TWO YEARS OF SITE DIVERSITY MEASUREMENTS IN GUAM, USA

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Abstract

As NASA communication networks upgrade to higher frequencies, such as Ka-Band, atmospherically induced attenuation can become significant. This attenuation is caused by rain, clouds and atmospheric gases (oxygen and water vapor), with rain having the most noticeable effects. One technique to circumvent the increase in attenuation is to operate two terminals separated by a distance that exceeds the average rain cell size. The fact that rain cells are of finite size can then be exploited by rerouting the signal to the terminal with the strongest link. This technique, known as site diversity, is best suited for climates that have compact (<2km) and intense rain cells such as in Guam.

In order to study the potential diversity gain at the Tracking and Data Relay Satellite (TDRS) Remote Ground Terminal (GRGT) complex in Guam a site test interferometer (STI) was installed in May of 2010. The STI is composed of two terminals with a 900m baseline that observe the same unmodulated beacon signal broadcast from a geostationary satellite (e.g., UFO 8). The potential site diversity gain is calculated by measuring the difference in signal attenuation seen at each terminal.

Over the two years of data collection the cumulative distribution function (CDF) of the site diversity gain shows a better than 3 dB improvement for 90% of the time over standard operation. These results show that the use of site diversity in Guam can be very effective in combating rain fades.

I. Introduction

NASA's communication networks are transitioning operations from the current use of X/Ku-Band spectrum to Ka-Band by 2018. By implementing Ka-Band operations, data rates of 1 Gbps or higher can be realizable for subsequent NASA missions. However, transmissions at Ka-Band are particularly susceptible to rain attenuation, which is caused by the scattering and absorption of water droplets. Rain attenuation can cause very large variations in received signal levels, and in tropical rain zones such as Guam the necessary fixed link budget margin to reliably maintain a link at Ka-Band during rain events would be extremely large and impractical. One alternative to having a large margin is to utilize site diversity. It is believed that the compact rain cell size of the local Guam climate could potentially provide meaningful site diversity gain to improve ground to space link margin availability.

To determine the feasibility of Ka-Band communications in a tropical region and to assess the role that site diversity may play in enhancing system availability NASA has deployed the Guam Atmospheric Monitor at the Guam Remote Ground Terminal (GRGT). Data, including signal attenuation, phase and surface metrological measurements such as temperature, humidity, pressure, rainfall and rain rate, has been recorded at the site for two consecutive years and is scheduled to continue until five years has been collected.

II. Site Diversity Explained

Rain cells normally consist of convective clouds which are a source of heavy rainfall and lightning in equatorial regions. In topical rain zones such as Guam most of the rain cells are compact having an average spatial dimension ranging from .5 to 2 km in diameter and tend to have a short duration. Topical rain cells however short lived, are capable of produce peak precipitation rates of about 75–150mm/hour which at Ka-Band can cause upwards of 30dB of signal attenuation, enough to cause even the most robust of links to go down.

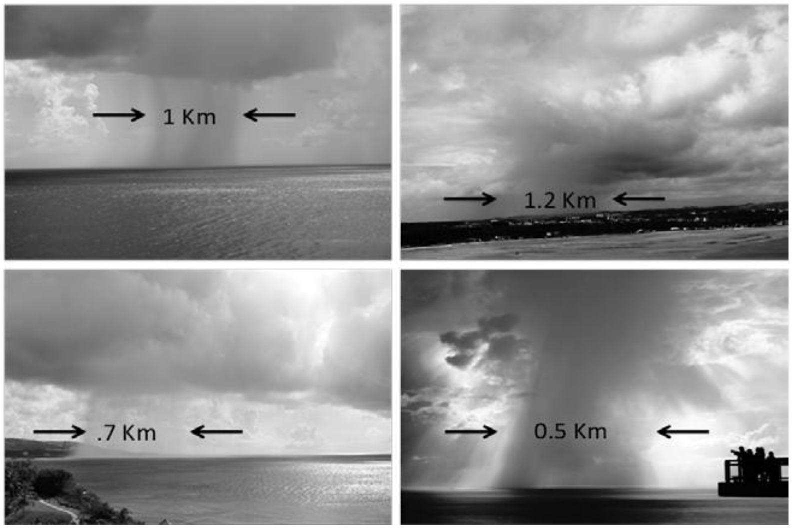

Figure 1: Typical Rain Cells in Guam

The site diversity technique takes advantage of the localized nature of rain cells in tropical regions by using two ground stations, exploiting the fact that the probability of rain attenuation occurring simultaneously on both paths is significantly less than the probability of rain attenuation occurring on either individual path.

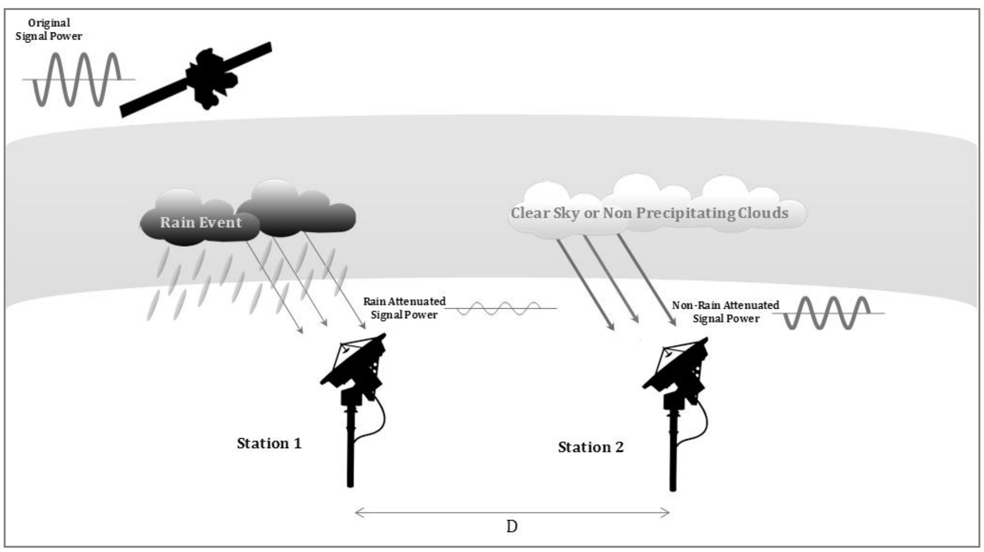

Figure 2: Example of Site Diversity

By employing two spatially separated communication terminals with a large baseline diversity gain can be achieved, wherein one terminal experiences less rain attenuation than the other. During periods of rain the terminal that is used for receiving the signal can be shifted to the one that is experiencing the least amount of fade thus decreasing the effect of the rain attenuation and increasing the likelihood of maintaining the link and overall system availability. Figure 3 shows actual data taken in Guam by the Atmospheric Monitor, the attenuation seen by the north antenna is 10dB higher than that seen at the south due to an isolated rain cell that past over the North antenna.

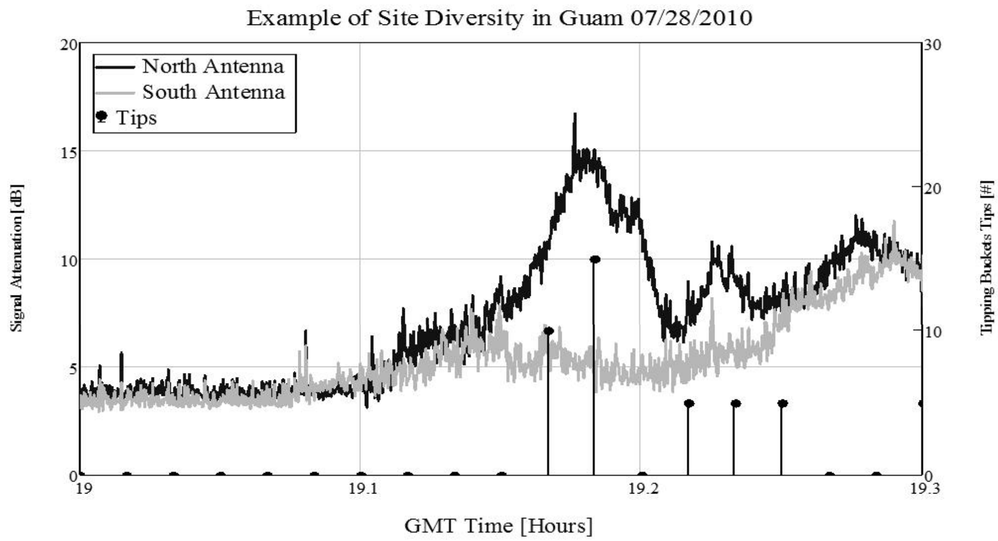

Figure 3: Site Diversity in Guam

III. Description of Hardware

Atmospheric Propagation Monitor in Guam was designed primarily to determine the performance of Ka-Band communications in a tropical location, and to determine the effect to which site diversity may play a role in enhancing overall system availability. In order the accurately measure the effects of the atmosphere on Ka-Band it is necessary to monitor a beacon signal at the frequency of interest (Ka-Band) and to have sampling rate that is sufficient to capture the atmospheric induced fades (1 Hz). Being able to correlate the attenuation measurements with surface meteorological data is also needed to ensure that any fade being analyzed is actually caused by rain along the path and not another phenomenon. Additionally to determine the potential site diversity improvement two spatially separated stations are required.

The characteristics of the propagation terminal are given in Table 1. The terminal equipment includes computer controlled beacon receivers that are designed for continuous unattended operation.

TABLE 1: Propagation Terminal and Preprocessing Program Characteristics

Antenna	1.2m offset reflector
Digital Beacon Receiver	FFT Based - Frequency Tracking 1 Hz Detection Bandwidth < 3s to reacquire after loss of signal 0.1dB *rms* measurement accuracy 50dB dynamic range
Data Collection	1 sample per second (1Hz) Time Stamp Signal Level (Arbitrary Reference) Receiver System Status Surface Weather at the Terminal
Preprocessing	< 0.3dB *rms* error in estimated attenuation

The layout of the propagation measurement system consists of two antennas separated by approximately 600 m on a North-South baseline.

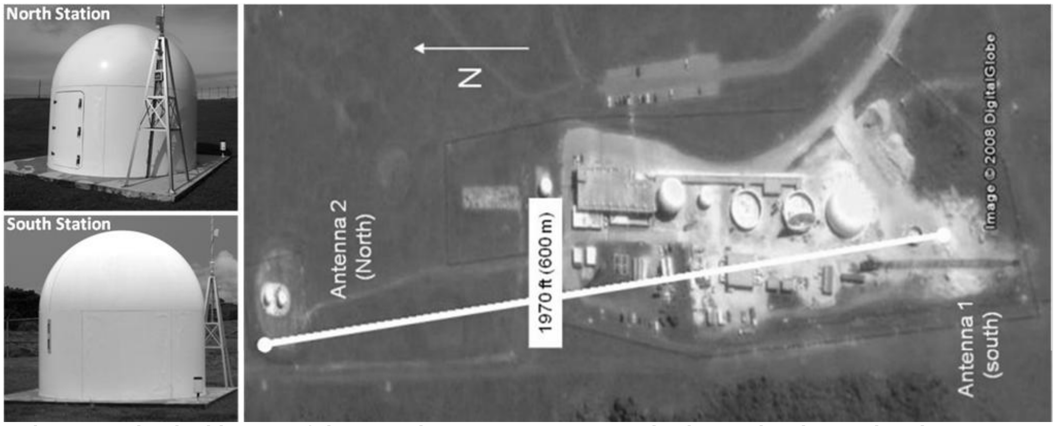

Figure 4: Physical layout of the two-element Guam Atmospheric Monitor located at the GRGT.

The two terminals are physically situated at the locations described in Table 2.

TABLE 2: Antenna Physical Locations and Pointing

	North Antenna	South Antenna
Elevation	446 ft.	464 ft.
N. Latitude	13° 35.493’	13° 35.200’
E. Longitude	144° 50.420’	144° 50.455’
Azimuth Angle	253°	253°
Elevation Angle	38°	38°

The Guam Atmospheric Propagation Monitor monitors an unmodulated beacon signal. This particular signal is a 20.7 GHz beacon broadcast from geostationary satellite UHF Follow-On (UFO8). The unmodulated beacon signals at 20.7 GHz are received, amplified and down-converted to 70 MHz in the RF feed box enclosure. The 70 MHz signals are further down-converted to 455 kHz (double conversion) in the IF box enclosure. These 455 kHz signals are sent to the indoor facilities for analog-to-digital conversion (3.64 MHz sampling rate, with 524,288 samples) and further signal processing. In software, the in-phase (I) and quadrature (Q) components are determined to derive the signal amplitude and phase with a 1Hz sample rate. The system block diagram for the two-element interferometer is depicted in Figure 2.

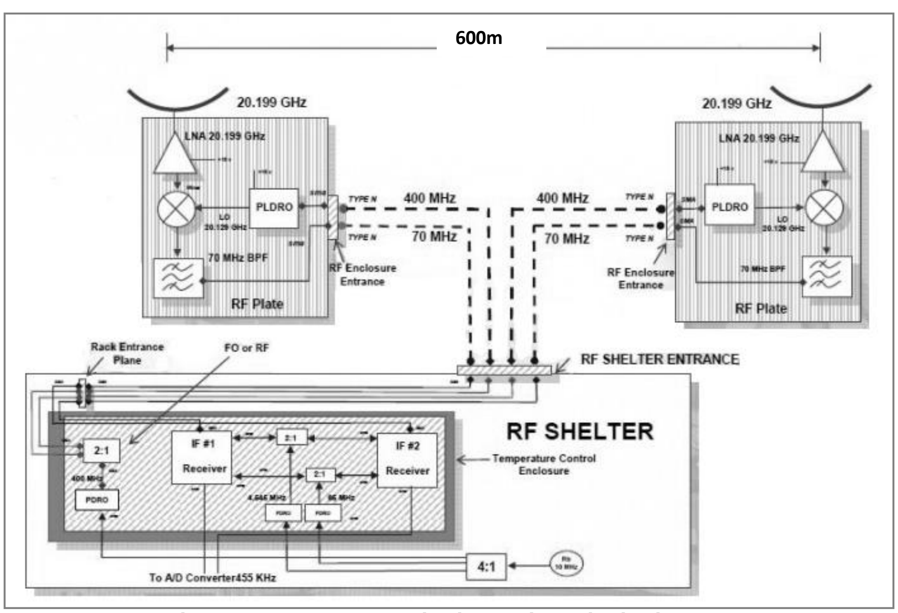

Figure 5: Guam Atmospheric Monitor Block Diagram

Also part of the Guam Atmospheric Monitor are two weather stations located near each of the ground terminals. The weather stations record surface meteorological data and rainfall accumulation and rain rate. Each weather station is identical and equipped with an anemometer, a pressure transducer, a humidity/temperature monitor and a tipping bucket. The weather measurements (with exception of the tips) are averaged over a one minute period and recorded. The tips measured by the tipping buckets are summed over the minute period then recorded.

Figure 6: top left anemometer, top right RH/Temp, bottom Left tipping bucket, bottom right pressure transducer

IV. Diversity Results Derived from Measurements

The cumulative distribution function (CDF) can be used to determine the potential effectiveness of implementing a site diversity technique in Guam. Figure 7 shows the CDF of the actual attenuation seen by each ground station and the theoretical CDF that could have resulted if site diversity had been implemented over the same period of time. The diversity improvement was derived by comparing the two stations attenuation and choosing minimum attenuation seen by either antenna for a given sample time.

$$Diversity_t = min(North\_Attenuation_t, South\_Attenuation_t)$$

This created a new time series on which the CDF analysis was preformed. The diversity curve shows a .5dB improvement for better than 90% of the year and a 1dB and 4dB improvement for 99% and 99.9%, respectively. Assuming a standard fixed system margin of 3dB using site diversity would have resulted in approximately 500 hours of additional availability during this time period. A larger baseline between the two ground stations could significantly increase the effectiveness of the site diversity technique. If the baseline is larger than the average rain cell diameter it would be possible to achieve very high availability percentages.

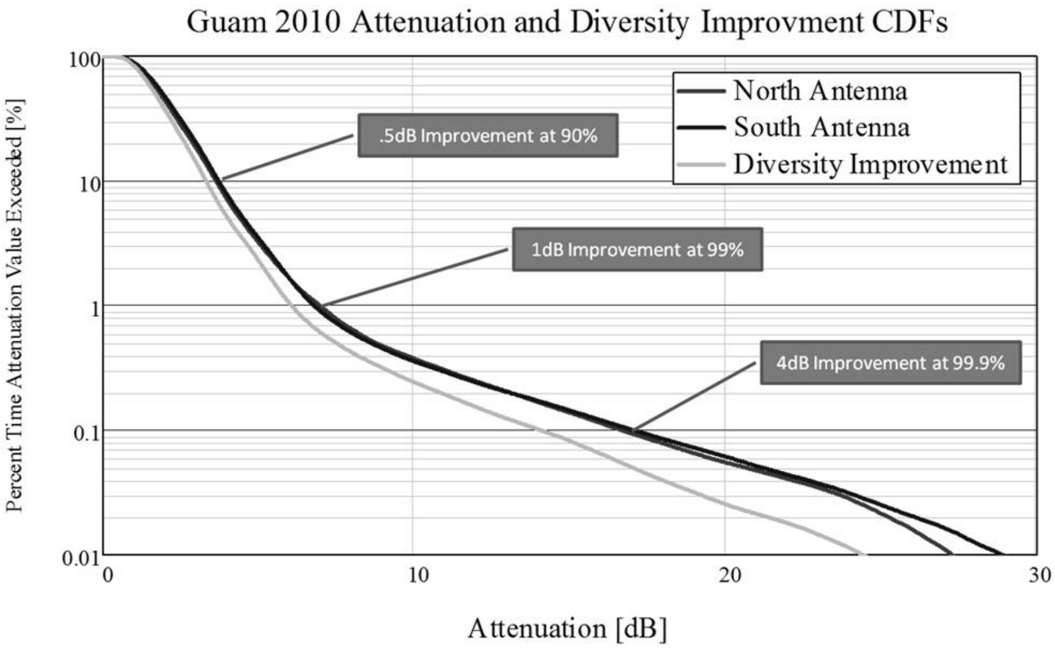

Figure 7: Attenuation CDF

However, site diversity will have different characteristics for different seasons, years, frequencies and topographical features, etc. Guam is in an equatorial region and so doesn't have a traditional summer and winter in terms of temperature, none the less it does have seasonal variation in the amount of rain fall it receives. Figure 8 shows the total rainfall accumulation by month for 2010-2012. From the plot it can be seen that Guam's rainy season is from July to Sept while the rest of the months are drier but not significantly so.

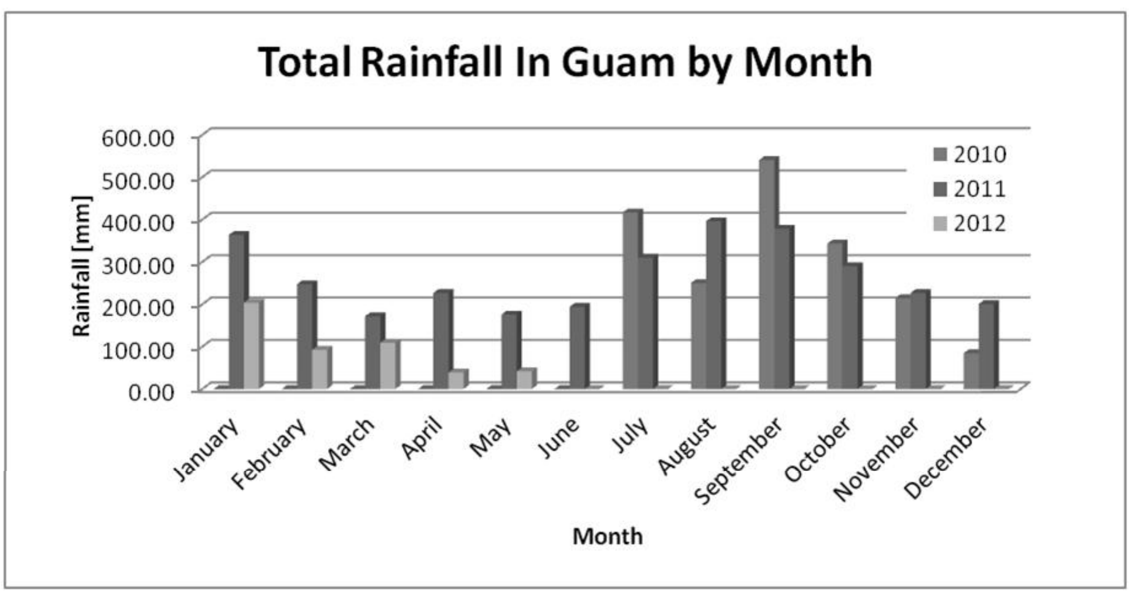

Figure 8: Rainfall Amount in Guam

Given that the performance of any site diversity implementation will be directly affected by the amount of rainfall, the next CDFs highlight the impact that site diversity will have during each of the seasons.

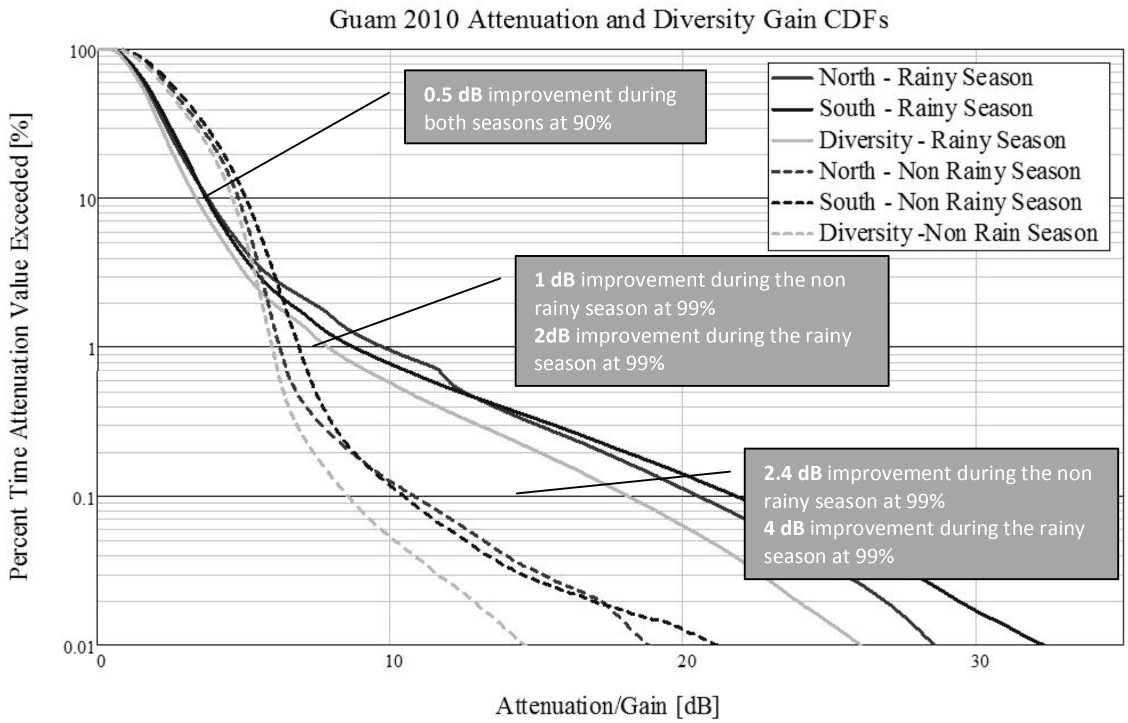

Figure 9: Seasonal CDFs

Looking at the above figure it can be seen that the impact of site diversity will be greater in the rainy season than in the non rainy season. In Guam the most severe rain occurs during the rainy season and even more specifically during the day when there are more frequent and intense rain storms. However, the overall amount and severity of rainfall during the non rainy season is not substantially less due to Guam's equatorial location. These small seasonal variations demonstrate the problem with using a static fade margin at Ka-Band. For example, a fade margin that would provide an availability of 99.9% in the non rainy season would only provide 99% availability in the rainy season.

V. Conclusions

The analysis presented in this paper supports the claim that site diversity can be a highly effective means of rain fade compensation in tropical, high rainfall rate regions. The use of site diversity schemes can improve the overall system margins by as much as 3dB and lead to over 500 additional hours of availability (depending on fade margin). Ka-Band Communication is not only possible in tropical locations such as Guam but can be made practical as well by employing site diversity.

VI. References

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