A Satellite Link-Like Bit Error Model Based on the Received Signal Level for Link Simulator's Error Implementation

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https://doi.org/10.15017/1516215

出版情報：九州大学大学院システム情報科学紀要. 11 (1), pp.1-6, 2006-03-24. 九州大学大学院システム情報科学研究院

九州大学大学院
システム情報科学紀要
第11巻 第1号 平成18年3月

Research Reports on Information Science and
Electrical Engineering of Kyushu University
Vol.11, No.1, March 2006

A Satellite Link-Like Bit Error Model Based on the Received Signal Level for Link Simulator's Error Implementation

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(Received December 9, 2005)

Abstract: This paper proposes the bit error generation algorithm based on data from experiments. According to the rain intensity, it uses the received signal, the coefficient of variation and the variation of the coefficient of variation during its processing stage. The generated and raw bit errors are compared. The proposed algorithm is an important element for the development of in-door experimental test environment.

Keywords: Satellite communication, Simulator, Bit error generation, Received signal, Link model

1. Introduction

Low cost and high data-rate communication link for real-time multimedia and internet application is becoming more in demand. Therefore the Ka-band(30/20 GHz) and above frequencies satellite links are now considered for the achievement of high data-rate and error-free services. However, these frequencies are subject to severe climatic effects, especially rainfall, which sometimes disable any communication for a period of time and bring down an efficient use of automatic repeat request (ARQ) protocols on satellite link.

In some existing systems, the fading problems are solved by providing an extra power margin to the system. The required link margin is about 10-20dB at these frequencies with a large fade duration depending on the rain region. If this power is supplied for a long period of time, the system will turn out to be inefficient. Other solutions to this problem are offered by the development of new protocols or the improvement of existing one. In order to develop such protocols, it is necessary to conduct some experiments. However, the experimental condition is not permanently available and the experiments on satellite links are costly. Therefore, an indoor apparatus, which can simulate the satellite links, can be used efficiently as the key tool for the development and improvement of satellite compatible protocols. Since simulators used for modern digital communication systems are mostly based on the occurrence of the bit error during the transmission process, we need a satellite link-like bit error model.

For this purpose, many time-series satellite link-like received signal generators have been presented in Ref. 1) and are successfully used for other simulation routine such as diversity simulator[1)]. Some satellite link-like bit error simulators have been developed and presented. However, these simulators use an Additive White Gaussian Noise (AWGN) to generate the channel error[2),3)]; as a result, they are not necessarily suitable for practical cases. We therefore need an efficient channel model of rain fading for computer simulation. As the frequency increases, the rain fade dynamic on the propagation path becomes complex and difficult to be modelled using a simple time-series generator based on a distribution function. A. Paraboni et al.[4)] observed two types of simultaneous fade duration phenomena (as well as rain fade phenomena): fast phenomena and slow phenomena. Each of these phenomena is characterized by a specific distribution and both cannot be modeled by a single fade probability distribution function.

This paper aims to present and evaluate a bit error generation algorithm based on the statistical analysis of the received signal level from experiments.

2. VSAT Experimental System

As shown in **Fig. 1**, the experimental system used for the data acquisition consists of one rainfall intensity sensor and three Very Small Aperture Terminal (VSAT) of 1.8 m diameter directed toward JCSAT-1B communication satellite at the geostationary orbit of longitude 150°E. These terminals

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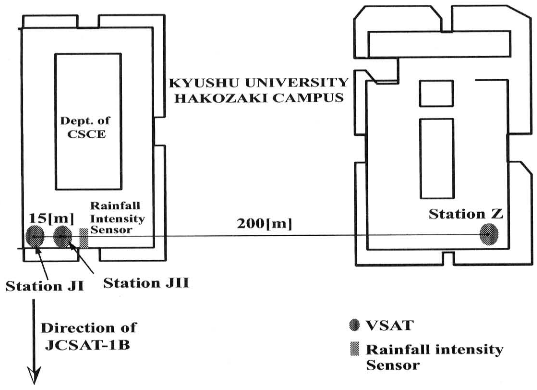

Fig. 1 Experimental system's location.

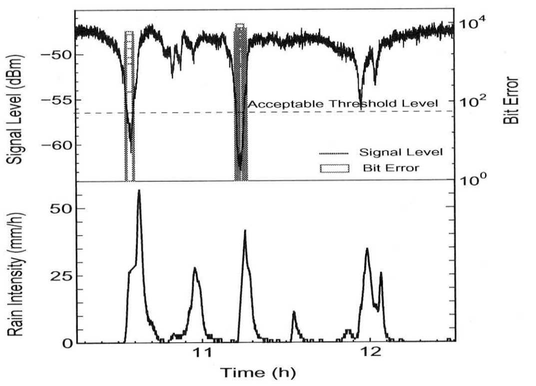

Fig. 2 Bit error and signal level cause-and-effect relation under rainfall.

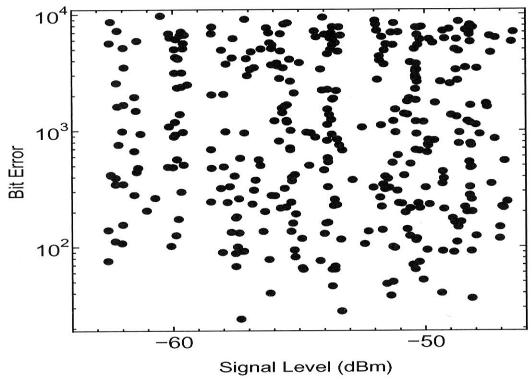

Fig. 3 Scatter plot representing the random variation of bit errors collected as a function of signal level during rainfall. The collection is made within 1 second with bit rate 64 Kbps.

are located in Hakozaki Campus of Kyushu University, Fukuoka, and are being used to conduct several experiments for earth-satellite link clarification in Ku-band (14/12 GHz) since 1997. To avoid multipath fading contribution, the VSATs and the rainfall intensity sensor are installed on top of 2 buildings and separated by about 200 m as shown in **Fig. 1**. In this paper, these stations are called Station JI, Station JII, and Station Z.

3. Data Collection and Analyzed Data

During experiments, one of the VSATs is used for data transmission to the satellite and all of them receive the returned signal. The modulation mode used is the Quadrature Phase-Shift Keying (QPSK) with coding rate $r = 1/2$ and the transmission rate is 64 Kbps. The experimental system observes and records the rainfall intensity every second through a rainfall and the received signal level every 0.2 second using a spectrum analyzer. Occurred bit errors are recorded every 2 seconds during which, the first 1 second is utilized for data transfer, and another 1 second is used for data processing and storage. It is assumed that the occurred bit errors are due to the entire signal level within data transfer period; hence, the received signal level corresponding to the occurred bit error is obtained by averaging out the signal level within the instant of data communication. Collected data are stored in two personal computers. Since the data transfer takes place every second, the system sents 64 Kbits within this period. The occurred bit errors are the total bit errors collected within the data transfert period. Hence the Bit Error Rate (BER) in this paper is obtained by using the following equation: $\mathrm{BER} = \mathrm{BitError}/64 \cdot 10^3$.

Bit errors and received signals used for the development of a bit error generation algorithm have been collected from June to September in 2001 and 2002 (Four months each year). These periods have been chosen according to the raining map of Kyushu, Japan, which is known to be the rainiest in the sub-region. In our analysis, we also use the rainfall data to ensure that the attenuation of signal level is due mostly to rainfall. All along the following evaluation, we note that the standard level is defined as the minimum value of the monthly standard level of the received signal level under no rain condition during the period of studies and for each station.

4. Description of the Statistical Link Model

To model a statistical relation between bit errors and received signal levels, we made two observations: 1) The received signal was mostly attenuated by the local rainfall (**Fig. 2**), and 2) The bit errors occurred during the attenuation.

From the aforementioned considerations, the received signal level (Sl) and the corresponding bit error (BE) are collected and depicted in **Fig. 3** for the periods of study. As shown in this figure, it may be impossible to obtain a relationship describing the behavior of these two parameters using parametric regression because of their randomness under rainfall. Thus, the appropriate method to be used in this case is the smoothing method (nonparametric regression) [5]. This method is used to the case where the parametric regression is not appropriate and helps us to extract among the data only those that are suspected to be right points.

Let us denote $(\widetilde{BE_i}, Sl_i)$ as a set of fitted points expressed by the occurred bit error and its corresponding received signal level. The time dependent subscript i represents a point defined by BE and Sl. The nonparametric regression model is defined by

$$\widetilde{BE_i} = m(Sl_i) + \epsilon_i \tag{1}$$

The regression curve $m(Sl_i)$ is the conditional expectation defined by $m(Sl_i) = E(BE|Sl = Sl_i)$ and ϵ_i is the noise contribution of the received signal due to scintillation. Here ϵ is a set of normally distributed random parameter defined by $E(\epsilon \mid Sl = Sl_i) = 0$ and $V(\epsilon \mid Sl = Sl_i) = \sigma^2(Sl_i)$, where $E(\cdot)$ and $V(\cdot)$ are the expectation and the variance of the normal random set of variable, respectively. Many methods have been proposed for the estimation of $m(Sl_i)$. For our estimation, we choose the simplest in application called averaging method or moving average filter[6]. According to the method, $m(Sl_i)$ can be described by

$$m(Sl_i) = \frac{1}{N}\sum_{j=-k}^{k} BE_{i+j} \qquad i \geq k \tag{2}$$

where $N = 2k + 1$ is the window size. In this paper, the best window size is found to be $N = 41$. It comes out that this value is optimal for our data because the random white noise is reduced while keeping the sharpest step response (Chap. 15, in Ref. 6)).

The smoothed data are fitted plotted in **Fig. 4** using an optimal fucntion described by

$$m(Sl_i) = \alpha + \beta Sl_i + \gamma Sl_i^2 \tag{3}$$

where α, β and γ values are given in **Table 1**.

Then, by applying $BE_i - m(Sl_i)$ to the raw data, we obtain the normally distributed ϵ_i for each station with the parameters given in **Table 2**. Therefore, when a signal level is given, the occurring bit errors can be estimated using the following relation:

$$BE(Sl) = m(Sl) + \epsilon \tag{4}$$

Table 1 Expectation function fitting parameters per station.

	α	β	γ
JI	-47463.93	-1620.55	-12.57
JII	-47957.78	-1601.46	-12
Z	-45007.20	-1540.35	-11.91

Table 2 Parameters of the normal distribution of random errors for each station.

ϵ	JI	JII	Z
Standard deviation	2920	3039	2830
Mean	-89	-85	-96

Table 3 Standard signal level and threshold level estimated value for each station.

	JI	JII	Z
Standard signal level$\langle Sl \rangle$ (dBm)	-46.74	-47.10	-46.16
Threshold level Sl_{th} (dBm)	-57.34	-57.17	-56.47

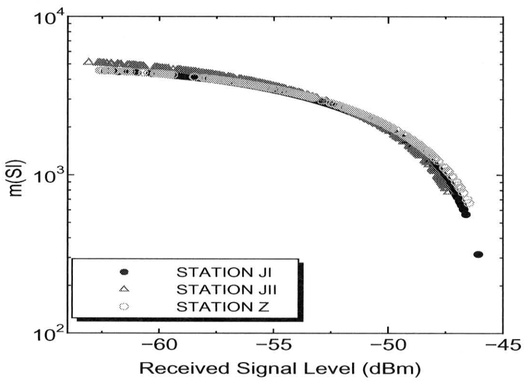

Fig. 4 Evaluation of the expected function obtained from the statistical analysis using the received signal level data.

5. Bit Error Generation Algorithm

Bit error appearances can be located using two parameters. These are

- The threshold level $Sl_{\rm th}$, which represents the minimum attenuation below which bit errors occur quasi-continuously. The obtained threshold levels for each station are given in **Table 3**, and

- The coefficient of variation (COV) which is the mean of a signal over its standard deviation. The standard deviation becomes significant when comparing with the mean (Chap. 2 in Ref. 6)).

These parameters are defined and discussed below.

The bit errors generally occur under certain behavior of the received signal level. Most of the time it appeared when the signal level was lower than Sl_{th}. This state is described by

$$Sl \leq Sl_{\mathrm{th}} \tag{5}$$

We observe that although the received signal level is less than Sl_{th}, bit errors do not occur continuously. Moreover, some rare bit errors are shown in the upper part of the threshold level. In order to locate the appearance of bit errors, we introduce a parameter which can measure the variability of Sl in relation to the mean of the Sl in a short period of time ΔT. The statistical parameter COV is used to compare the relative dispersion in a set of data as shown in **Fig. 5** and defined by

$$COV = \frac{\mathrm{std}\,(Sl)_{\Delta T}}{\langle Sl \rangle_{\Delta T}} \times 100\ \% \tag{6}$$

with
- ΔT: a short period of time before the evaluation of COV,
- $\mathrm{std}\,(Sl)_{\Delta T}$: the standard deviation of Sl, and
- $\langle Sl \rangle_{\Delta T}$: the mean of Sl in ΔT second.

From **Fig. 5**, we can see that the COV has a particular variation and does not follow absolutely the variation of the received signal. This parameter suddenly increases with the signal impairments. Furthermore, it keeps a low value with low attenuation or high and quasi constant attenuation. In this work, we take ΔT as 30 s. This value is found from the observation that, using our database, the COV curve is not greatly altered below 30 s. This may be related to the coherence time of the rain fading. Using the COV and with the respect of Eq. (5), we observe that although the signal keeps a high level, bit errors mostly occur if the Eq. (7) is satisfied.

$$COV \leq COV_{\max} \tag{7}$$

Here $COV_{\max}$, is the maximum COV below which bit errors occur quasi-continuously. From the observation of the experiment data, we estimate the $COV_{\max}$ to be 15.086 %.

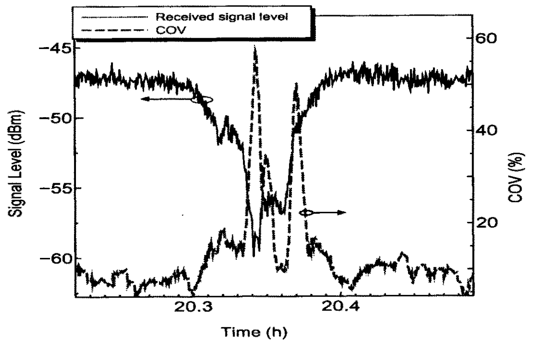

Fig. 5 Example of coefficient of variation and the received signal level interdependence.

Algorithm 1 Step-by-step description of different processes of bit generation

```
1:  Set COV_max
2:  Set Sl_th
3:  Set ΔT
4:  repeat
5:    Input t, Sl
6:    Do Moving Average
7:    Compute BE(Sl), COV
8:    Compute ξ = ΔCOV/ΔT
9:    if Sl ≤ Sl_th then
10:     if COV ≤ COV_max then
11:       Goto 16:
12:     else
13:       Be ⇐ 0 {No generation of bit error}
14:     end if
15:   else
16:     if ξ ≫ 1 then
17:       Be ⇐ BE(Sl) {Generation of Bit Error}
18:     else
19:       Be ⇐ 0 {No generation of bit error}
20:     end if
21:   end if
22:   Print t, Be
23: until end of Sl input
```

We observe generally for both $Sl > Sl_{\mathrm{th}}$ and $Sl \leq Sl_{\mathrm{th}}$ that bit error occurrence during a sudden fluctuation of the signal level (sudden abrupt change of COV) is guided by the following equation.

$$^{\Delta COV}/_{\Delta T} = \frac{COV_i - COV_{i-1}}{T_i - T_{i-1}} \gg 1 \quad [\mathrm{s}^{-1}] \tag{8}$$

Equation (8) gives the time-to-time variation of the signal due to rainfall attenuation. It measures the amount of noise added to the signal for a short period of time. In this algorithm, the quantity $^{\Delta COV}/_{\Delta T}$ is estimated to be 13.6 $[\mathrm{s}^{-1}]$ in the upper part ($Sl > Sl_{\mathrm{th}}$) of the threshold level, and 23.9 $[\mathrm{s}^{-1}]$ in the lower part($Sl \leq Sl_{\mathrm{th}}$). By combining Eqs. (1), (3), (5), (7) and (8), we derive the bit error generation algorithm described by **Algorithm 1**. This algorithm describes, step by step, the bit error generation processes. We note that it uses a FIFO buffer to temporarily collect the received signal level for the evaluation of the COV. A relaxation time of ΔT is indispensable for the setup of initial parameters. Then, many tests are performed in order to detect the appearance of the bit error and evaluate its size. We note that parameters such as Sl_{th} and the $COV_{\max}$ depend on the local site and should therefore be determined and set up for each station.

6. Evaluation of the Model Using the Received Signal Level

We generated bit errors for a short time period using the received signal level according to the proposed algorithm. **Figure 6** compares our result with the corresponding experimental bit errors. Let X_g be the number of generated bit errors and X_g' be the number of generated bit errors matched in position and almost in size with raw bit errors. The $X_g - X_g'$ denotes the overestimated bit errors. We define

- the percentage of matched or simulated bit errors over the total amount of generated bit errors by $(X_g'/X_g) \times 100$ and
- the percentage of overestimated or over-generated bit errors by $[(X_g - X_g')/X_g] \times 100$.

The algorithm used with COV has simulated 75% of occurred bit errors while only 25% of generated errors were overestimated. On the other hand, when COV was not used, about 58% of raw data has been followed, and about 42% of data are over-generated (**Fig. 6**). We can observe that, although bit errors are extremely random in size, their position is well located using the COV. Then the COV reduces the continuity of the generated bit error under the condition of $Sl \leq Sl_{\mathrm{th}}$.

We carried out a long time simulation of the bit error generation during the period of studies to test our algorithm in a statistical point of view. **Figure 7** displays the distribution of bit errors at the three stations. In these figures, we compare the result of our simulation to the raw data distribution and the log-normal fitting of the raw data. As well known[7], the received signal level data expressed in dB and the collected bit errors mostly follow a log-normal distribution with the probability density function (PDF) defined by

$$\mathrm{PDF} = \frac{\exp\left[-\frac{1}{2}\left(\frac{\log(BE)-\mu}{\sigma}\right)^2\right]}{\sqrt{2\pi\sigma^2 BE^2}} \tag{9}$$

where the parameters μ and σ for each station are given in **Table 4**. We can observe that the obtained results are close to the fitted curve.

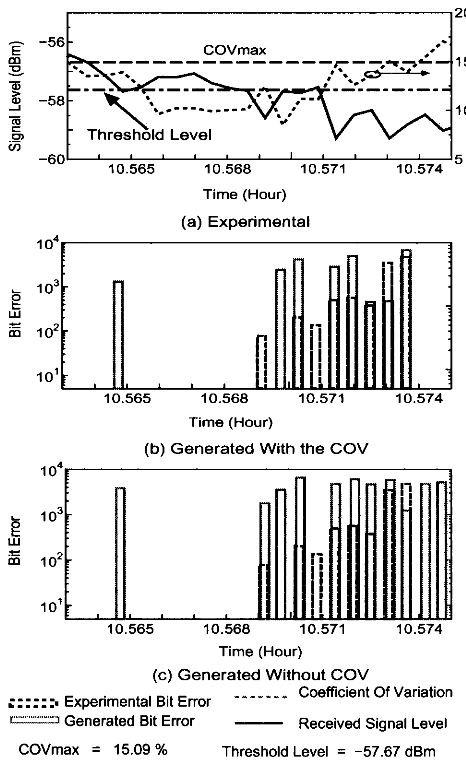

Fig. 6 Short period simulation of the obtained algorithm. The $COV_{\max} = 15.09$ and the threshold level $Sl_{\mathrm{th}} = -57.67$ dBm with the same condition as in **Fig. 3**.

In order to present the analysis of the time dependence of our model, we illustrate in **Fig. 8** the percentage of time exceeding abscissa of the total bit error obtained by simulation and experiment. Because of the random behavior of the bit error on satellite link, it is really difficult to generate a bit error with the same distribution as the raw data. The difficulty is due to the fact that some bit errors are indirectly related to the received signal level fluctuations. We can observe that the simulated results agree well with those from raw data except for the region below about 100 in size of bit errors. The difference comes from the fact that our model has been developed using bit errors due to rainfall; therefore the algorithm cannot generate small size bit errors produced by a random fluctuation of the links. The algorithm could be improved by the addition of an AWGN algorithm for the generation of such a small size bit error.

7. Conclusion

In this paper, we have presented and evaluated a method to generate bit errors using incoming signal level for a local station. The method produces the

Table 4 Log-normal fitting parameters of bit errors in our station during the period of studies.

	Station JI	Station JII	Station Z
Standard deviation σ	1.594	1.564	1.551
Mean μ	6.724	6.952	6.810

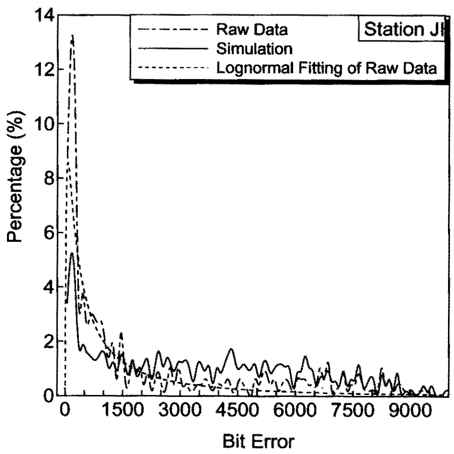

Fig. 7 Experimental and generated bit error distributions, where the experimental data was obtained during June to September in 2001 and 2002 at Kyushu University with the same condition as in **Fig. 3**. Similar results were obtained for JII and Z.

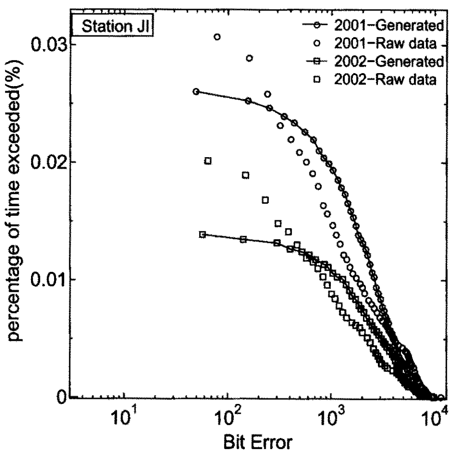

Fig. 8 Percentage of time exceed of the experimental and generated bit errors, where the experimental data are the same used in **Fig. 7**. Similar results were obtained for JII and Z.

bit errors based on statistical parameters obtained by analyzing the received signal threshold level and the signal fluctuations. The results of simulations have shown a good agreement with the experimental data except for small size of bit errors. The method may be improved by taking into account the AWGN bit errors generation algorithm at the computer implementation.

The proposed algorithm can also be used in satellite link simulators as an active bit error generator for a permanent observation and evaluation tool of the link which will therefore accelerate the development of efficient ARQ protocols and routines for satellite link .

Our method has not yet been extended to other regions in the world because it is difficult to find an experimental station which can collect the 3 databases of signal attenuation, bit error and rain fall. However, this analysis open a new horizon to new experimental protocols and analysis.

Acknowledgments

This research was partly supported by the 21st Century COE Program 'Reconstruction of Social infrastructure Related to Information Science and Electrical Engineering' in 2004.

References

1) U.-C. Fiebig, J. Lemorton: "Overview of available channel models for time series generation," 1st International Workshop of COST-Action 280, Malvern, UK, 2002.

2) S. Horan and R.Wang, "Design of a Space Channel Simulator Using Virtual Intrumentation Software," IEEE Trans. on Inst. and Meas., Vol. 51, No. 5, pp. 912-916, October 2002.

3) K. K. Choi, G. Maral, and R. Rumeau,"Space link simulator for development of a new packet-based space communication protocols," Int. J. Satell. Commun. Vol. 17, pp. 383-398, June 1999.

4) A. Paraboni and C. Riva, "A New Method for the Prediction of Fade Duration Statistics in Satellite Links above 10 GHz," Int'l. J. Satell. Commun., vol. 12, pp. 387-394, 1994.

5) T. P. Ryan, Modern regression methods, NY: J. Wiley, 1996.

6) S. W. Smith, The Scientist and Engineer's Guide to Digital Signal Processing, Second Edition, California Technical Publishing, 1999.

7) ITU-R Recommendion P.1057-1, "Probability distribution relevent to radiowave propagation modelling," (1994-2001).