Design of Wireless Disaster Alarm System Using Microwave Links

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***Abstract*—Two microwave links operating at 5GHz and 26GHz are characterized in this research to correlate the rain rate in terms of power attenuations in the links. Regression analysis is used to estimate the degradation in the received power levels in the microwave links in terms of the measured rain rates from traditional tipping buckets. The regression model is compared to the regression analysis models done in different countries. Results show that the estimation done in this research is more appropriate to be used in the Philippines compared to the existing models. This research is the basis of all the highly scalable wireless sensors systems that aim to determine the classification of tropical rains according to the received power levels in the microwave links. Finally, a knee point of -85dBm in the received signal level was observed in the 26GHz band that serves as the transition point between the safe condition yielding 0dB loss and unsafe rain conditions that increase the packet loss rates of the received signals. This knee point may serve as a trigger point for disaster alarm systems**

***Index terms*—Rain Estimation; Regression Analysis; Wireless Sensor Networks.**

I. INTRODUCTION

In this research, a hybrid wireless test bed based on two fixed wireless Internet Protocol network technologies were used to explore the feasibility of a designing a wireless disaster alarm system. These wireless sensor networks aim to estimate the rain rates in their respective area of coverage and may serve as alert systems for possible floods and landslides. These networks will also complement measurements made from already deployed tipping bucket sensors and existing weather radar installations especially in areas that have no such deployments. Different studies are published showing the degradation of the received power levels of wireless links during rainy seasons [1][2][3][4]. The behavior and the statistical fluctuations on the power during rainy-day conditions have become a focus of research that aims to be used as support systems in some disaster management and monitoring systems. Several researches [5][6][7][8][9] have made advance studies to understand and simulate the behavior of wireless sensor links in the presence of rain or even typhoons. From the collected data based on these behaviors and statistical variations on the received signal levels of the wireless links, several groups designed different algorithms and models [10][11][12][13][14][15] that estimate the correlation between the rain rates and the amount of power degradations in wireless links due to rain. This paper is the basis of the disaster alarm systems designed by researches shown in articles [16] and [17].

II. PROBLEM SETTINGS

This research uses two fixed wireless Internet Protocol (IP) networks that cover the following objectives.

A Smart Broadband (SmartBro) receiver terminal monitors the statistical behavior of the Received Signal Level (RSL) during normal (no rain) condition and during different rain conditions. Least Squares Method of Regression is used to estimate the correlation between the rain rate measurements from the traditional tipping bucket and the RSL due to rain.

A Wireless Internet Protocol Access System (WIPAS) terminal monitors the statistical variations in the RSL of the WIPAS terminals during normal condition and during rainy conditions. Again, Least Squares Method of Regression is used to estimate the correlation between the attenuation due to rain and the rain rate from tipping buckets. The Bit Error Rates (BER) of the link is also monitored during different rain conditions

III. METHODOLOGY

This research uses two IP access links to estimate rain rate by monitoring the degradation of the RSL of the receiver terminals during rainy conditions. Least Squares Method of Regression is used to estimate the correlation between the attenuation due to rain observed at the receiver terminals and the rain rate measurements from tipping buckets. The following tasks are done in this research.

A. Test Bed Setup

Two IP access links were used as test beds to monitor the performance of these links during no rain condition and during rainy conditions - the SmartBro receiver terminal and the Wireless Internet Protocol Access System (WIPAS) terminals.

The first test bed used in this research is the SmartBro receiver terminal. This link uses one tipping bucket to measure the rain rate during different rain conditions.

The second test bed is the Wireless Internet Protocol Access System (WIPAS) terminals donated by the Japan Radio Corporation (JRC) to Ateneo de Manila University.

B. Deployment of Smart Broadband (SmartBro) Terminal

The setup used by SmartBro IP system is shown in Table 1. The transmitter and receiver link distance is 0.4182 km and the operating frequency is 5.815GHz.

Table 1
Deployment parameters of Smart Broadband Terminal

	Smart Bro
Transmitter Coordinates	14° 38' 9.3"N 121° 4' 43"E
Receiver Coordinates	14° 38' 17.44"N 121° 4' 33.74"E
Link Distance	0.4182 km
Frequency	5.815GHz
Tx Power	23 dBm
Antenna Gains	9 dBi
Threshold RSL	-86 dBm

The link performance of SmartBro was monitored during different types of rain conditions. During rainy days, there are degradations in the Received Signal Level (RSL) in the SmartBro receiver terminal. This degradation is used to correlate the signal levels with the rain rate measurements from a GSM enabled tipping bucket.

The deployment details of the WIPAS terminals are shown in Table 2.

Table 2
Deployment parameters of WIPAS and Smart Bro

Parameters	WIPAS
Transmitter coordinates	14°38'23 N, 121°04'37E
Receiver coordinates	14°40'34 N, 121°04'53E
Link distance	4.08 km
Frequency	26 GHz
Tx Power	14 dBm
Antenna Gains	31 dBi
Threshod RSL	-79 dBm

The WIPAS terminals use direct wave mode of propagation. The transmitter and receiver terminals are 4.08 km apart and use a center operating frequency of 26 GHz. The Master station uses a GSM enabled tipping bucket whereas the Slave terminal uses a commercial tipping bucket. The measurements from these tipping buckets are used to estimate the correlation between the degradation in the received signal level on both terminals and the rain rate.

C. Data Gathering

The system gathered three months of rain data from the SmartBro receiver and the WIPAS terminals.

The RSL of the SmartBro receiver terminal was continuously monitored and recorded every three seconds for the entire monitoring period.

The WIPAS terminals logged the RSL as well as other system parameters such as packet loss rates and accumulated received packets. The data was logged every second for the entire duration of the monitoring period.

The rain rate data from the Master station tipping bucket was logged and retrieved after the monitoring period. The event-driven tipping bucket from the slave terminal logged the rain rate and the accumulated rain every second for the entire duration of the monitoring period. Table 3 shows the different classification of rains according to their rain rates.

Table 3
Rain Classifications according to rain rate.

Classification	Rain Rate in mm/hr
Condition on very light rain	Less than 0.25
Condition on light rain	between 0.25 and 1.0
Condition on moderate rain	between 1.0 and 4.0
Condition on heavy rain	between 4.0 and 16.0
Condition on very heavy rain	between 16.0 and 50
Condition on extreme rain	Greater than 50.0

IV. DISCUSSION OF RESULTS

The performance of SmartBro terminal was monitored during no rain and during rain conditions. The received signal levels on the SmartBro were logged every three (3) seconds during rain events for the duration of three months.

Figure 1 shows the statistical variations of the Received Signal Level (RSL) of the SmartBro terminal under no-rain condition. The concentration of the RSL is seen to be between -44dBm and -46dBm. Under normal condition (norain condition), the RSL is expected to be within the -44dBm to -46dBm mark for a link distance of 0.4182km. However, during rain events, RSL will experience degradation which is directly proportional to the intensity of the rain. The figure shows a clear view on the no-rain condition and rain condition of a Smart Bro Terminal.

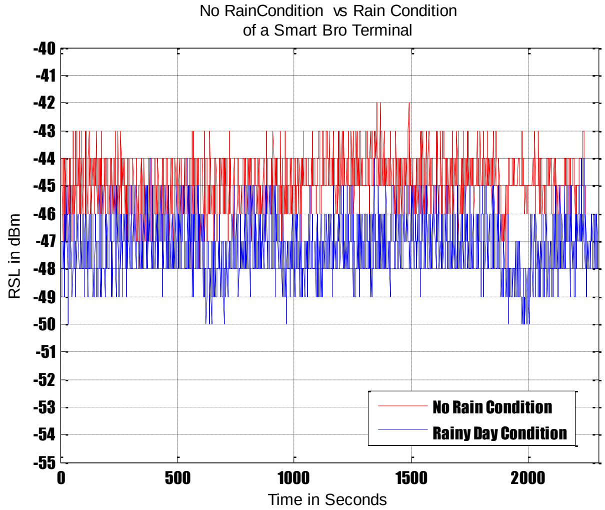

Figure 1: Statistical variations of RSL of a SmartBro terminal under rain and no-rain conditions.

A GSM enabled tipping bucket was used to correlate the degradation on the RSL and the rain rate. The tipping bucket has a 2mm resolution that logs the data every 15 minutes giving the total number of tips acquired. Several rain events were monitored using the SmartBro receiver Terminal and the GSM enabled tipping bucket.

The data for several rain events for the SmartBro receiver terminal RSL and the rain rate from the tipping bucket were gathered.

A. Attenuation due to Rain

The Smart Broadband receiver terminal exhibits degradation in the RSL power that is directly proportional to the rain rate. Given these two parameters, Least Squares Method of Regression is used to estimate the correlation between the rain attenuation on received power and the rain rate. Equation (1) is the general equation in solving for specific attenuation in dB/km.

$$A = a R^{b} \qquad (1)$$

where: A is the attenuation in dB/km
R is the Rain rate in mm/hr
a and b are constants depending on the frequency

Using recorded RSL power of Smart Broadband receiver terminal and tipping bucket data, the result of the regression analysis for Smart bro is shown in Equation (2).

$$A = 1.3479\ R^{0.2045} \tag{2}$$

Equation (2) yields a coefficient of correlation to be 0.3214. The best fit for this correlation has a value of 1 while the worst fit has a value of 0.

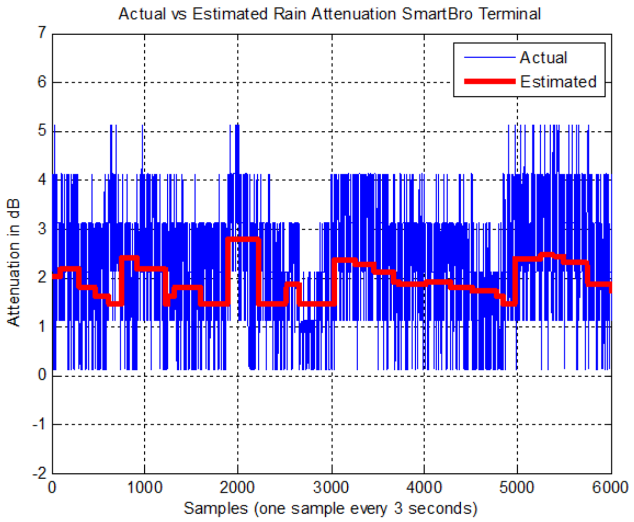

Figure 2: Measured (monitored) Attenuation vs estimated attenuation due to rain using Least squares method of regression.

Several rain events are used to monitor the degradation of the RSL from the normal (no rain) condition of a SmartBro terminal concurrently with a GSM tipping bucket. Statistical variations on the measured and estimated values of RSL power is shown in Figure 2 above. The blue lines show the monitored (actual) attenuation due to rain of a SmartBro receiver terminal and the red lines show the estimated attenuation due to rain using the parameters a and b in Equation (2). It is proven that the wireless link can be used to monitor the degradation of the RSL in Smart Bro receivers. This degradation on the RSL may be used in estimating the rain rate by monitoring the link attenuation due to rain.

The WIPAS terminals are deployed 4.08 km apart. The link line-of-sight installation has been calibrated to maximize the RSL on both sides. Figure 3 shows the statistical variations on the RSL on the Master Terminal and slave terminals. The power transmitted on both sides was set to 14dBm. The master terminal receives a power of -64dBm whereas slave terminal receives an average power of (-65.5) dBm for (normal) or condition without rain.

The received powers on the WIPAS terminals are monitored during different rain conditions. The attenuation on the received power of each WIPAS terminal rises as the amount of rain increases. Figure 4 shows the statistical variations on the RSL power on moderate rain and heavy rain and the combined rain statistics. The graph shows that the link suffers moderate attenuation, around 5dB, of the RSL on both terminals under moderate rain while both terminals suffer heavy attenuation, around 15 dB to 20 dB, during heavy rains. This shows that the 26GHz link is more susceptible to attenuation due to rain than that of a SmartBro terminal. The graph also shows that the degradation on the RSL on WIPAS terminals is directly proportional to the rain rate.

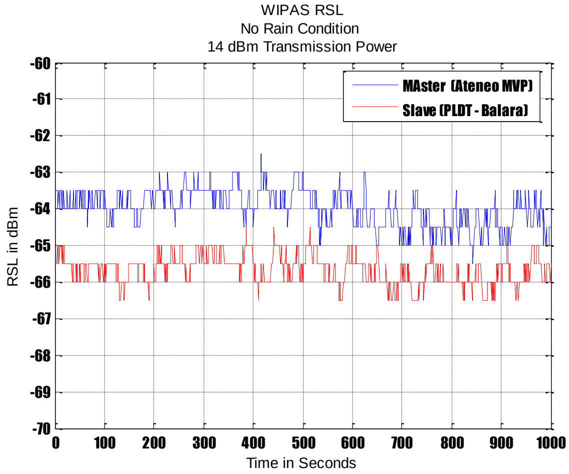

Figure 3: Statistical variations on the RSL power of Master terminal and Slave terminal of WIPAS link.

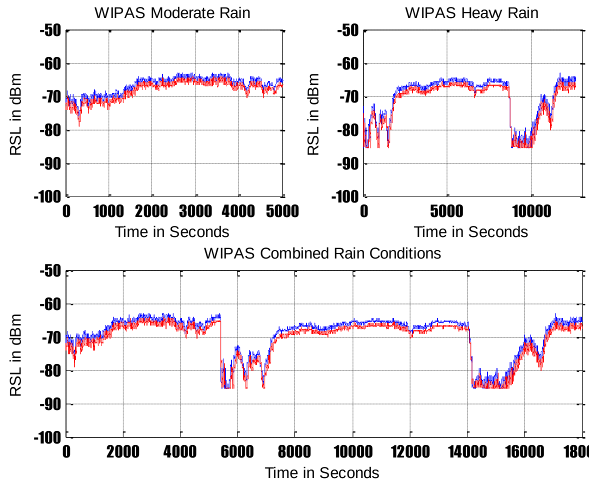

Figure 4: Statistical variations on the RSL power WIPAS terminals. The blue line is for the master station and the red line for the slave station.

The recorded rain data was correlated with the received signal power on both the WIPAS terminals. This is shown in Figure 5. It is clearly shown the statistical variations on the received power on both WIPAS terminals degrade as a factor of the rain rate. The degradation of the WIPAS terminals is more robust than that of the Smart Broadband terminals. WIPAS terminals operate in 26 GHz band that is very highly susceptible to degradation due to rain while Smart Broadband terminal operates in 5.815 GHz band that is less susceptible to rain conditions. Using the Least Squares Method of Regression, the amount of attenuation due to rain for WIPAS terminals were simulated and computed. The results are shown in Table 4.

Table 4
Parameters for WIPAS Master and Slave terminals

	Master	Slave
TippingBucket Resolution	15-minute	Event-Driven
A	1.6908	2.1139
B	0.5348	0.8724
Coefficient of Correlation	0.5879	0.7067

The coefficient of correlation (cc) is used to measure the "goodness" of the fit using least squares. The number should be -1 or 1 depending on the slope of the trend line. The value for exact fit is cc = -1 for a negative slope and cc = 1 for a positive slope. For a bad fit, the value becomes close to zero(0). Table 3 shows that the result of regression analysis for the WIPAS slave terminal is better than the results for WIPAS master terminal. The two link receivers have different regression coefficients that are due to the different types of tipping bucket resolutions used.

The WIPAS link is 4.08km apart. The two tipping buckets are deployed near each terminal. Only the rain events near the tipping buckets properly monitored by the system. Tropical rains have several variations within a rain cell. For a 4.08km link, there are several variations that may happen along the link, the data on the terminals may allow us to set alarms in estimating the amount of rainfall and rain rate the link is experiencing.

The WIPAS master terminal's performance is simulated and shown in Figure 5. The computed attenuation due to rain is shown in red line. The actual variation in the received powers on the Master terminal is shown in blue lines.

It is clearly shown that the prediction done in the WIPAS slave terminal is better than that of the master terminal because the tipping bucket used in the slave terminal is more real time than that on the master terminal.

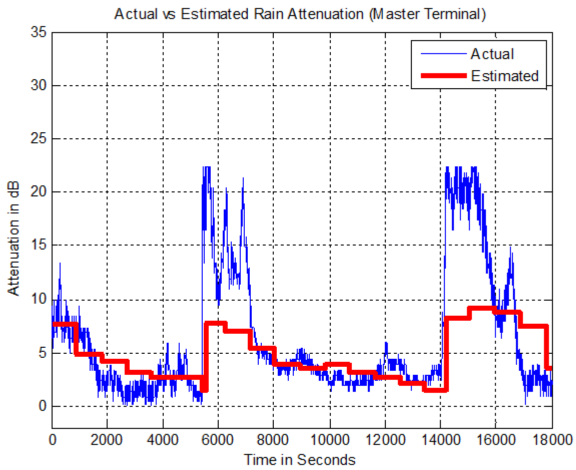

Figure 5: Graph showing the actual attenuation of WIPAS Master Terminal due to several rain events vs the estimated values using Least Squares of Regression.

The WIPAS slave terminal also monitored the degradation of the RSL power due to several rain events and correlated it to a commercial event-driven Tipping Bucket. These two parameters are used to compute the variables necessary to estimate the attenuation due to rain using rain rates. Figure 6 shows a clearer picture of the actual (measured) degradation of the RSL power and the estimated attenuation due to rain. It better estimates the behavior of the system than the Master terminal because of the resolution of the tipping bucket.

B. Comparison with existing models.

The values computed from the experiment were compared using existing parameters gathered from different countries. The comparison between each one is shown in Figure 7. The estimated values better approaches the measured values compared to the models used by different countries. The values for a and b previously solved bests characterize the rain behavior for this particular area in Quezon City.

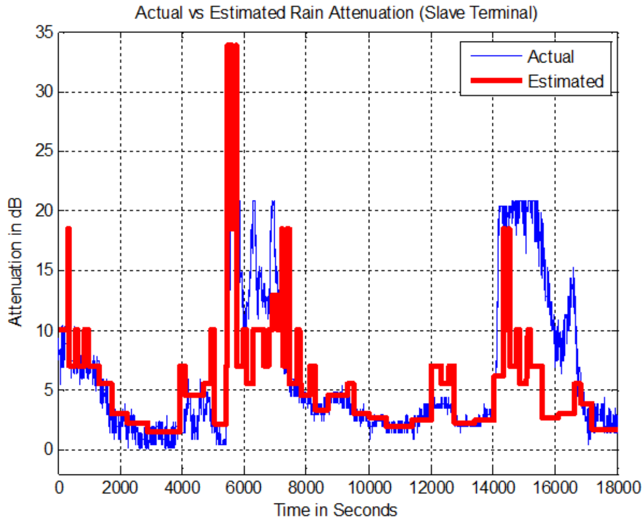

Figure 6: Actual (measured) attenuation due to different rain events for WIPAS slave terminal.

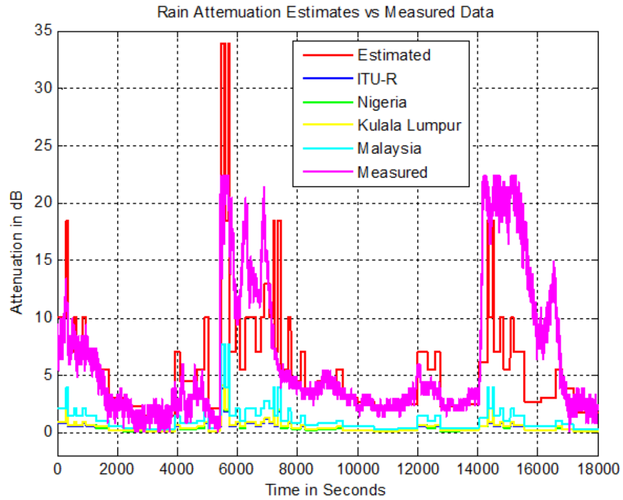

Figure 7: Graph shows the computed attenuation due to rain using different models as compared by the actual (measured) attenuation due to rain.

The attenuations due to rain were computed using different models to see the exactness of the computed parameters a and b for WIPAS terminals operating in the 26GHz. The mean square error of each model was also computed and summarized in Table 5.

Table 5
Coefficients a and b for different models. The mean square error was computed using their coefficients and measured rain rate

Model	A	B	Mean Square Error
Estimated	2.1139	0.8724	25.3360
ITU-R	0.1358	1.0522	66.7222
Nigeria	0.1451	1.0483	66.2343
Kula Lumpur	0.1626	1.0171	65.7478
Malaysia	0.4096	0.9227	56.3350

C. Packet Loss Rate

The performance of WIPAS links in terms of its packet loss rate was also examined during normal and different rain conditions. During normal conditions, the packet loss rate for

WIPAS terminals was found to be zero (0dB). However, during rain events, the packet loss rate starts increasing until the system reaches its threshold RSL which is -85dBm in this experiment. The system tends to go down due to increased BER which is also due to heavy rain conditions. This is shown in Figure 8. The arrow points to the knee of the graph when there is heavy rainfall and the link tends to go down due to high packet loss.

This can best used as an indicator for designing Wireless disaster alarm systems. During normal and light rains, the system performs well and indicates zero or minimal packet loss rate. However, during heavy rains, the RSL of WIPAS terminals suffer heavy attenuation that causes the link to reach and go beyond the threshold RSL. In this state, the link goes down and a knee can be observed in the packet loss rate of the system wherein the system also suffers heavy packet loss. As the system recovers from the big degradation of its RSL, the packet loss rate also tends to stabilize. This is a good indicator showing normal or light rain conditions with almost zero packet loss rate as well as heavy rain depicted as knee, giving the system a sudden burst in the packet loss rate

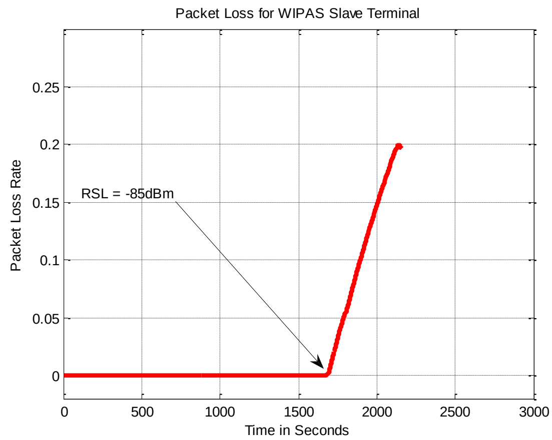

Figure 8: Performance of WIPAS in terms of Packet Loss Rate with respect to the Received Signal Level (RSL)

V. SUMMARY

The correlation between the Received Signal Level (RSL) power and the rain rate was presented and proved that the Smart Broadband terminal, having a frequency of 5GHz is less susceptible to degradation due to rain compared to the WIPAS link operating in the 26GHz band. The effect of rain in the propagation of line-of-sight communications is very significant in the frequencies above 10GHz.

The feasibility of using these links in designing wireless disaster alarm system was shown and proven. The possibility of estimating the attenuation due to rain has been presented. Table 6 below that summarizes the computed parameters for Smart Broadband terminal and WIPAS terminals.

The resolution of the tipping bucket in correlating the RSL power and the rain rate is one factor that affects the evaluation of the "best fit" curve using the Least Squares Method of Regression. For WIPAS link, evaluated the Master station, with GSM enabled tipping bucket and the slave terminal with event driven tipping bucket shows that the WIPAS slave terminal yields better results in predicting the amount of link attenuation due to rain. The coefficient of correlation of the slave terminal is better than that of the coefficient of correlation of the master terminal.

The SmartBro terminal yielded a low coefficient of correlation than the WIPAS terminals. There are two reasons for having low coefficient of correlation. First is that SmartBro uses operating frequency of 5.815GHz which is less susceptible to rain attenuations than the WIPAS terminals operating in 26GHz band. Second is that the SmartBro terminal used GSM enabled tipping bucket that has a resolution of 15 minutes. This tipping bucket is not capable of characterizing the fast statistical variations of the RSL power of the link.

The attenuation due to rain of the SmartBro terminal and the WIPAS terminal is summarized in Table 7. The results in the Slave terminal of WIPAS is chosen for its higher coefficient of correlation than the WIPAS master terminal.

Table 6
Summary of parameters for $A = aR^b$ for Smart Broadband terminal and WIPAS terminals

	A	B	Coefficient of correlation	Tipping bucket resolution
SmartBro	1.3479	0.2045	0.3214	15-minute GSM enabled
WIPAS master	1.6908	0.5348	0.5879	15-minute GSM enabled
WIPAS slave	2.1139	0.8724	0.7067	Event-Driven

Table 7
Mathematical equation for Attenuation due to rain for SmartBro and WIPAS terminals

Prediction of Attenuation due to rain (A)	
Smart Broadband	$A = 1.3479\ R^{0.2045}$ (dB/km)
WIPAS	$A = 2.1139\ R^{0.8724}$ (dB/km)

This research monitored the performance of a single SmartBro terminal. The Tipping bucket is located near the SmartBro server and the SmartBro receiver terminal, where we logged the RSL, is 0.4182 km from the server. Tropical rains have numerous rain variations within a rain cell, so using only one terminal may not give enough information about the exact behavior of rain within the area

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