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Assessments of Time Diversity Rain Fade Mitigation Technique for V-band Space-Earth Link Operating in Tropical Climate

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***Abstract*—Satellite communication systems are moving towards greater capacity. Millimeter wave frequency offers a large bandwidth allocation, requires small antenna size and should not experience congested spectrum environment. Nonetheless, rain posses a grave threat to such satellite communication links especially in tropical region where the hydrometeors can severely affect the signal. Rain is the factor that typically limits the implementation or use of higher frequencies for satellite communications in this region. Time diversity is a promising mitigation technique to countermeasure such impairments. It is envisioned that the technique will not be requiring extensive auxiliary's equipment. This paper outlines the likely improvement of a future V-band frequency space-Earth link using proposed time diversity (TD) technique. The analyses relating to the performance prediction of a projected satellite communication link in a tropical climate environment assimilating TD scheme are also included. The recovery strategy and its associated equations were deduced reflecting the likely memory capacity requirement of TD. The knowledge will be incorporated accordingly at the receiver with hopes to mitigate attenuation due to rain endured by the propagation path.**

***Index Terms*—satellite communications, fade mitigation techniques, time diversity, and millimeter wave**

I. INTRODUCTION

Since 1965, the reaches and capabilities of satellite communications grow intensively in terms of usages and offered services. At the first preface, satellite communications was used to provide telephony services. The trend of the services provided by satellite then diversifies into the area of broadcasting services. It gradually expanded to TV broadcast distribution, direct-to-home (DTH), internet trunking, broadband access and fixed satellite services (FSS). HDTV and video-on-demand (VOD), are two of the examples of the current services offered in demand by most customers. The HDTV is progressively replacing standard TV [1]-[3]. Satellite communication system is the most viable system to convey information over vast distances or regions, where the conventional systems i.e. terrestrial TV and telephony connectivity are inaccessible.

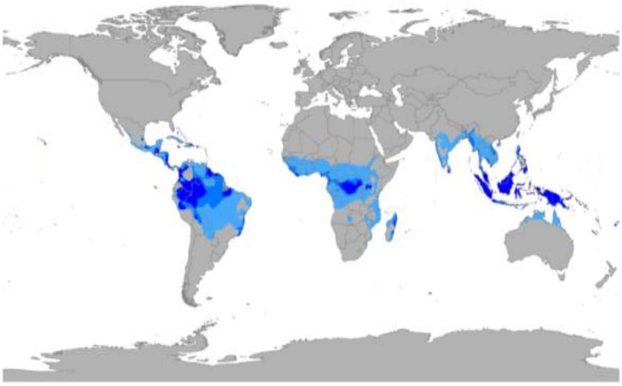

Figure 1. Tropical regions world map [10]

Advancements and evolvements of satellite communication services are forming a contemporary dimension in the requirement of new higher frequencies for satellite communication links. In the future, the communications system will be required to operate at higher frequencies, inevitably in frequencies above 10 GHz. The frequencies are indeed higher than the traditional C-band and Ku-band frequency which is in line with Shannon's capacity theorem, in order to enable the link to meet larger capacity requirements, high data rates and speed for the advance multimedia satellite communication and broadcasting system [4] and [5] However, the propagation of radiowave signal at these frequencies will be subjected to acute attenuation due to precipitation, ice melting layers, clouds, fog, and gaseous absorption [6] and [7]. At high frequency, the propagating signal is undeniably sensitive to rainfall; and rain fade degrades the system availability and performance of satellite communication system [8] and [9]. Hence, this becomes the factor that bounds the

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implementation of high frequency on satellite systems. Rain attenuation is the highest contributor of link impairment within the tropospheric region. The challenge is more apparent in the tropical regions where rainfall is copious throughout the year. The tropical regions can be identified as blue coloring shaded portrayed in Fig. 1.

II. TIME DIVERSITY TECHNIQUE

Fade mitigation technique has been introduced as a countermeasure technique in order to minimize the induced attenuation effects and to improve the space-Earth link's performance. Several diversity techniques have been explored and exploited as means to overcome rain fade. Numerous investigations had been carried out to identify the best probable technique of mitigating rain fade to improve the signal performance [11]-[17]. Time diversity seems to be more promising technique to be implementing in space-Earth path in terms of benefits and cost. The main novelty of this technique is that it will not require major modification of satellite equipment, redesigning of the established hardware nor involves complicated synchronization procedures [18]. This is a technique that can be considered extremely cost effective. It does however require a large memory unit to temporarily store data at the earth terminal before it is being compounded. Nevertheless, there is evident market trend where higher frequency satellites are planned and rapid decreases of price of high capacity home-use memory, such as HD, together with higher performance CPU [19]. The implementation is realistic, undeniably practical, and inexpensive and somewhat presents less challenges compare to other diversity techniques.

In TD, the information or signal is being transmitted twice with appropriate time delay in between transmissions. The receiver will then store the information in the memory. The next sequence signal will be compared with the previously stored signal. The best signal will be directed to the display. The motivation for the continual interest in TD as feasible fade mitigation technique was based on the fact that the most rain events usually have limited time span [20]. Fig. 2 shows the underlying theory of how this method can be implemented in space-Earth link.

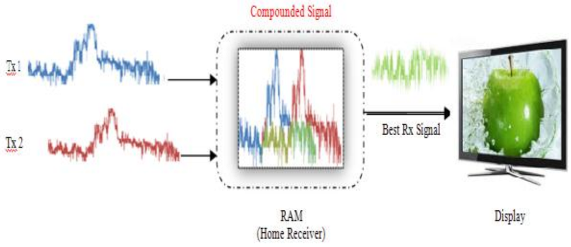

Figure 2. TD conceptual implementation on space-Earth link

In this paper, the performance prediction of TD for future space-Earth link operating at 38 GHz in Malaysia was studied. Latest ITU-R model [21] was used as a reference model for space-Earth path and the parameters involve in attenuation prediction procedures is shown in Fig. 3. The parameter and calculation involved can be referred in [22].

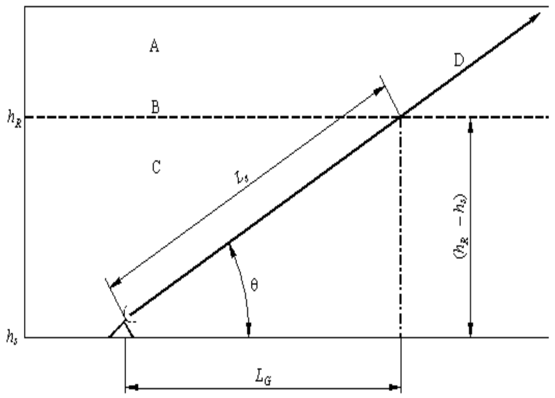

Figure 3. Schematic presentation. A: frozen precipitation, B: rain height, C: liquid precipitation, D: Space-Earth path, *LG*: horizontal projection, *LS*: slant-path length, *hr*: rain height, *hs*: station height, : elevation angle [22]

III. EXPERIMENTAL SETUP

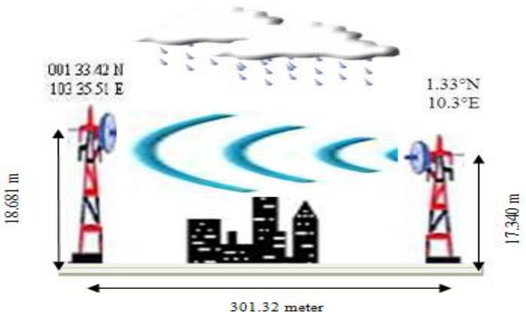

Figure 4. Terrestrial link experimental setup for 38 GHz

Fig. 4 above illustrates microwave link at V-band frequency set up established in UTM, Skudai, Johor Bahru [23]. A 38 GHz experimental Ericsson MINI-LINKS was installed with 0.6 m diameter antennas covered by radomes, with the horizontal polarization. The antennas were separated 300 m apart from one another. The heights of the antennas were 18.681 m and 17.340 m respectively. The transmitter was installed on a tower located at 103.38˚E and 1.33˚N. The receiver was positioned on a rooftop at 103.35˚E and 1.33˚N. The line of sight of this set up was at approximately 18 m above sea level (ASL). The setup transmitted 38 GHz signals on 24-hour basis, 365 days per year. The automatic gain control (AGC) output level of the RF unit was interfaced with a PC through a data acquisition card. During clear sky condition data were sampled every 1-minute and during rainy condition and during rainy events, the sampling time will change to every second. One year of data was recorded from April 1999 to March 2000.

Possible rain induced attenuation impairment to be experienced by a V-band link at Johor Bahru was generated. In identifying the probable performance of TD on such space-Earth link, the terrestrial link was converted in the form of space-Earth link. The conversion involves appropriate scaling of the two setups. The conversion scaling factor was determined as in equation (1). With the knowledge of real effective path length of satellite link, L_E, the value is divided by the microwave distances.

$$ScalingFactor = \frac{2.19896km}{300m} = 7.329 \qquad (1)$$

From (1), the measured attenuation value on terrestrial link was been multiplied by seven-time in order to compute the new attenuation value for space-Earth link path.

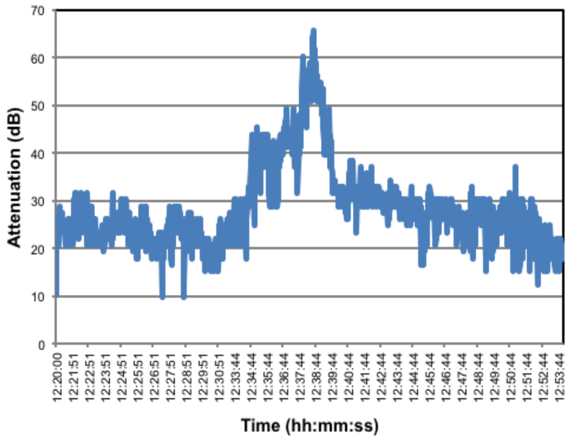

Figure 5. Typical time series of rain event (Recorded on 30th October 1999)

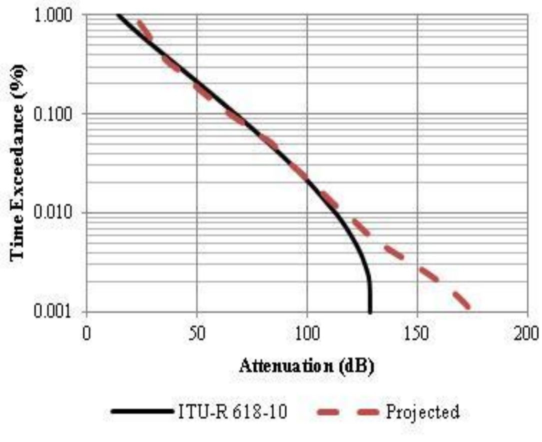

Figure 6. ITU-R prediction and 38 GHz attenuation comparison

Fig. 5 denotes a recorded time series of a rain fading event on one of the days during the measurement campaign. The event was measured and recorded on October 30 1999. Form the figure; for 2.2km space-Earth link path, the highest attenuation is 65.73 dB. Comparisons are being made with ITU-R model. Fig. 6 depicts the cumulative distribution of rain attenuations for 38 GHz frequency band compared with ITU-R model. The assessment is beneficial for extracting a convenient numerical model for an ideal TD gain for a system. There are slightly differences between measured and estimated value. At less 0.01% of time, the ITU-R model underestimated the attenuation induced in such system.

IV. DATA ANALYSES

The studied involves the evaluation of rain attenuation for 12 month of data. To represent the long term of attenuation data, cumulative distribution function was being used and it is the most effective way. The processed data have been analyzed into daily, monthly and annual CDFs. The CDF for various interests of time delays was also being computed in order to obtain the desired TD gain on space-Earth link. Linear regression method has been used to assess the CDs improvement as a recovery strategy.

V. RESULT AND FINDINGS

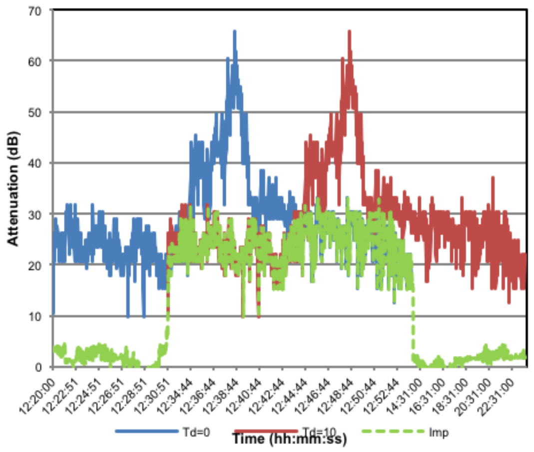

Figure 7. 10 minutes time delay implementations on space-Earth link

Fig. 7 illustrated the implementation of a probable 10 minutes delay for specific day of rain events. As stated earlier, TD is a technique based on time tolerant. The original transmission signal is plotted as the blue curve. The time-diversity approach involves the action of re-transmitting the same signal 10 minute later. Whilst enduring a rainy condition, the signal will be experiencing attenuation that may even lead to service interruption. The delayed signal is redrawn in red color. Comparison then can be made between the original signal and the delayed signal. In this particular instance, the green curve indicates the improvement of signal level at the particular time. Considering the fade margin of the system is 40 dB, the signal is experiencing 65.73 dB for over 5 minutes of time. However, with the implementation of TD, the improvement on the attenuated signal can be defeated.

Twelve-months of rain event data from April 1999 to April 2000 were analyzed. Subsequently, the monthly CDs and annual CDs were computed in order to identify the improvement of the attenuation level on space-earth path with and without TD implementation. These is done to identified the required fade margin for a given time exceedance and the percentage outage of link availability [24]-[26]. Fig. 8 exemplifies the monthly rain fade CDs for 38 GHz space-Earth link. According to [24]-[26], the rain-induced attenuation is concern to the intensities of the experienced rainfall rate. From the figure, it can be deduced that, at time exceedance of 0.1%, April 2000 has the highest attenuation level which is 171.5 dB while April 1999, has the lowest attenuation level, approximately 115.5 dB. Additionally, the most rain event for most of the time fraction was detected on month of October 1999.

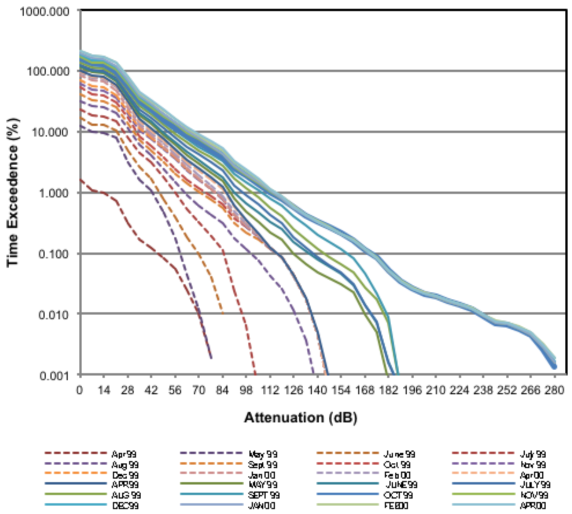

Figure 8. Monthly CD for 1 year of data

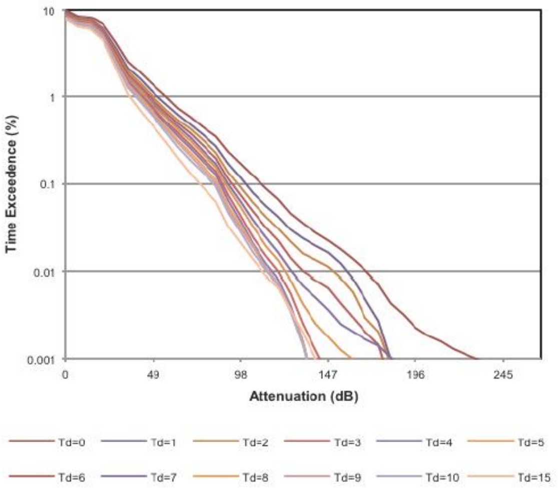

Figure 9. Annual CD for several of time delay

Fig. 9 indicates the annual CDs for various time delay (Td=0,1,2,3,4,5,6,7,8,9,10,15) of 12-months of data. From the figure, at 0.1%, time exceedance the highest attenuation level is 168 dB for Td=0. If the TD was being considered, at Td=1 minute, the highest attenuation level at 0.1% time exceedance is 161 dB, while at Td=10 minute, the attenuation level approximately 112 dB. The differences of both value with Td=0 minute, the differences is 7 dB and 56 dB respectively. These values show that, the attenuation level is respectively changed with time delay.

VI. TD GAIN

For any diversity technique, the parameter that is usually used to determine the performance is diversity gain. Diversity gain is defined as the difference between path attenuation associated with single terminal and diversity mode of operation for a given percentage of time [24]-[26]. Meanwhile, TD gain is defined as dB differences between the signal level which with and without time delay implementation. Mathematical expression of diversity gain is given by [24]-[26]:

$$G(p) = A_0(p) - A_{td}(p) \tag{2}$$

where $G(p)$ is diversity gain, A_0 is the signal without time delay and A_{td} is the signal with time delay. The diversity improvement factor, I denoted by:

$$I(A) = \frac{p_0(A)}{p_{td}(A)} \tag{3}$$

where $p_0(A)$ is the percentage time associated with original distribution and $p_{td}(A)$ is the percentage of associated with diversity distribution which both must be taken at the same value of attenuation.

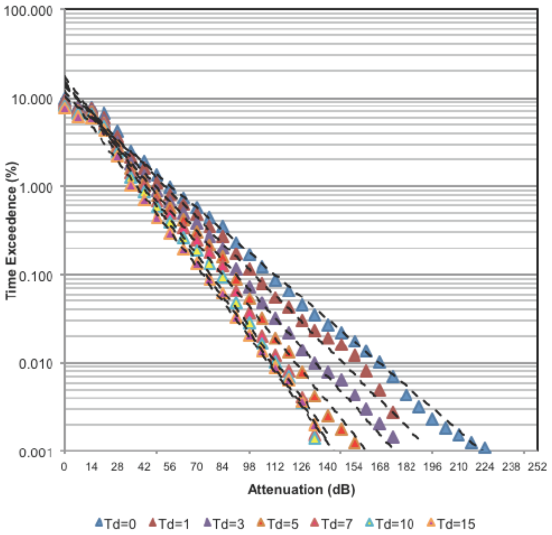

Figure 10. Diversity gain as a function of delay

The TD gain for the projected 38 GHz space-Earth path is showed as in Fig. 10. From this figure, it can be deduced that the diversity gain is changing respectively with the delay time, where the outage percentage of time exceeded decreases as time delay increases. There is significant and increasing diversity gain for delays between 1 and 15 minutes. The attenuation and time delay improved cumulative distributions can be represented by the below equation:

$$P(A) = \beta \exp(-\alpha A) \tag{4}$$

where α and β coefficients' values are given as in Table I. Coefficients α and β which are time delay dependant coefficients. This equation is important to indicate the required memory capacity on the ground receiver.

TABLE I. ALPHA AND BETA COEFFICIENTS FOR SPACE-EARTH LINK

Time Delay (Min)	α	β
0	0.291	14.129
1	0.341	19.039
3	0.379	20.607
5	0.416	22.508
7	0.464	27.792
10	0.468	24.811
15	0.458	18.966

For further assessment, the linear regression was performed to estimate the relationship between the selected time delay with α and β coefficients. The relationship is portrays as in Fig. 11 below.

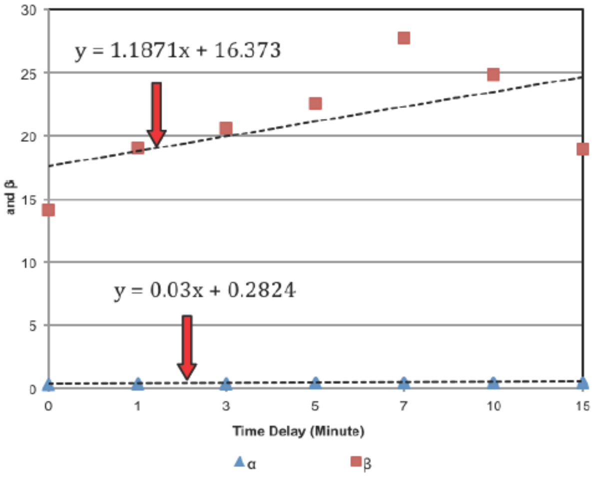

Figure 11. Estimation of α and β values for various selected time delays

VII. CONCLUSION

TD is a technique that involves the retransmission of the information after certain delay to moderate poor condition. This technique does not require extra expensive installations on the satellite end. It does require only minor upgrade to existing home receiver involving incorporation of memory bank, which after all can be considered trivial in terms of its price. This TD technique can be considered as most cost effective option. Moreover, this technique involves only a single unit of satellite link and reception component. On the downside this technique does occupy two channels at the same time for the transmission and re-transmitting actions. The findings can be used for new space-earth link employment all over the world including tropical regions in order to provide higher quality of broadcasting services.

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