AN APPROACH FOR BER DETERMINATION USING LOGGED AERONAUTICAL TELEMETRY DATA

Jimmy B Tamakuwala[2], Souvik Sonar[1], Avijit Jena[1]
[1]Integrated Test Range, DRDO Chandipur
[2]Defence Research and Development Organization
jb.tamakuwala@hqr.drdo.in, *souvik.sonar@itr.drdo.in*, *avijit.jena@itr.drdo.in*

Abstract

BER is regarded as the link-performance metric in a digital communication system. It is a function of E_b/N_0 and is dependent on the modulation scheme used. This relation is often used in prediction of ground telemetry systems performance for a mission configuration. However, there is no objective way of comparing the post flight results, as BER measurement in a flight test is not practically feasible for want of transmitting sufficient reference bit patterns. In this paper, an indirect way of computing BER and, in turn, link E_b/N_0 is proposed for a PCM/FM link based on the frame synchronised data logged by the ground telemetry equipment. Using known quantities like bit rate and frame rate, a quantity defined as frame loss rate is computed. Applying the relations between frame loss probability, frame sync pattern and SFID information in the PCM format, an approach for bit error probability is demonstrated based on field data. By using a sliding window over a fixed length of data, BER for the entire flight duration can be determined as a function of flight time with the step size of the length of data window.

E_b/N_0, BER, PCM/FM modulation, Telemetry

INTRODUCTION

In digital communication, bit error rate (BER) represents the ratio of number of received bits that are flipped due to impairment in channel characteristics such as AWGN, inter symbol interference, synchronization error, etc. to the total number of bits transmitted. The BER can be taken as bit error probability (P_e) provided that it is computed for sufficient number of symbols. In [1], it has described several factors that may improve the BER viz. bit energy, modulation scheme, forward error correction (FEC) code, etc.

For a particular channel (AWGN channel with and without *fading*) and modulation scheme, the P_e is function of received E_b/N_0 (*energy per bit to noise spectral density*). The E_b/N_0 parameter can be used for comparing the performance of different digital modulation schemes without taking into account the factor of modulation bandwidth. The minimum value of E_b/N_0 required for reliable communication is given as $E_b/N_0 > ln(2)$ in dB [2].

The technique of simulating the BER from E_b/N_0 as input on random bits for a satellite communication link is described in [3] and [4]. The basic idea of BER measurement is simple, that is, to send a known data stream through the communication channel and compare the output to the input. The pseudorandom noise (PN) codes [5], [6] and [7] are used as known data for the measurement of BER. The problem with this approach is that to make high degree of accuracy in measurement it is required to use long PN codes. This in turn, takes a long time and extra bandwidth, which is not, afforded in aeronautical telemetry applications. Furthermore in aeronautical telemetry applications, the challenge also lies in the fact that the data frame does not have any reference on receiver side.

In this paper, we present a method for BER determination using telemetry data for AWGN channel in a particular mission scenario. We first discuss the overall system model on which the proposed approach have been formulated. Subsequently we highlight a brief overview of the structure of an aeronautical telemetry data format as per IRIG-106 standard. We then discuss a method for computing frame loss probability, P_{fl}. Thereafter we compute P_e with a novel approach by generating a look up table which is followed by determination of E_b/N_0. The comparative analysis of the calculated E_b/N_0, which shows the quality of computed BER value to the recorded AGC of the receiver during the corresponding flight test is presented in Results section.

THE SYSTEM MODEL

In this study, we have considered flight-test data for PCM/FM systems operating in S-band. The coherence time and the maximum Doppler spread are inversely proportional to each other. The maximum Doppler spread, that is, maximum Doppler shift is given as $f_m = v \times f_c/c$, where v is the velocity of air-borne vehicle, f_c is the transmission frequency and c is speed of light in free space. In this study we have consider two cases. In first case, the bit rate considered is *1 Mbps* and the velocity is *5 km/s* whereas, for the second case, the bit rate is *3.5 Mbps* and velocity is *4 km/s*. For both the cases, the f_c is taken as 2250 MHz. With these figures, in both the cases, the coherence time of the channel is very large in comparison to the bit period and therefore the channel is considered as slow fading channel. The coherence time from the maximum doppler spread, f_m is obtain using Clarke's model [8] as given by Eq. 1

$$T_c \simeq \frac{0.423}{f_m} \tag{1}$$

In the first scenario, the approximated value of T_c comes around $1.1272\text{e}{-5}$ s with $fm = 37.526$ KHz which is very large compared to the bit period whose value is $1\text{e}{-6}$ s. Also in the second scenario, the value of T_c is $1.4090\text{e}{-5}$ s with $fm = 30.0208$ KHz and the bit period is $2.8571\text{e}{-7}$ s which is very small compared to the value of T_c henceforth it is a slow fading channel.

In aeronautical telemetry application, LoS component is always present and is comparatively strong in comparison to its reflected components. Henceforth, the channel is characterized by Rician distribution. The ground telemetry station tracks the air-borne vehicle using either *monopulse* or *E-scan* tracking technique. The received RF signal is demodulated and then fed to PCM decommutator system. The PCM decommutator does frame synchronization based on IRIG-106 specified frame synchronization word pattern, displays critical parameters and logs the telemetry data of all sub-systems for post mission analysis. The overall schematic model is depicted in Fig.1

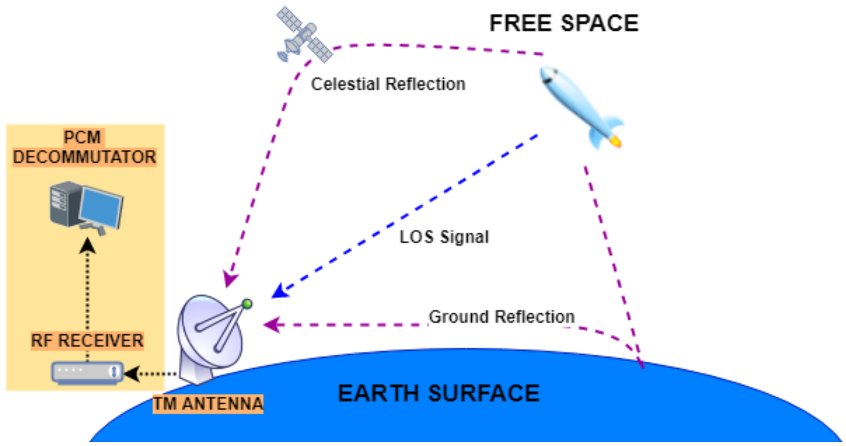

Figure 1: The Overall Schematic Model

AERONAUTICAL TELEMETRY DATA FORMATTING

The air-borne telemetry system formats the data as per IRIG-106 specified format, comprising minor frames and a group of sequential minor frames forming a major frame. The minor frames are numbered from 1 to n and each minor frame consists of m words. The numbering of minor frames is also called as sub-frame identification (SFID) which is a part of data in every minor frame. The length of sub-frame identification word may vary as per the data word length, l and number of words selected for SFID for a particular minor frame. The end of a minor frame is identified by frame synchronization (FS) words. The length of frame synchronization words may vary from 16-bits to 32-bits as per IRIG-106 recommended standards. Fig.2 consists of a PCM telemetry data format with one major frame consisting of n minor frames.

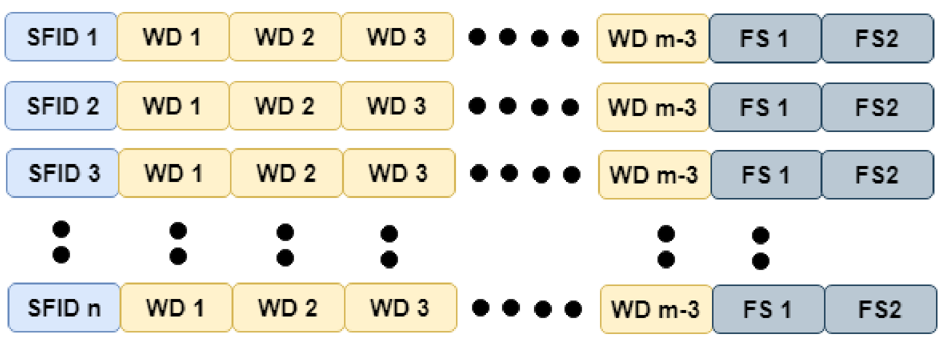

Figure 2: IRIG-106 Telemetry PCM Frame format

The data logger system logs the frame-synchronised and time tagged PCM data based on the reception of two important parameters, namely, FS word and SFID word. In this approach, it is assumed that the data transmission is over slow fading channel. Henceforth, any number of bit-errors in FS and SFID words due to channel characteristics can be taken in to consideration for determination of quality of channel (E_b/N_0) over which the telemetry data is being transmitted.

COMPUTATION OF FRAME LOSS PROBABILITY, P_{FL}

The block diagram of the system under study is shown in Fig.3. In this block diagram dashed rectangle box can be modelled as binary symmetric channel with bit error probability (P_e).

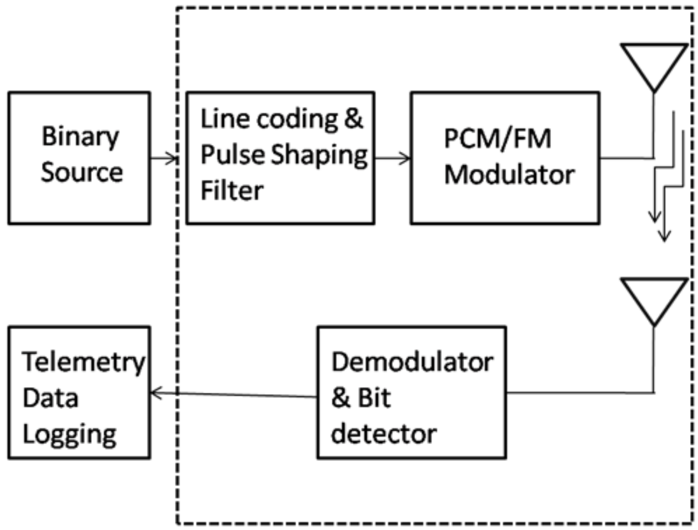

Figure 3: Block Diagram of the System Model

The frame loss probability (P_{fl}) is the ratio of the number of received telemetry data frames in a given time interval to the total number of frames in that time interval. The minor frame loss probability for successive time intervals is computed using the *sequential window approach* from the logged telemetry data. The time interval, t_{int} is chosen based on the bit rate of transmission. The information regarding the total number of frames lost during a particular time interval in a test is obtained from the frame loss report. The total number of expected frames between the time interval is thereafter computed using the bit rate and the frame size. We then segment the time interval based on user input and henceforth compute the probability of missing telemetry frames, P_{fl}. The algorithm for computing the value of P_{fl} from the logged telemetry data is mentioned in Algorithm 1.

COMPUTATION OF BIT ERROR PROBABILITY, P_E

The value of P_{fl} computed in section is used for calculating the bit error probability, P_e using Eq. 2

$$P_{fl} = (P_{fse} \times P_{sfide}) + (P_{fse} \times P_{sfidc}) + (P_{fsc} \times P_{sfide}) \tag{2}$$

where,
P_{fse} = Prob. of Frame Sync error
P_{sfide} = Prob. of Subframe id error
P_{fsc} = Prob. of correct Frame Sync pattern
P_{sfidc} = Prob. of correct Subframe id

Algorithm 1 Algorithm for Computing P_{fl}

Input: Telemtry_Frame_info, logged_binary_data
Output: frame_loss_report, P_{fl}

Initialisation :
start_time, st=0
end_time, et=0
no_of_lost_frames, nlf=0
P_{fl}[]=0, l, m, bit_rate(br), t_{int}
Extract the frame_loss_time, flt
frame_acq._time, fat
no_of_lost_frames,nlf
Compute frame_time, ft = $(l \times \text{m}) \div (\text{br})$
LOOP Process
for $i = 1$ to $end\_of\_data\_file$ with interval t_{int} **do**
    Compute st = first frame with valid FS & SFID
    Compute et = st + t_{int}
    Assign nlf = No. of frames lost during t_{int}
    Compute frame_tot_expected, fte = (et - st)$\div(ft)$
    Compute P_{fl} = nlf$\div fte$
end for
return P_{fl}

The value of P_{fse}, P_{sfide}, P_{fsc} and P_{sfidc} can be computed using Eq. 3 and Eq. 4 as mentioned in [9]

$$P_{fse/sfide} = \sum_{j=k+1}^{N} \binom{N}{j} P_e^j (1 - P_e)^{(N-j)} \tag{3}$$

$$P_{fsc/sfidc} = (1 - P_e)^N \tag{4}$$

where,
N = Sync /Subframe id Pattern length in bits
k = Permissible number of bit errors in the Sync/Subframe id word (*default* = *0*)

Since it is a closed form equation, we generate a look up table, (*LUT*) mapping the values of P_{fl} with P_e. Thereafter the nearest value of P_e is derived from the table, corresponding to the value of P_{fl} computed in section for a given user-defined time segment. The algorithm for generating the look up table, (*LUT*) using the value of P_e from P_{fl} is mentioned in Algorithm 2.

The algorithm for getting the value of P_e from P_{fl} from *LUT* is mentioned in Algorithm 3.

Algorithm 2 Algorithm for generating the *LUT*

Input: N, k, ber_int, P_e_arr
Output: P_{fl}_arr, *LUT*

for P_{fl}_arr = 1e−6 to 0.99 with interval *ber_int* **do**
    Compute an array of $P_{fse/sfide}$ and $P_{fsc/sfidc}$ using Eq. 3 & Eq. 4
    Compute an array of P_{fl}_arr using Eq. 2
    Assign *LUT(1)* = P_e_arr & *LUT(2)* = P_{fl}_arr
end for
return *LUT*

Algorithm 3 Algorithm for getting P_e from P_{fl}

Input: *LUT*, P_{fl}
Output: P_e

Compute the minimum distance between input P_{fl} and *LUT*(2)
Assign the value of *LUT*(1) to P_e
return P_e

DETERMINATION OF E_B/N_0 USING P_E

The value of E_b/N_0 from the derived P_e in section for successive time segments is calculated using Eq. 5 as mentioned in [10]

$$P_e = Q\left(\sqrt{\left(\frac{1}{2}\frac{E_b}{N_0}D^2_{min}\right)}\right) \tag{5}$$

where,
$Q(.)$ is the error function representing tail probability of normal distribution, and
D^2_{min} is the minimum squared Euclidean distance as a function of modulation index, h. [11]
For *PCM/FM* modulation with modulation index, h = 0.715, the value of D^2_{min}= 2.43

RESULTS AND CONCLUSIONS

For this study we have considered two scenarios. In first case, a fast moving target with bit rate equal to *1 Mbps* is considered. For the analysis, the telemetry logged data of *200 s* duration is considered and time interval of *0.25 s* is considered for computation of P_{fl}. For second case, a slow moving target with *3.5 Mbps* bit rate is considered and analysis is done for *1400 s*. The P_{fl} is computed for *0.5 s* interval. We have measured the performance of the purposed method for various bit-rates and also with respect to slow moving *vs* fast moving air-borne vehicles. For a given mission scenario, we have computed the BER performance of ground telemetry station as a function of slant range using Friss equation from the recorded AGC signals of the telemetry antenna system and compared the same using Eq. 5.

Fig.4 shows the result for *1 Mbps* data rate and fast moving target, whereas, Fig.5 shows the result for *3.5 Mbps* data rate and slow moving target.

Figure 4: Comparison analysis with Bit Rate = 1 Mbps

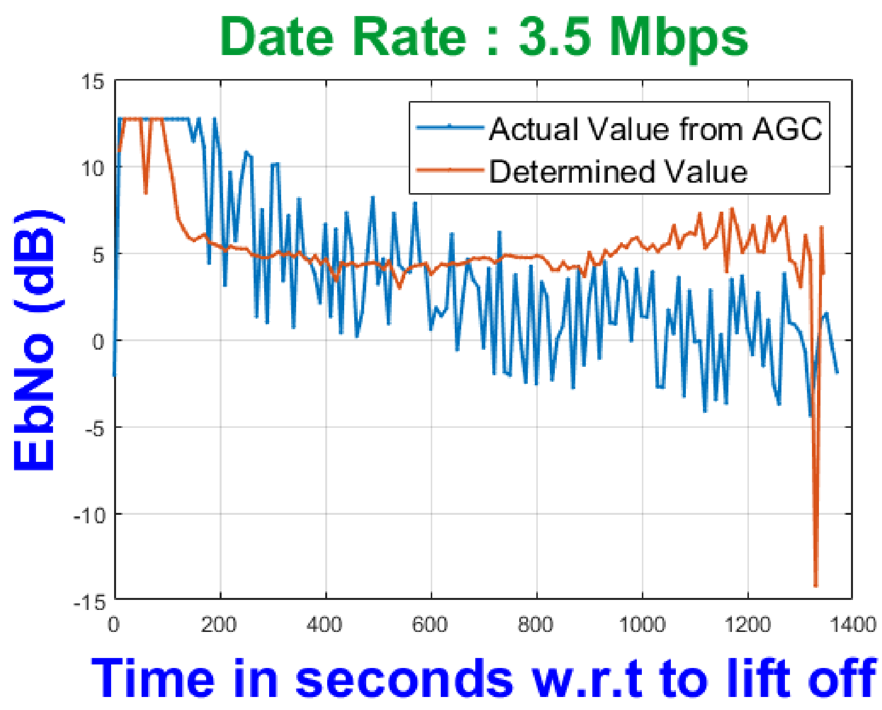

Figure 5: Comparison analysis with Bit Rate = 3.5 Mbps

In Fig.4 and Fig.5, any values higher than 12.69 dB is being limited to 12.69 dB that corresponds to the BER of $1\mathrm{e}{-6}$, which is the acceptable BER for error free data transmission in case of aeronautical telemetry application. The actual value computed from AGC has some effects of rotational dynamics of the moving air borne vehicle which has not been taken into account in calculation while determining the E_b/N_0 from P_{fl}. We can also observe that the determined E_b/N_0 value from P_{fl} is almost at the mean level with respect to the plot of the value computed from AGC of the antenna system. Henceforth it can be concluded that in both the scenarios, the computed value of E_b/N_0 from P_{fl} is matching to the value that we arrive from the real mission scenario very closely.

FUTURE SCOPE

The BER determination can be further improved by applying time interval in moving average manner instead of using sequential window of fixed length. By choosing appropriate FPGA and other hardware, this method can be executed for real-time determination of E_b/N_0 during any flight test scenario.

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