2014

Design and Development of an Integrated Web-based System for Tropical Rainfall Monitoring

Edgar Marko Trono

Ma. Leonora Guico

Rollyn T. Labuguen

Andrei Navarro

Nathaniel Joseph C. Libatique

See next page for additional authors

Authors

Edgar Marko Trono, Ma. Leonora Guico, Rollyn T. Labuguen, Andrei Navarro, Nathaniel Joseph C. Libatique, and Gregory L. Tangonan

Available online at www.sciencedirect.com

ScienceDirect

Procedia Environmental Sciences 20 (2014) 305 – 314

Procedia Environmental Sciences

The 4th International Conference on Sustainable Future for Human Security, SustaiN 2013

Design and Development of an Integrated Web-based System for Tropical Rainfall Monitoring

Edgar Marko Trono[a]*, Maria Leonora Guico[a], Rollyn Labuguen[a], Andrei Navarro[b], Nathaniel Joseph Libatique[a,c], Gregory Tangonan[c]

[a]*Department of Electronics, Computer and Communications Engineering, Ateneo de Manila University, Quezon City, Philippines*
[b]*Department of Information and Computer Sciences, Ateneo de Manila University, Quezon City, Philippines*
[c]*Ateneo Innovation Center, Ateneo de Manila University, Quezon City, Philippines*

Abstract

This study is about the design and development of an integrated web-based system for tropical rainfall monitoring. The system gathers data using a network of low-cost, Android-based acoustic rainfall sensors, a nationwide infrastructure of 5 GHz wireless broadband links, and remote weather stations. The low-cost Android-based acoustic rainfall sensors are deployed at high densities over a local area and the 5 GHz wireless broadband sensors gather rainfall information on a nationwide scale. The sensor network provides information about spatial-variations that are characteristics of tropical rain rates, and complement data from the scarcely deployed remote weather stations. Gathered data is then processed and displayed on a web interface.

Keywords: Rainfall monitoring; web technologies; acoustic sensors; wireless broadband links; wireless sensors

1. Introduction

Tropical rainfall is characterized by variations in intensities over sub-kilometer distances. Rainfall intensity variation is an important parameter in engineering high-frequency, high-bandwidth wireless spatial diversity schemes. Monitoring spatial variations in rain rate is also critical in disaster management and alarm systems. For instance, landslides may be triggered if high-intensity rain falls over an already saturated slope [1,2,3].

Previous studies have used wireless communications networks for rainfall monitoring in temperate climates [5,6]. The current study is about an integrated system for real-time tropical rainfall monitoring. The system imports data from a sensor network that uses a high-density deployment of low-cost, Android-based acoustic sensors, a nationwide infrastructure of 5 GHz wireless broadband links, and Davis Vantage Vue™ remote weather stations.

* Corresponding author. Tel.: +8190-9118-3476.
E-mail address: markotrono@alumni.ateneo.edu

doi:10.1016/j.proenv.2014.03.038

The data then are transmitted to a server and displayed on a web interface. The high-density deployment of low-cost sensors and the nation-wide wireless broadband network are able to show the spatial-variations that are characteristics of tropical rain rates, and complement the measurements provided by the remote weather stations.

Gathering rainfall data at sub-kilometer scales require radar equipment and ground-based rainfall sensors, such as tipping buckets, to be deployed at high densities. However, developing tropical countries, such as the Philippines, have limited access to such equipment and need a cost-effective system to complement the scarcely deployed ground-based equipment.

Previous studies have used low-cost, Android-based acoustic point sensors for tropical rainfall monitoring. Acoustic-sensors collect rainfall data by recording the acoustic signal levels generated by raindrops. Higher rain rate values relate to higher acoustic signal levels. A high-density deployment of acoustic rainfall sensors shows the spatial variance of tropical rain intensity over sub-kilometer areas [1,3,4].

Rainfall also causes attenuation in the received signal levels (RSLs) that are directly related to rain rate. Various wireless broadband link frequencies have been used in previous studies to gather rainfall information [2-7]. In this study, RSL data from a nationwide infrastructure of 5 GHz wireless broadband links between 730 subscribers and their base stations are collected at 1-minute intervals. The gathered data provide information about the rain events that occur along the link paths.

In the current study, a system that integrates the high-density deployment of low-cost acoustic sensors and the nation-wide network of 5 GHz wireless broadband links is used to gather tropical rainfall information. The system sends the data to a server and displays data on a web-interface.

With such system, areas that lack access to rain event information (e.g. rural areas without the resources to deploy expensive and complex weather stations), can obtain the data they need to respond to rain events. The system provides data that notify users if rain events are exceeding safety thresholds (i.e. rain rates are reaching torrential levels). Given such information, users and disaster managers can react to the situation accordingly, and generate the appropriate disaster management plan. The rain data gathered from the sensor network can be used to trigger an alarm system. The whole system offers great potential to save lives and prevent property damage and loss.

2. Android-based Acoustic Rainfall Sensors

Low-cost, Android-based acoustic-sensors collect rainfall data by recording the acoustic signal levels generated by raindrops. Previous studies show how that higher rain rate values relate to higher acoustic signal levels detected by acoustic rainfall sensors [1,3,4,7]. Figure 1 shows the acoustic data that are compared with rain rate data gathered the Casella CEL Tipping Bucket Rain Gauge™. Figure 1 shows the acoustic signal power and the derived rain rates from the November 10, 2010 rain event. The rain rates were calculated from accumulated rain measurements of a tipping bucket. Time intervals of 1, 3, 6, and 12 minutes were used to derive the rain rate. As the rain rates increases to 36 mm/hr, the acoustic signal power also increases to approximately -5 dB. When the rain rate is low (i.e. 0 mm/hr), the acoustic signal power is also low (approximately -30 dB).

In the current study, a field-deployable Android-based acoustic rainfall sensor was developed. The sensor was designed for always-on remote data gathering and transfer. Software was developed that allows the Android-based acoustic sensor to gather the acoustic signal levels generated by rain events, store data files, and transmit files to a remote server. A 50-watt solar panel was connected to a solar charge controller. The controller charges a 12-volt battery. The 12-volt battery is connected to a DC converter, which produces an output of 5 V and charges the Android-based acoustic rainfall sensor. An HTC Wildfire Android 2.2 mobile device was used for acoustic data gathering. The sensor continuously gathers and writes rainfall data on *.csv files. The sensor then sends the *.csv files through a Wi-Fi or 3G network to a remote server. Figure 2 shows the Android-based acoustic sensor diagram.

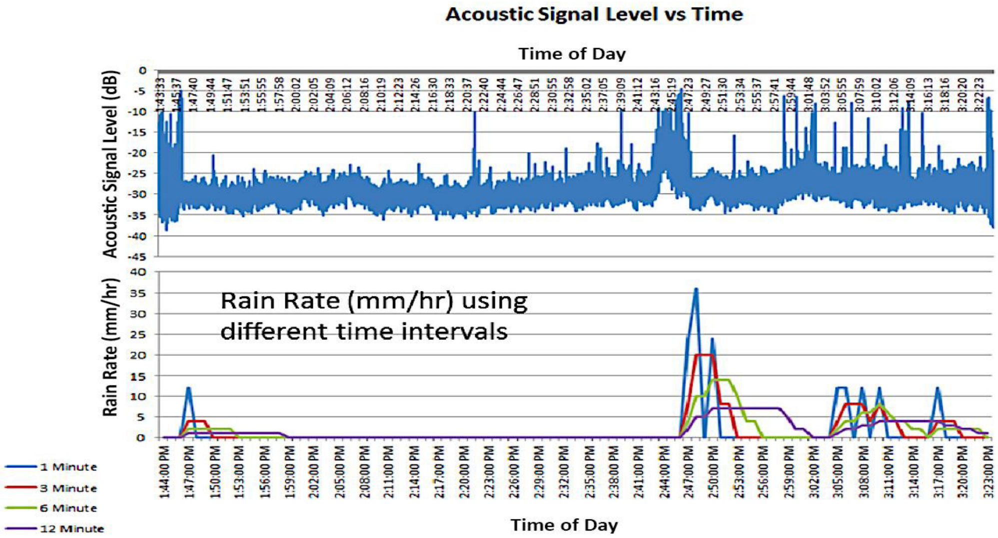

Fig. 1 A comparison of the acoustic signal power and rain rate values from the November 10, 2010 rain event. (top) Acoustic Signal Level; (bottom) Rain rates for time intervals = 1, 3, 6, and 12.

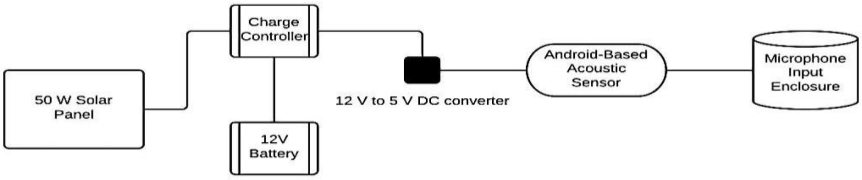

Fig. 2 Android-based acoustic sensor diagram.

During rain events, the Android-based acoustic sensors are deployed within a sub-kilometre^2 area inside the Ateneo de Manila University campus as shown in Fig. 3. Each sensor gathers the acoustic signal levels generated by the raindrops falling on its microphone input enclosure. Data gathered by the sensors are stored in a remote database for analysis and visualization using a web-based interface.

Fig. 3 Deployment locations of the Android-based acoustic sensors within a sub-kilometre^2 area within the Ateneo de Manila University campus.

Figure 4 shows acoustic signal level data gathered by the deployment during the October 21, 2011 rain event from four points inside the Ateneo de Manila University campus. Tipping bucket data show the direct relationship between the accumulated rain and acoustic signal levels.

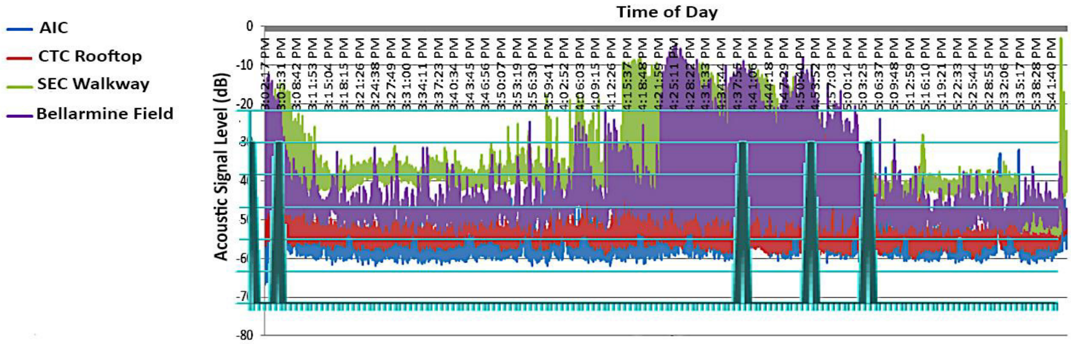

Fig. 4 Rainfall data gathered during the October 21, 2011 rain event in four locations in the Ateneo de Manila University campus. The teal curve shows the accumulated rain from a tipping bucket rain gauge.

The Android-based acoustic rainfall sensors are mobile and easily deployable. For the current study, the sensors were deployed in a citywide scale. During the August 6, 2012 monsoon, four Android-based acoustic sensors were deployed in different locations within Metro Manila. Figure 5 shows the deployment locations in Antipolo, Manila, Cubao, and Project 8.

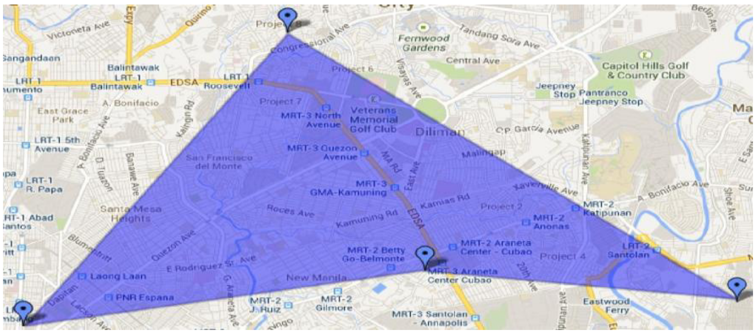

Fig. 5 Deployment locations of the Android-based acoustic sensors during the August 6, 2012 monsoon from top to bottom left: Project 8, Antipolo, Cubao, and Manila.

Figure 6 shows the acoustic signal levels gathered from the acoustic sensors deployed in Manila and Antipolo. The higher acoustic signal levels (that reached values of approximately -3 dB after 11:08 PM) from the Antipolo sensor indicates that the rain rates in Antipolo were greater in magnitude than the rain rates in Manila (readings reached only approximately -18 dB after 11:08 PM).

During the August 2012 Southwest Monsoon event, flooding occurred all over Metro Manila because of heavy rains. Antipolo has a higher elevation than Manila (156 m and 16 m respectively). In a disaster situation, knowing that the Antipolo highlands are experiencing higher rain rates than the Manila lowlands can serve as a warning for impending flooding.

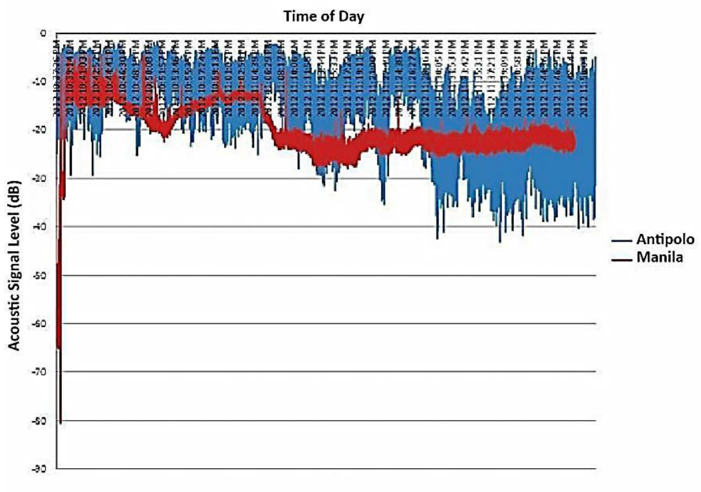

Fig. 6 Rainfall acoustic signal level (dB) gathered by the Android-based acoustic sensors deployed in Antipolo (blue) and Manila (red) during the August 6, 2012 Southwest Monsoon event. The difference in acoustic signal levels shows the spatial variance in rain rates that is characteristic of tropical rain.

The Android-based acoustic sensor is low-cost, mobile, and easily deployable. A high-density deployment of the sensors can provide more accurate information about the spatial distribution of tropical rainfall. Sensors placed at waterlogged mountainside slopes near rural settlements can detect if rain rates in the area are exceeding safe levels and aid in disaster management.

Tipping bucket rain gauges, while widely recognized as the standard for accumulated rain measurement, are prone to inaccuracy during heavy rain events. The gauges rely on moving parts that are easily affected by environmental factors such as strong winds. The gauges tend to over-estimate rain rates because external vibrations can tip the water bucket. Tipping buckets do not provide real-time rain data because they are accumulation sensors. The Android-based acoustic sensor design addresses these issues because the acoustic sensors do not rely on moving parts and can gather information in near-real time. Therefore, a high-density deployment of acoustic sensors can complement existing rain gauge deployments.

3. 5 GHz Wireless Broadband Links

Previous studies have shown the relationship between rain rate and the attenuation of wireless communication links. Rainfall causes drops in the received signal levels that are directly related to rain rate. 26 GHz WiPAS, 2.4 GHz Wi-Fi, GSM, 3G, and 5 GHz wireless broadband links have been used to gather rainfall information [2,3,5-7].

For the current study, a nationwide infrastructure of 5 GHz wireless broadband links was integrated in the rainfall monitoring system as a high-density sensor network. This marked the first time that this nationwide wireless broadband link infrastructure was used to gather rainfall data.

Through a partnership with a major telecommunications service provider in the Philippines, the RSLs from an existing nationwide infrastructure of 5 GHz wireless broadband links between subscribers and access points were collected in real-time. There are estimated 25,000 access points in the Philippines with 7 to 12 subscribers each. This infrastructure gives approximately 250,000 points from which rainfall data can be remotely gathered in near real-time. Future deployments can use this high-density sensor network for rainfall data gathering.

The RSLs (measured in dBm) of 730 wireless broadband subscribers from across Luzon and Visayas are collected at one-minute intervals, written on a time-stamped text file, and sent to a File Transfer Protocol (FTP) server in the Ateneo de Manila University Campus. Table 1 lists the numbers of wireless broadband subscriber and access point links per Philippine region.

Table 1. Nationwide distribution of 5 GHz wireless broadband links

Philippine Region	Number of Monitored Links
Region 1	81
Region 2	31
Region 3	164
Region 4	178
Region 5	28
National Capital Region	153
Cordillera Administrative Region	31
Visayas	64

The large-scale sensor network of 5 GHz wireless broadband links complements existing satellite and radar technologies. The existing weather instruments can provide rainfall data in the scale of hundreds of kilometers and the 5 GHz wireless broadband sensors can provide data at high spatial resolutions.

In the current study, the RSLs between each wireless broadband subscriber and their corresponding base station are polled at one-minute intervals and are written in a text file. This text file is then sent to the cloud and is transferred using FTP to a server in the Ateneo de Manila University Campus. The received text files are then collected for analysis and visualization.

The first step in the analysis is the calculation of the baseline RSL of each link. The baselines are calculated during periods without rain. The baselines will be constantly recalculated until RSL changes occur or when the other sensors (e.g. Android-based acoustic sensors and remote weather stations) indicate that a rain event has started. During a rain event, the value of the baseline will then be subtracted to the RSL measurements to determine the attenuation due to rain.

The simplest method to determine the RSL baseline is to get the most frequent value recorded during days without rain. Another method is to calculate a moving average of values using a fixed timing window size (e.g. every 10 minutes).

Attenuation values (in dB) are then derived from the determined baseline for each link and the RSL values during rain events. Figure 7 shows a histogram of the RSL values of a single link during a day without rain. The RSL values that had the highest frequencies range from -46 dBm to -48 dBm. This range was then used as the RSL baseline for the link.

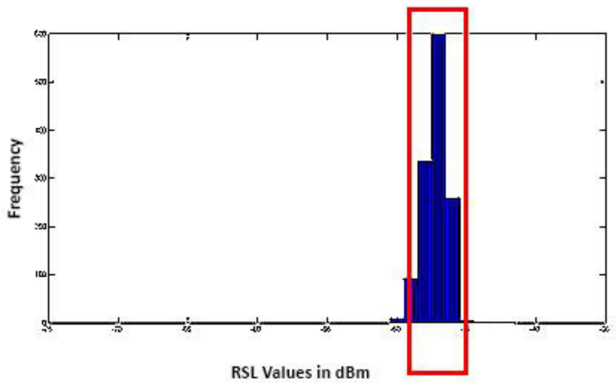

Fig. 7 Histogram of the RSL data set of a link during a day without rain. The value range from -46 dBm to -48 dBm was used as the baseline.

Figure 8 shows the time domain plot of the RSL data set on the day when August 2012 monsoon incident began. The baseline is boxed in red and the values observed below the baseline are attenuated due to rain.

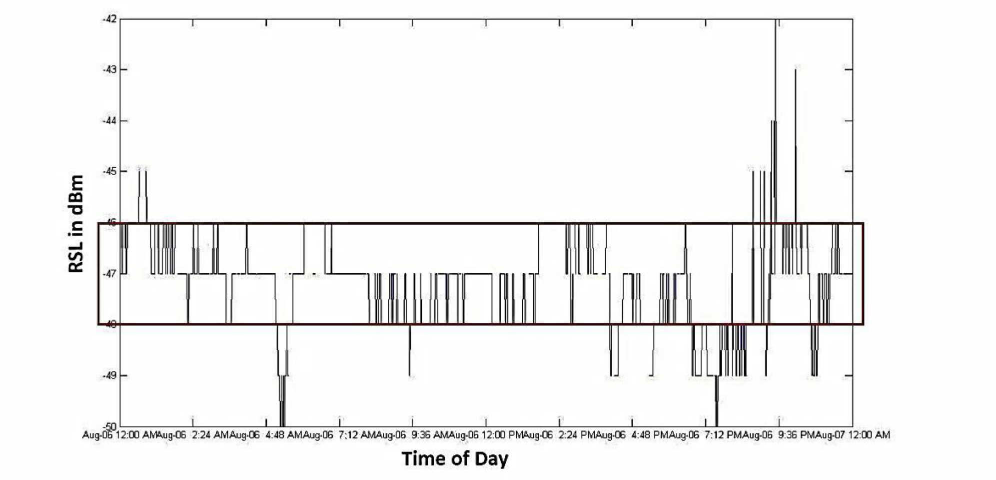

Fig. 8 Time domain plot of RSL data set from the first day of the Southwest Monsoon event (August 6, 2012). The vertical axis indicates the RSL in dBm and the horizontal axis indicates the time. The red area indicates the baseline range.

The RSL data sets are used to differentiate between rain and non-rain events. Early observations indicate that rain events are marked by noticeable attenuation. Data analysis requires software that obtains data on demand, calculates the baseline using a moving window, and determines the attenuation from the current baseline among others. Figure 9 shows the data analysis algorithm used in the current study.

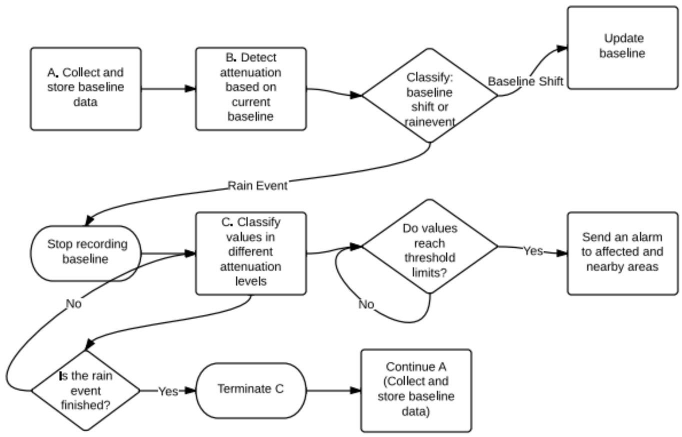

Fig. 9 Proposed data analysis algorithm for 5 GHz wireless broadband RSL data.

The algorithm was tested for links in the Barangay Loyola Heights area located in Quezon City. The algorithm was run for six wireless links and the results were recorded and compared to the tipping bucket data from Manila Observatory, which is closest to the chosen locality.

The first step was to identify a time period where there is no rain. The values in this time period will be used as baseline for the attenuation measurements. This step was repeated for each link in Barangay Loyola Heights. The values were extended by ± 1 dB that resulted in a 2 dB range with the baseline values located in the middle. The next step was to measure the attenuation for each 1-minute interval. The process was repeated for all the links in the area. The measured attenuations were classified into three levels: Level 1 for attenuations of 1 dB to 2 dB, Level 2 for attenuations of 3 dB to 4 dB and Level 3 for attenuations of 5 dB or greater. Each point that fell on a level would have a designated score. Every twenty minutes, the scores were summed up and divided by the number of senders multiplied by the window size, which was 20 minutes. If the score reached the first checkpoint, an indicator was set to moderate rain. If the score reached a second and higher checkpoint, the indicator was set to heavy rain. A twenty-minute window size was implemented because the links were in different locations and not expected to attenuate at the same time.

Two scoring systems were used. The first system counted and summed the number of signal values that reached a certain threshold. The sum was then divided the number of links. The second system first checked that the attenuated measurements were present in more than half of the subscribers and not just a small percentage. The first score might indicate a rain event, but, unless confirmed by the second score, an alarm should not be triggered.

For the alarm trigger, the distance between each sender and access point was estimated to be 500 m and 3 dB attenuation was estimated for a rain rate value of 20 mm / hr. Given these, a 5 dB attenuation indicated a significant increase in rain rate.

Figures 10 and 11 show that the algorithm performed well during the tests conducted on August 06, 2012. This was the first day of the Southwest monsoon event and was generally a good test day since there were periods with rain and without rain. All of the 20-minute intervals that triggered alarms were actually periods with rain. The alarm did not trigger on intervals with no rain.

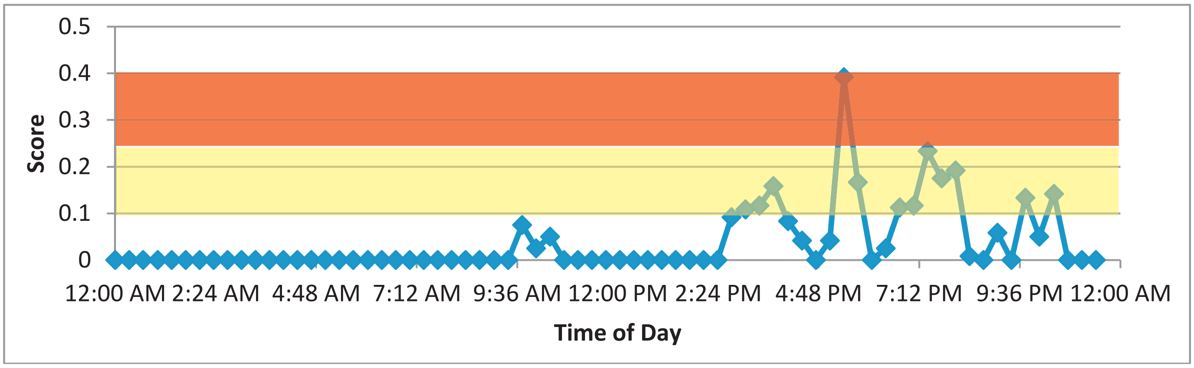

Fig. 10 Result of the application of the algorithm to a group of six wireless links located in Loyola Heights with respect to time on August 6, 2012. The red area represents heavy rain and the yellow area represents light rain.

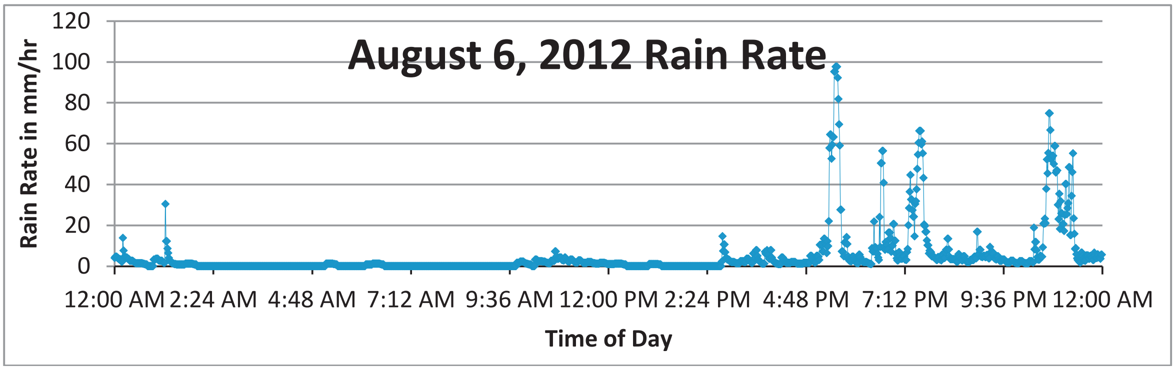

Fig. 11 Rain rate (in mm/hour) measured by Manila Observatory Weather Station located in Ateneo de Manila University on August 6, 2012

Figures 10 and 11 show that the algorithm based on attenuation of a group of wireless links coincided with the rainfall data from Manila Observatory. Figure 9 uses color indicators with yellow for moderate rain and red for heavy rain based on thresholds. Values between 0.08 and 0.25 were considered as moderate rain and values over 0.25 were considered as heavy rain.

4. Development of a Web-based Analysis and Visualization Software

To provide controlled access to the rainfall data gathered during the project, web-based software was developed for the current study. The system imported data from the different monitoring stations. Each station sent a data file (in CSV and other formats) that was compiled daily or hourly. The files were uploaded to a folder in the server. A process in the server scans the folder periodically. Data found on the uploaded files were imported using a file type-specific parser. Custom parsers would be built for new stations that send files with new formats. The imported data could then be viewed using the analytics interface.

A major telecommunications service provider sent wireless broadband data that included subscriber locations and RSL values from 730 wireless broadband subscribers around the Philippines. The locations were imported into the system and were geocoded using Yahoo! and Google services. The system kept a database of all known cell sites that have been imported to the system for historical purposes. Using the data, the system could create an approximated map of the cellular network.

The web interface had three components: the public-facing component, the member-only data-viewing component, and the administration component.

The public-facing component was accessible by the general public. It had a map view (provided by Google) that displayed a hit map of weather readings. This hit map was based on weather station data, 5 GHz wireless broadband RSL data, and API (external source)-provided data. The public-facing site also linked to pages that described the research.

The data-viewing component provided a view of the collected data from all the weather stations. The data were displayed in graphics. The data could also be aggregated. Because of the data in the system were sensitive, access was restricted to users who had the proper access rights to the system.

Because of the high number of data points available (e.g. minute-to-minute data), the system used an implementation of the Map Reduce programming model. This allowed the near real-time plotting of data points, data point aggregation from different sources, high scalability, and potential operations across multiple servers.

The administration interface provided a general management tool for the entire website. It provided a facility for providing authorization to different users. It also enabled management of the content on the website, including the public-facing pages and the auditing of imported data onto the system.

5. Conclusion and Recommendation

In the current study, an integrated system for real-time tropical rainfall monitoring was designed and developed. The system gathered data using novel Android-based acoustic point sensors, a nationwide scale 5 GHz wireless broadband network, and remote weather stations. The system was cost-effective and complements scarcely deployed ground-based weather stations and radar equipment. The acoustic point sensors and 5 GHz wireless broadband links provided data about the spatial variations in tropical rain rates, and can be used for disaster alarms and management in places where access to rain equipment and data are limited.

The current study addresses a sensor density problem. Tropical rainfall is characterized by high spatial variance. The spatial variations, which are present in sub-kilometer areas, cannot be accurately measured by radar and satellite-based instruments that provide information in the range of hundreds of kilometers. A high-density of ground sensors, such as tipping buckets, is needed to obtain accurate spatial variance information. The Android-based acoustic is low-cost, mobile, and can easily be deployed in remote areas. With a high-density deployment of the sensors, more accurate information about the spatial distribution of tropical rainfall can be gathered. Sensors placed at critical points, such as in mountainsides near rural settlements, can detect if rain rates in the area are exceeding threshold levels.

The high-density of 5 GHz wireless broadband sensors across the country (25,000 access points nationwide and 7 to 12 subscribers per access point) provides a rainfall sensor network that far outnumbers any deployment campaign of traditional weather stations. Moreover, the cost of deployment is minimal because the infrastructure of the wireless broadband sensor network is already in place. The current study also addresses a sensor design problem. Tipping bucket rain gauges, while widely recognized as a standard instrument for accumulated rain measurement, are prone to yield inaccurate measurements because of their design. The gauges rely on moving parts and legacy sensing technology that are susceptible to interference, especially during events with high rain rates and strong winds. The gauges tend to over-estimate rain rates because vibrations due to the force of raindrop impacts, strong wind, and flying debris can tip the water bucket. Also, tipping buckets do not provide real-time rain data because they are accumulation sensors. The integrates system addresses the aforementioned issues because the acoustic sensors and wireless broadband links do not rely on moving parts and gather information in near-real time.

Acknowledgement

This research was made possible by the Department of Science and Technology - Engineering for Research and Development for Technology Consortium, the Ateneo de Manila University Research Council, SMART Communications, and Manila Observatory.

References

1. Trono EM, et al. Rainfall Monitoring Using Acoustic Sensors, *TENCON 2012: The 2012 IEEE Region 10 Conference*, Philippines, 2012.
2. Ando M, et al. Localized Behaviors of Rain Measured in Tokyo-Tech Millimeter-Wave Wireless Network, *The 5th European Conference on Antennas and Propagation (EUCAP)*, Rome, Italy, 2011.
3. Libatique NJC, et al. Design of a Tropical Rain – Disaster Alarm System: A New Approach based on Wireless Sensor Networks and Acoustic Rain Rate Measurements, *International Instrumentation and Measurement Technology Conference*, Singapore, 2009.
4. Zamora J. et al. Rain-Induced Disaster Alarm System using Microwave and Acoustic Sensing, Paper 146, in GHTC 2011, *Proceedings for the IEEE Global Humanitarian Technology Conference 2011*, Seattle Washington, USA, Oct 30 - Nov 1, 2011.
5. Messer H, et al. Environmental Monitoring by Wireless Communications Networks, *Science Magazine,* 2006;vol. 312(5774), p. 713.
6. Overeem A, et al. Country-wide rainfall maps from cellular communication networks," PNAS, 2013;vol. 110(8), p. 2741–2745.
7. Tangonan GL, et al. Microwave Transmission in Tropical Rainstorms, *2010 Asia-Pacific Radio Science Conference*, Toyama, Japan, 22-26 September 2010.