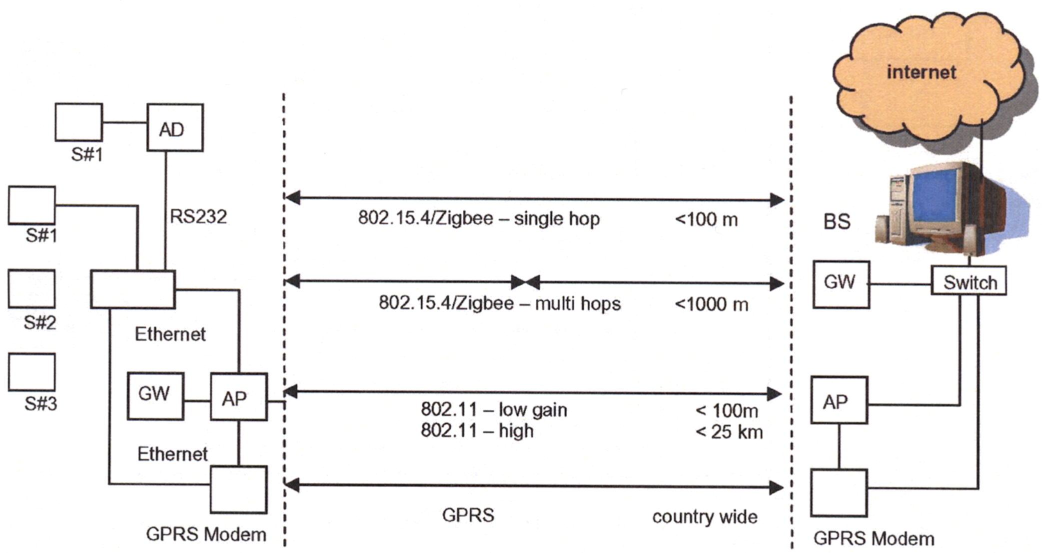

Figure 3. Alternative wireless links and coverage

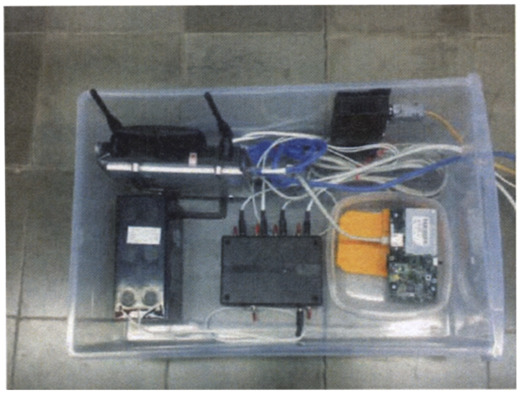

Figure 4. Aggregator node assembled in a box for field measurement trial

Figure 6. WSN deployment during the field measurement trial. The black box attached to the pole is ultrasonic sensor for water level monitoring

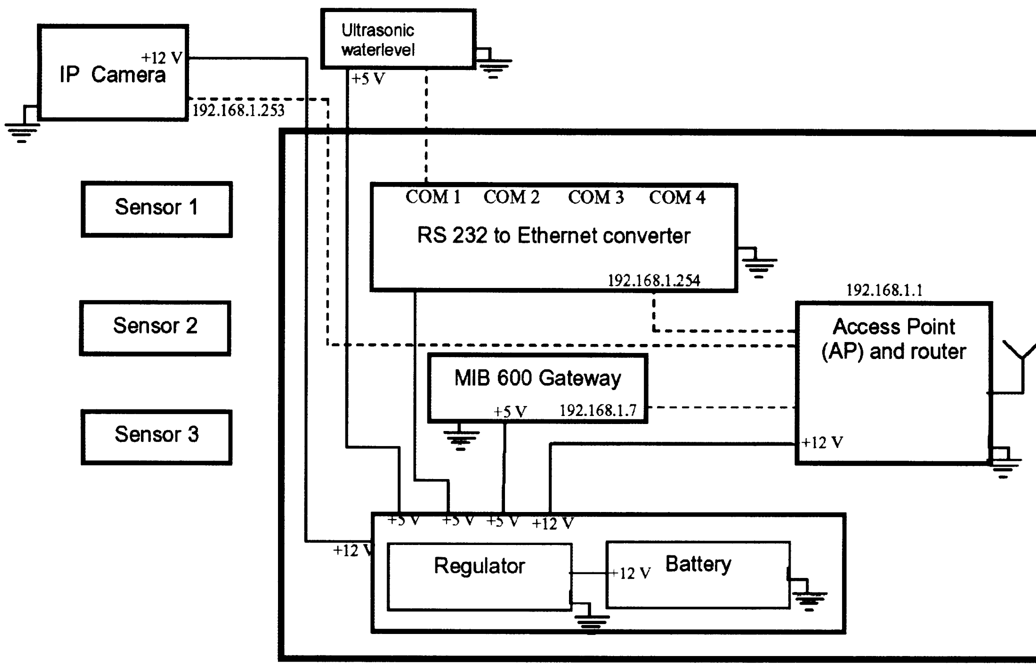

Figure 5. Circuit diagram of aggregator node