Nationwide 5GHz-Fixed Wireless Network for Prototype Rain Alarm System

Observations during Southwest Monsoon (2012) and Typhoon Haiyan (2013)

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***Abstract*— We present the first results of a nationwide experiment that uses 5GHz fixed wireless network as a rain alarm system through monitoring the changes in received signal levels. This paper proposes an alternative framework and correlation approach for rain sensing, which rely mainly on the attenuation from broadband wireless systems. Unique to this system is an automatic reporting of received signal levels coming from a central location that gathers data of one-minute resolution from SmartBro subscribers. The SmartBro wireless system is one of the largest deployments in the world composed of 5 GHz links, which may help in reinforcing rain data collection due to their ubiquity of deployment in the Philippines, with nearly 20,000 land-based antennas. To demonstrate this capability, we selected eastern seaboard cities near the Pacific Ocean with fixed wireless subscribers virtually at random, and studied the changes from baseline attenuation during strong rain events. The reckoning method comprises of (1) baselining method to determine signal loss in normal weather condition, (2) sigma scheme technique that uses the variation of the signal in order to determine rain presence. Lastly, we also made a visualization tool for highly intense precipitation events. Time series videos of signal loss in the Philippines, with plotted location-specific signal loss data were developed for key meteorological events in the past two years: of which include the Southwest Monsoon season in 2012 and the devastation of Typhoon Haiyan in 2013.**

***Index Terms*—signal attenuation, wireless communication, rainfall monitoring, sensor networks**

I. Introduction

The presence of rain is a meteorological phenomenon that is of great importance in weather and climate, and its presence and severity has greatly affect human activity. The ability to detect rain, therefore, is important in many fields and applications such as weather forecasting, climate analysis, urban flood mapping, and also in agricultural crop monitoring. Likewise, having continuous, cheap, and widespread sources to gather weather data from are of the essence. Existing methods, such as satellite monitoring, lack the temporal resolution necessary for a lot of applications, as well as the spatial resolution for fine-scale rain mapping necessary for urban locations. Doppler radar systems are themselves expensive to create and provide upkeep for. Tipping buckets have great time resolutions, but are of limited spatial extent and are expensive to set up for a large enough area. As such, rain detection methods using cellular networks have been in development in recent years, making use of the attenuation of certain cellular network signals in the presence of rain [1].

Because of devastations caused by typhoons like Haiyan, an efficient real-time monitoring system is needed. This could be used in enacting swift actions and quick decisions when needed and could help in preventing other tragedies. Additionally, the rapid deployment of cellular networks globally, to which rain gauge deployment has been lagging behind and even in some parts decreasing in active networks, means that the likely sources of rain data from this method will only increase in time, with a good portion of the world covered by cellular networks.

It has been shown that the attenuation of a radio signal of frequencies in the tens of GHz range is dominated by rainfall, with the accepted model being $A=aR^b$, commonly described as Crane's Law [1], describing the effects of rainfall of said frequencies, with A being the attenuation, R the rain rate, a and b being constants related to link frequency and polarization [2]. To determine the signal loss due to rain, a baseline is taken. The baseline value is the estimated received power of the link solely due to atmospheric conditions and other constant factors, subtracted from the received signal level in current. The difference of the baseline and the signal level currently would correspond to the contribution of rain, with studies indicating the near-linear relationship between rain fall and the drop in signal from the baseline [3].

There have been quite a number of experiments that validate the relationship between actual measurements and effects of wireless signal attenuation with the presence of rain [4] [5], with some of them using digital fixed radio systems (DFRS) cellular backhaul links compared to radar data and tipping bucket measurements found that the performance of links of tens of GHz [6]. In a study done in Metro Manila, a tropical rain disaster alarm system design was explored using a 26.0 GHz, 5.0 GHz, and 2.4 GHz paired with tipping bucket measurements and acoustically sourced rain data, which showed the feasibility of using 5.0 GHz links, with a distance of 400m and rain rates of up to 15mm/hour, despite the band's relatively lower absorption by water molecules [7]. As far as the adaptation of commercial microwave links are concerned, certain studies by Overeem [8] made use of a cellular links in the tens of GHz to detect the amount of rainfall from a network of 2902 commercial microwave links. Though practical applications in this field have been few, the exact nature of its methods and operational settings are still unclear despite its being well understood on a theoretical level.

The behavior of rain attenuation at 5GHz microwave signal on a tropical setting leads us to expand and leverage on the large existing network links of Smartbro. Thus, we designed our experiment around the urban deployments of SmartBro in cities around the Philippines. Today, there are more than 20,000 subscribers and many of these subscribers are a kilometer or so from base stations. According to the Crane formula, we expected that even a small sampling of a few hundred users or terminals would reveal a few dB changes in received signals levels for rain events exceeding 10 mm/hr. We further expected to be able to investigate the temporal and spatial correlations of these deviations from baseline transmission loss in urban areas, as storms passed through the urban area, and to develop new alarm systems for urban flooding.

II. Methodology

In this paper, we have developed a system that is able to detect the presence of rain with pertinent time and space data, using a series of exploratory data analysis on the received signal levels from commercial grade cellular network of 5 GHz links deployed all over the country as seen in Fig. 1.

This experiment utilized built-in network performance monitoring of subscriber signal levels in cities along the eastern seaboard of the Philippines. Figure 1 shows a map of the locations where the subscribers' received signals were monitored. In this way, we did not have access to the exact locations of the subscriber but only that they connect to a particular base station in the network. In total, we were given access to the received signal levels of over 700 subscribers with one minute updating. We are presently considering the next deployment which may approach on having at least 2000 reporting terminals.

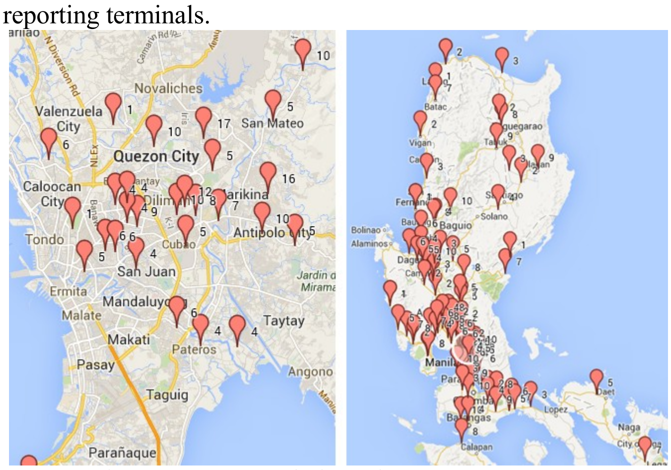

Fig. 1. Reverse Geocached Google Maps Custom Layout
Left: Metro Manila Layout. Right: Map for Luzon Area.

A. Data Pre-processing and Availability

All data are coming from a central station of Smartbro network and tossed through a secured FTP server to Ateneo every one minute. These measurements were pre-processed in Matlab and imported them as data matrices for easy cross-platform access, comma separated valued (CSV) files, which contain the Received Signal Levels (RSL). CSV files were segmented by month, with each month containing the number of minutes. Each month has typically 44,640 or 43,200 minutes, or 40,320 for February. The entirety of the data from July 2012 to the end of 2013 is now archived in CSV files for easy access, loading a month's data in Matlab.

B. Mapping Methods and Techniques

Since the exact locations of the antenna are confidential, we employ the use of Google Map to get the latitude and longitude locations of each barangay. In this manner, the behavior of the RSL variations is visualized clearly after processing. Real time visualizations can be made with the RSL data for each user in a specific time, to be used as an alert system in the event of widespread, consistent, and considerable signal attenuation in certain locations.

Mapping is done with an intensity classification scheme of 1 to 10, with subscribers with strong attenuation getting redder colors. Colored boxes roughly corresponding to the location of the subscribers are superimposed on the maps to visualize the attenuation, and correspondingly, rain, in that certain location, as well as the general spatial and temporal trends of attenuation.

To get the attenuation itself, the baseline is first computed from the previous RSL values, and the current RSL value is subtracted to the baseline, giving the equation

$$A(t) = RSL(t) - RSL_{baseline}(t) \tag{1}$$

with $A(t)$ as the attenuation at time t in dB,
$RSL(t)$ as the received signal level at time t, and
$RSL_{baseline}(t)$ as the received signal level baseline at time t, measured in dBm.

A problem for comparing drop in signal level for different subscribers would be the disparity of the attenuation due to rain for each of them. As for the power-law equation mentioned prior, for the rain rate, attenuation is a function of link distance. Longer links tend to react in a stronger manner to intense rain (and atmospheric conditions and fluctuations for that matter) than do shorter links. Our expectation for the attenuation due to rain can be understood using Crane's Law. We surmise that the average distance of each subscriber from the base station is approximately a kilometer. For these ranges we would expect to see attenuation changes from free space absorption alone of a few dB to 10 dB, depending on the temporal variations of the rain events. In light of this, a sigma classification scheme was conducted using the property of the proposed variability of the different links.

First, the baseline was computed for the entire data set, and then the RSL values were subtracted by the baseline, to get the attenuation for the entire data set. Here, the mean of the attenuation should, theoretically, be zero, for the presence of no rain. Then, the base variability of a given link is computed by getting its standard deviation, and the entire data set is classified according to how many standard deviations they are from the mean. Shorter links will naturally deviate less owing to their more robust and consistent communication link to the base station, while farther links will fluctuate more in variable water vapor, pollution, and atmospheric conditions. The equation is given as follows:

$$\alpha(t) = j \quad \text{when} \quad \tfrac{j}{2}\sigma \le A(t) < \tfrac{j+1}{2}\sigma \tag{2}$$

$$\text{for} \quad \sigma = \sqrt{\frac{1}{N}\sum_{t}^{N}(A(t)-\mu)^2} \quad \text{and} \quad \mu = \frac{1}{N}\sum_{t}^{N}A(t) \tag{3}$$

with *α(t)* being the sigma level of the attenuation value at time *t*, if it is the *j*th multiple of the half of the standard deviation, given by *σ*, with *N* done over the entire data set.

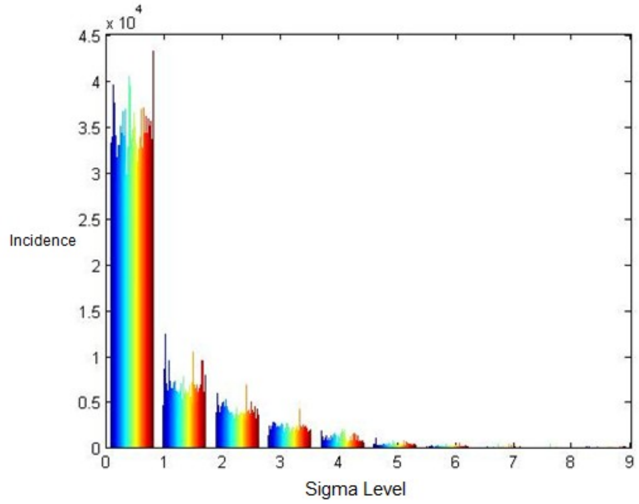

Fig. 2. Histogram of Sigma Level of ALL subscribers for August 2012. (Note that each color represents a subscriber, and that the general variability for each sigma level is discernible.)

As shown in the diagram in Figure 2, the distribution of the subscribers per sigma level are more or less even, with an exceeding majority of the data set within sigma level 3, which corresponds to 3 halves within the standard deviation. Compared using the raw attenuation values for rain determination and visualization, this would place them on equal footing in terms of relative contribution and should make up for the lack of information in link length by inference. Notice that the system can detect 1 or 2 difference readily and that there is a common movement of the returns towards high attenuation. We must recall that in this experiment, the distance to the base station varies, so the attenuation strength will also necessarily vary.

III. Results and Discussions

The sigma classifications were processed to good effect, with good concurrency of sigma levels in subscribers with select intense rain events for subscribers in the same base station. When the sigma level increases up to more than two, it indicates that the received signal level is already deviated from the baseline.

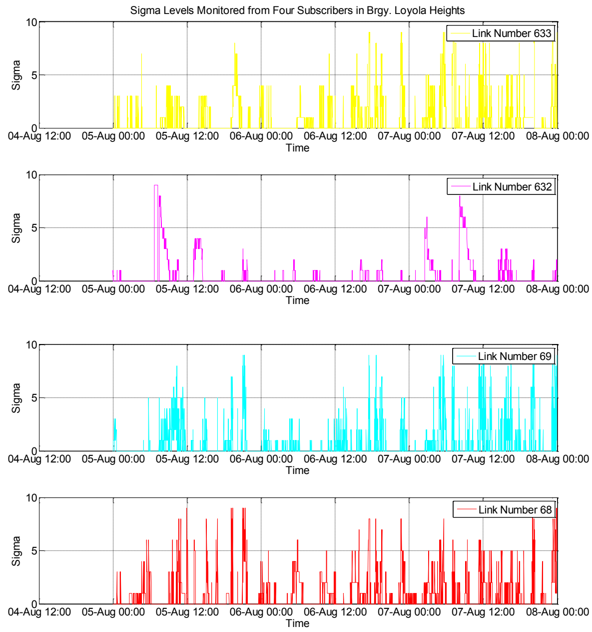

Fig. 3. Sigma Levels from Four Subscribers in Barangay Loyola Heights during Southwest Monsoon Rains on August 4 to 8, 2012.

Figure 3 shows the case for some of the subscribers of the base station found inside Loyola Heights, Quezon City, during the events of Southwest Monsoon in 2012, when a good number of locations in Metro Manila reached peak and sustained rainfall intensities above 100mm/hour. Concurrent peaks were found during the initial day of this season, showing most of sigma scores going above 5, giving good indication that this was the time that the rain event caused much attenuation in the surrounding area.

This also displays one good possibility for the system itself that despite confidentiality issues with the location of the base stations, local government units can be notified or may have access to the data of the base stations within their jurisdiction as a means of a rain alarm. In addition, Figure 4 shows a comparison between the actual rainfall data obtained from a tipping bucket and the average of the sigma levels measured by each subscriber inside Barangay Loyola Heights. The tipping bucket of the Manila Observatory weather station and the base station are co-located inside the same barangay, roughly within a few hundred meters to a kilometer of each other. The arrowheads indicate periods where rain events occurred and likewise, sigma levels started to rise up to send an alarm.

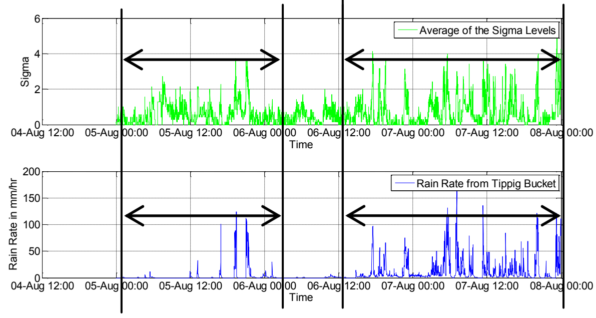

Fig. 4. Average Sigma Level of the subscribers in Barangay Loyola Heights compared to Rain Intensity measured by Manila Observatory Tipping Bucket

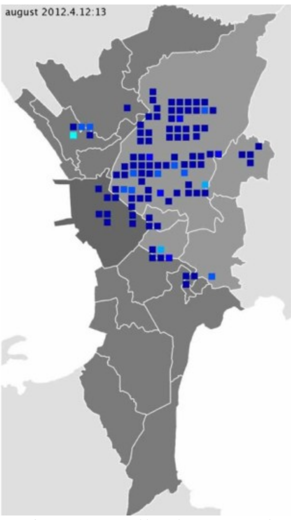

Fig. 5. Visualization of Metro Manila Sigma Levels, August 4, 12:13am, Without Rain Before the Duration of Southwest Monsoon

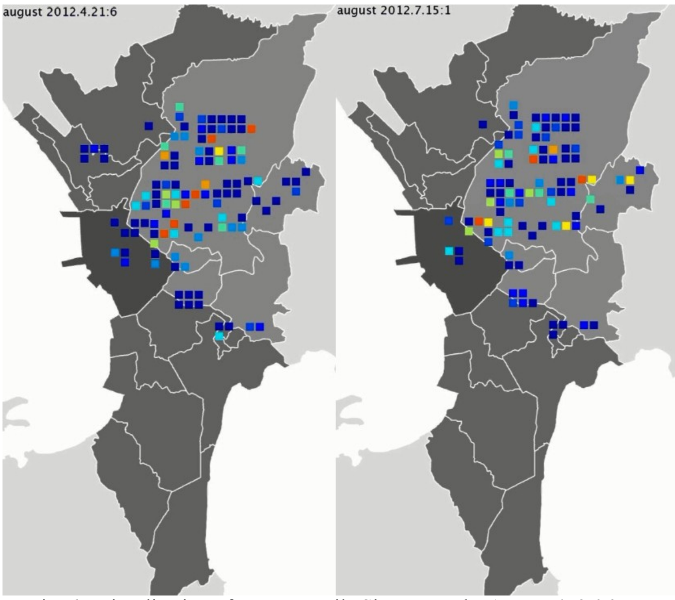

Fig. 6. Visualization of Metro Manila Sigma Levels, August 4, 9:06pm; August 7, 3:01pm, During the Duration of Southwest Monsoon.

Time-lapse videos are created to visualize the dynamic coloration of the sigma values for Metro Manila, Greater Luzon, and all of the Philippines. Figure 5 shows an example of the sigma levels of Metro Manila during a normal day, at a time without rain, and during the night before the start of the heavy rains of Southwest Monsoon 2012, with a majority of the subscribers with a sigma level rating of either 1 or 2.

Figure 6 shows an example of a visualization of possible rain during the Southwest Monsoon season, with red and yellow instances happening concurrently in the graph in the times expected to have had rain during said event.

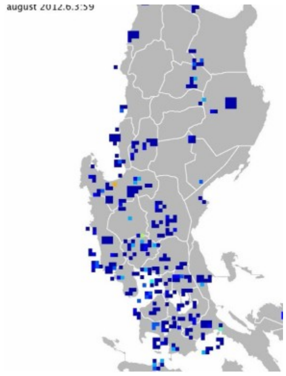

Fig. 7. Visualization of Northern Luzon Sigma Levels, August 6, 3:59am, During the Morning of Southwest Monsoon 2012.

Figure 7 shows that the system also has the capability of graphing and visualizing the sigma level readings for the rest of the Philippines and specifically that of greater Luzon, excluding all the readings specifically for Metro Manila, also in under a minute, but done separately. Northern Luzon is taken as a special case due to its comparably higher density of Smart reported subscribers. There is a perceived problem though in the comparative density of subscribers in the area of the Philippines outside of Metro Manila, with a large number of subscribers situated inside a small location, giving rise to a disparity in the density of the subscribers when taken together. This is, of course, due to the higher density of people living in Metro Manila, and this pattern is likely to hold in different telecommunications systems, making this method for rain determination well adapted for urban meteorology efforts.

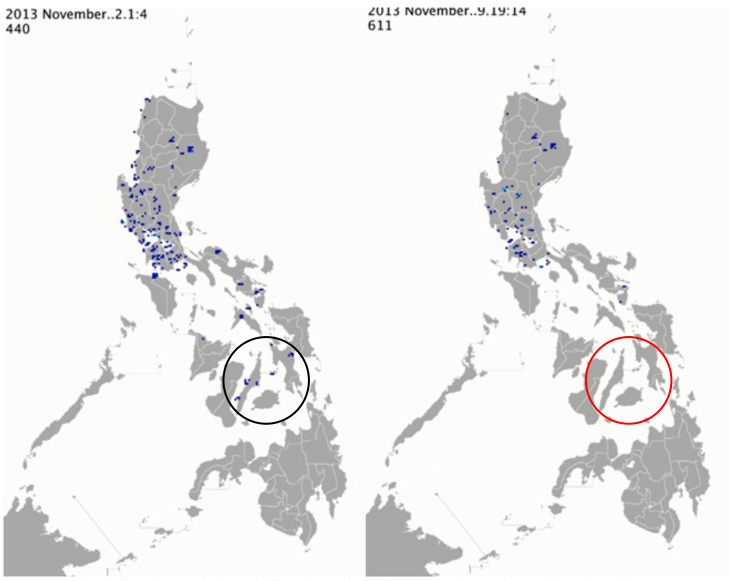

Fig. 8. Visualization of the Philippines for Sigma Values for All Subscribers.
Left: November 2, 2013 1:04 am, before Typhoon Haiyan.
Right: November 9, 2013 7:14 pm, after Typhoon Haiyan.

The system would also help in the determination of areas necessitating emergency telecommunications networks due to easily located outages in available subscribers or base stations, as shown in Figure 8, where Typhoon Haiyan affected mainly the region of Visayas, corresponding to a great loss of subscriber data in that same region.

A warning system for high intensity rain may be determined from a number of things observed hence, like an overall concurrent increase in the sigma levels of a certain location, or a widespread loss of subscriber links in certain locations. The loss of data for three days during Typhoon Haiyan event itself clearly shows how devastating typhoon was. Subscriber reportage fell from around 450 to 300 after the event, which then fluctuated on a daily basis, perhaps due to differing loads and the loss of other subscribers and backhaul links. All these features of fetching current data, baseline retrieval, attenuation determination, retrieving the sigma levels, and image plotting were designed to be processed in less than a minute so that it is able to update the graphs in real time, and the system currently has the capability to do so.

IV. Conclusions and Recommendations

We have demonstrated a unique method for a rain alarm system that is able to detect and visualize rain patterns. A baseline method was employed with a time moving average acting as a low pass filter. We use a classification method determine comparative dips in attenuation based in likely variability from each subscriber. The data on attenuation was successfully plotted for Metro Manila and all of the Philippines, along with special cases of extreme weather during Southwest Monsoon season as test subjects for the visualization and partial validation of the methods employed. Extreme weather conditions and effects on telecommunications networks were seen during Typhoon Haiyan, further helping understand the effects of disastrous rain events in a tropical setting. Moreover, these results from our preliminary tests were obtained without any additional infrastructure investment.

For future work, ground truth tasks are conceptualized by fusing multiple readings from different types of sensors such as the standardized measuring rain devices, automated weather stations, together with acoustic sensors placed along the paths of the microwave links. This system can also be an integral part of a rain alarm system that will predict upcoming urban flooding events and traffic jams, when correlated with social networking reports.

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