Assessment of time diversity as a fade mitigation technique in Ka band at a tropical location

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Abstract

Severe rain attenuation at Ka band frequencies over tropical regions is a major concern. In this paper, performances of time diversity technique as a fade countermeasure has been studied over a tropical location in India using simulated attenuation time series. The attenuation time series has been generated using drop size measurements of 30 second integration time from year 2005-2007 using synthetic storm technique. Time diversity gain has been modeled as a function of delay for these locations. It is found that time diversity technique can be a cost effective alternative to other diversity techniques in tropical conditions if link outage shorter than a certain critical length can be tolerated. The study will be helpful for system designing of broadcast and content distribution based service over tropical region.

1. Introduction

Severe rain attenuation is one of the major limiting factors for use of Ka band and above in future communication systems[1]. Typical fade mitigation techniques are not reliable for providing desirable system availability. Different Fade Mitigation Techniques (FMT) are studied worldwide to overcome this problem. Conventional FMT like adaptive power control is not capable of make up this severe fade associated with heavy rain. In general, the rain attenuation increases with frequency and rain rate. In tropical regions, fading greater the 10 dB occurs in Ka band for a significant percentage of a year. A fade of above 20 dB is very common features of this region and sometimes it goes up to 50-60 dB in Ka band [2]. Compensation of these types of severe fade is not possible by any means and the only way to mitigate the fade is by avoiding technique [3].

There are several FMT techniques are used for this purpose like site diversity, satellite diversity, frequency diversity and time diversity [3-4]. The diversity techniques actually bypass the fading channel by means of switching over to other non-fading channel. Site diversity and satellite diversity are efficient but not very cost effective. Separate hardware are required for the implementation of these types of FMT techniques. Also, the calculation of optimum inter-site separation for site diversity is not an easy task, particularly in absensce of actual experimental measurements [5]. This is particularly a critical issue for tropical regions where rain characteristics differs significantly from that of temperate regions [6-7]. Similarly, satellite diversity is also not economical for such purpose. On the other hand, frequency diversity reduces the data rate and bandwidth by switching to low frequencies during heavy rain fade condition. But, decision making for switching is also a very complicated process.

In time diversity (TD) technique, attenuated signal is retransmitted after certain time lag in favorable channel condition[8]. This technique is based on the temporal behavior of rain. Rain is very inhomogeneous in time. The repeated transmissions effectively avoid the severe fade in this way. Thus time diversity technique can effectively reduce the link margin required to guarantee specified service availability. The cost effectiveness of this technique is due to the fact that no separate hardware is required for this purpose. In tropical regions, severe rain is mainly occurring due to convection process. Convective rain is characterized by heavy rain in a short time span. For this reason, TD technique may be very useful over tropical region and got attention in recent times. However, the TD technique is applicable only for the services where a link outage shorter than a certain critical length can be tolerated. Content distribution service is one of such example where it could be very effective.

The TD technique is comparatively a less studied technique than other FMTs. This is mainly due to the reason that some application does not tolerate any outage and time diversity cannot be used for such applications. But, this technique is very promising for applications where link outage can have no effect up to some predefined threshold time. For example, TCP based service can tolerate continuous outage of 55 seconds and content distribution service may be able to tolerate link outage of an hour before the connection is lost. In general, this technique may be particularly very useful for broadcast applications at Ka band and above.

A very few attempts have been made to study the effectiveness of this technique [9], particularly over tropical regions. As per author's knowledge, this is the very first attempt to study time diversity technique in Indian tropical region.

Ka and V-bands communication satellites are scheduled to provide the backbone to the smart city initiative and 5G mobile communications over India. Recently, Indian Space Research Organization (ISRO) launched a Ka band beacon transmitter with GSAT-14 satellite to study the extent of rain attenuation on Ka band signal over these regions. Different meteorological parameters like rain rate, drop size distribution, wind speed is being measured at different location for this experiment in addition to the signal strength measurements. For this study, performance of time diversity technique is estimated with simulated fade data using drop size distribution (DSD) measured over Shillong, a hilly location in North-Eastern part of India.

2. Methodology

2.1 Experimental Details

The rain is measured using an impact type disdrometer, (JW-RD80) at Shillong, India. This location receives an average annual rainfall of about 3385 millimeters. The rain in this location occurs throughout the year due to monsoon circulation as well orographic condition. Moreover, frequent heavy rain occurs at this location due to convective activities.

Disdrometer measures the raindrop size distribution (DSD) in the range of 0.3 mm to 5 mm in 20 size classes. The data are measured with a 30 second integration time. The data collected during the experimental period are validated against the nearby tipping bucket rain gauge and micro rain radar measurements.

The rain attenuation and rain integral parameters are estimated from the measured drop size distribution. The synthetic storm technique is used to convert the rain rate time series to the attenuation time series.

2.2 Rain attenuation estimation

The rain attenuation time series is generated from rain rate using Synthetic Storm Technique (SST). SST assumed a frozen flow condition of the rain system originally conceptualized by Drufuca [10] and further developed by Matricciani [11]. It was reported to perform very well for individual rain events where the satellite link is aligned with the motion of the storm. In SST, the rain attenuation due to rain layer and melting layer are estimated separately and integrated over the slant path according to the translational speed of the storm. Using SST, the rain attenuation is calculated for a hypothetical links at 60º E for Ka band frequencies at 30 GHz. The rain height is taken as 4.5 km and specific rain attenuation is estimated using ITU-R P. 618 [12].

A typical rain attenuation event is shown in Figure 1. It can be seen that if the system can tolerate an continuous outage of 15 minute, the minimum link margin required for service availability is only 10 dB as shown by the line. In comparison, if no outage is desirable, 18 dB fade margin is required for such case.

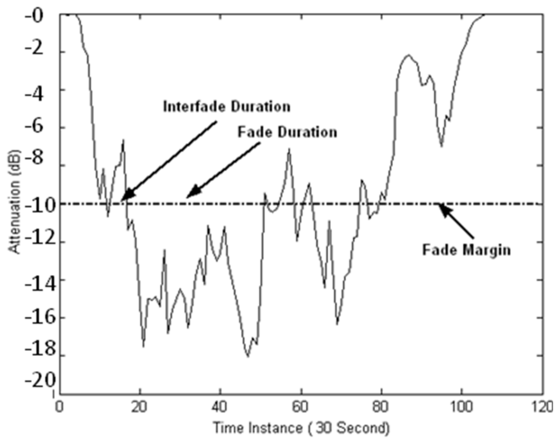

Figure 1: Typical rain attenuation occuring in India at 30 GHz.

Due to the high variability in the temporal behavior of rain, rain attenuation duration is usually modeled by statistical methods. It can also be seen from the Figure 1 that higher fade margin means shorter outage time. ITU-R recommendation for characterization of fade lengths is based on the observed fact that the fraction of fade time which exceeds a given length is independent of the attenuation threshold. The shorter fade lengths are modeled in a power law form, whereas the long fade durations are modeled with log-normal distribution. However, the validity of the ITU-R models needed to be verified over tropical regions where convective rain covers a major portion of the heavy rain periods.

In the present work, the event duration is not directly studied, rather focused on the performance of the time diversity technique as FMT. The time diversity gain is defined as the difference of attenuation threshold A_t required in a time diversity scheme to the attenuation threshold A for the same link availability percentage without any FMT. The link is counted as lost for the entire outage duration once the outage duration exceeds the permitted outage duration. The attenuation threshold

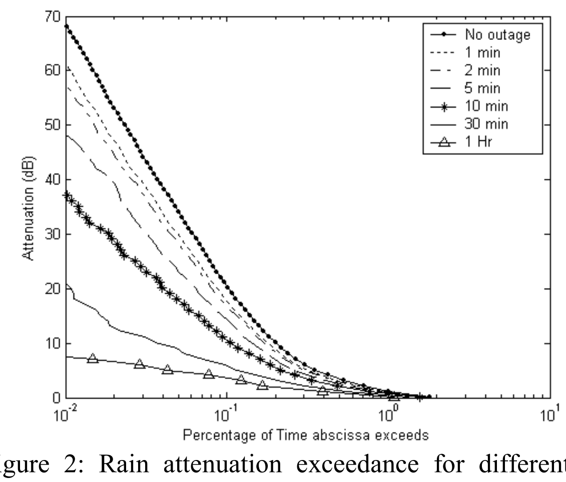

Figure 2: Rain attenuation exceedance for different outage tolarance configuration

A_t is obtained as the total time spent in fades of permitted outage duration is equal to the specified service outage time.

3. Results

In Figure 2, the percentage exceedance of rain attenuation for an average year is shown with different tolerable outage time. The maximum rain attenuation up to 50 dB is calculated only to emphasize that attenuation above that is very difficult to compensate. It clearly shows that as the tolerable outage time increases the minimum required link margin considerably decreases.

Figure 2 also implies that for maintaining 99.99% system availability without any FMT requires fade margin of 70 dB for Shillong. In comparison, only 38 dB fade margin is sufficient with TD technique with 10 minute tolerable time span. Hence, a 32 dB diversity gain can be achieved in such configuration without any additional infrastructure or cost.

In Figure 3, time diversity improvements have been shown with varied delay time for different link availability percentages. It can be seen that significant diversity gain can be achieved with ~10 minute outage tolerance. The diversity gain is more for higher link availability criterion. The figure also indicates that the diversity gain will not significantly increase if the time duration increases more than one hour.

4. Conclusions

Time diversity technique is a very useful technique in comparison to other FMTs for mitigation of high rain attenuation encountered in tropical locations in a cost effective manner. The performance of this technique has been studied at Shillong, a tropical location in India, with Ka band rain attenuation derived from the actual rain rate time series. Results indicate a 10 minute outage tolerance

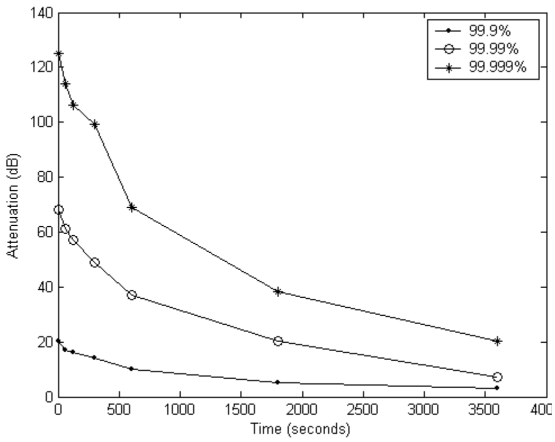

Figure 3: Variation of required fade margin with outage tolarance time for maintianing the minimum link availivility

will significantly lower the fade margin requirement at this location. The improvement in diversity gain is also observed to be greater at high rain attenuation value than the low rain attenuation value. The study will help in choosing TD as a suitable FMT for broadcasting and content distribution service over tropical region.

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