International Conference on Space Optics—ICSO 2006

Noordwijk, Netherlands

27–30 June 2006

Edited by Errico Armandillo, Josiane Costeraste, and Nikos Karafolas

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International Conference on Space Optics — ICSO 2006, edited by Errico Armandillo, Josiane Costeraste, Nikos Karafolas, Proc. of SPIE Vol. 10567, 105673U · © 2006 ESA and CNES
CCC code: 0277-786X/17/\$18 · doi: 10.1117/12.2308114

Proc. of SPIE Vol. 10567 105673U-1

CONDITIONS FOR THE OPTICAL WIRELESS LINKS BIT ERROR RATIO DETERMINATION

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ABSTRACT

To determine the quality of the Optical Wireless Links (OWL), there is necessary to establish the availability and the probability of interruption. This quality can be defined by the optical beam bit error rate (*BER*). Bit error rate *BER* presents the percentage of successfully transmitted bits. In practice, *BER* runs into the problem with the integration time (measuring time) determination. For measuring and recording of *BER* at OWL the bit error ratio tester (BERT) has been developed.

The 1 second integration time for the 64 kbps radio links is mentioned in the accessible literature. However, it is impossible to use this integration time for singularity of coherent beam propagation.

1. PHENOMENONS INCREASES THE *BER* IN OWL

For the fiber optics communications, there is possible to determine the *BER* on the main carrier to noise ratio. In comparison with optical fiber links, in OWL there are other phenomenons put into effect that increases the *BER*. The most important beam disturbances should be caused by three following reasons:

- a) The optical intensity extinction caused by absorption on molecules and aerosols.
- b) The optical intensity fluctuation during rainy, windy or foggy days.
- c) The beam interruptions by flying insect and birds.

It is appropriate to select the adequate long integration time according to the mentioned causes. This period is different for the various geographical locations.

2. OPTICAL LINK QUALITY PARAMETERS

To describe the quality of the optical link, two parameters are commonly used: The bit error rate – *BER* and the carrier to noise ratio – *CNR*. These parameters of the error rate and the signal to noise ratio

are closely related to each other. By measuring the *CNR* for specified conditions we can obtain the *BER* values and determine the link quality.

The bit error rate definition [2]:

$$BER \approx \frac{n_e}{N_B}, \quad (1)$$

where n_e indicates the number of error bits and N_B is the total number of received bits.

For the On-Off keying, the *BER* according to the several preconditions is given by (2). Those preconditions are: The “1” and “0” bit are transmitted with the same probability and the decision level is optimally set, then there is the same probability that the badly received bit is “1” (when transmitted was “0”) and vice versa.

$$BER = \frac{1}{2} \operatorname{erfc} \left(\frac{Q}{\sqrt{2}} \right), \quad (2)$$

$$Q = \frac{\mu_1 - \mu_0}{\sigma_0 + \sigma_1}, \quad (3)$$

where μ_1 and μ_0 are the mean values for the “1” and “0” respectively with the standard deviations of σ_1 and σ_0 . The *BER* solution depending on received signal parameters [3] and the precondition of $\sigma_1 = \sigma_0$ is shown (4).

Fig. 1. Received signal pattern.

$$\begin{aligned}
 BER &= \frac{1}{2} \operatorname{erfc} \left(\frac{1}{\sqrt{2}} \frac{\mu_1 - \mu_0}{\sigma_0 + \sigma_1} \right) = \\
 &= \frac{1}{2} \operatorname{erfc} \left(\frac{1}{\sqrt{2}} \frac{2P_{rxa} - P_n(t)}{2\sigma} \right) = \\
 &= \frac{1}{2} \operatorname{erfc} \left(\frac{1}{\sqrt{2}} \frac{P_{rxa}}{\sqrt{P_n^2}} \right)_{P_n(t)=0},
 \end{aligned} \quad (4)$$

where P_{rxa} is level of received optical power, P_n is noise level, erfc determines error function (matlab...).

$$\begin{aligned}
 BER &= \frac{1}{2} \operatorname{erfc} \left(\frac{1}{\sqrt{2}} \frac{P_{rxa}}{P_n} \right) = \\
 &= \frac{1}{2} \operatorname{erfc} \left(\frac{1}{\sqrt{2}} \operatorname{CNR} \right)
 \end{aligned} \quad (5)$$

The error rate measuring should be realized using one of the following ways [1]:

First way is *In-service testing*. The measurement is made in progress with the standard using of the link. The testing sequence is transmitted in its own channel (for example 64 kbps). The same acquired *BER* characteristics are considered for all of the channels in the same system.

Second way is *Out-of-service testing*. The link is used for transmitting the testing sequences only. This way of measurement is used most likely for science and research. The systems based on this principle are known as the *BER* testers or BERT.

3. BIT ERROR RATE TESTER

Fig. 2. Block schematic diagram of BERT.

BERT operates following method: Pseudo random bit sequence (PRBS) is transmitted one-way through the optical link. PRBS is generated according to the ITU standards. The synchronization signal is recovered at the receiver's site and the BERT compares the received data accuracy. Error bits are recorded into the format which includes the time index and more important data. These data are transmitted through the RS232 interface into the computer. Nowadays, we are monitoring the *BER* for four OWL's in selected city locations. With the obtained records, we are able to establish the advanced OWL statistical model. This model uses the measured data to determine how much of the time contains the error seconds and also determines the duration of the optical link unavailability.

The tester for the error rate measurement was designed and assembled for the E1 interface systems. The pseudo random bit sequence PRBS generator generates data sequences of the $2^{15}-1$ length according to the ITU-T O.151 standard. Data transfer speed is 2,048 Mbps. The ERROR detector is synchronized to the received sequence. After the receiving of the correct 64 bits long sequence, the receiver is designated as synchronized and ready to monitor the error rate. If there are six or more differences in the received sequence ($BER > 0.094$) the synchronization is broken and the process of synchronization starts again.

Information about the error bit is rendered to the microprocessor to be added into the error report string. Data for each 1 s length cycle are transmitted from microprocessor over the RS232 interface, where they are processed and archived.

The error report string example:

`EeeeePppppBbbbbbb<CR><LF>`,

where:

eeee gives the decimal number of blocks with one or more bad bits in the 1 s long interval (each 1 ms block contains 2048 bits).

pppp gives the total decimal number of 1 ms blocks, the time of broken synchronization.

bbbbbb gives the total hexadecimal number of bad bits in the 1 s long interval.

The bit error rate is measured only in the case when the receiver is synchronized. The sum of *eeee* + *pppp* can be at most 1000. When both *eeee* and *pppp* are non-zero, the number of bad blocks and bits is related to the time interval of $1000 \cdot pppp$ milliseconds.

4. THE DETERMINATION OF *BER* AND THE PROBABILITY OF OWL UNAVAILABILITY

Data acquired through the *BER* tester allow us to determine the unavailability time t_{un} (ms) in the N second long monitored interval

$$t_{un} = \sum_{i=1}^N p_i, \quad (6)$$

p_i is time in milliseconds, when the tester was out of the synchronization in the i -th second, N is the length of the monitored time interval.

The probability of the link unavailability p_{un} (%):

$$p_{un} = \frac{t_{un}}{1000 \cdot N} \cdot 100. \quad (7)$$

The number of milliseconds without error bits t_{ef} for the N second long interval:

$$t_{ef} = 1000N - \sum_{i=1}^N p_i + e_i \quad (8)$$

e_i is the number of 1 ms error blocks in the i -th second. The percentage probability of the errorless seconds is p_{ef} (%):

$$p_{ef} = \frac{t_{ef}}{1000 \cdot N} \cdot 100. \quad (9)$$

The *BER* for the chosen interval can be calculated as

$$BER = \frac{\sum_{i=1}^N b_i}{2,048 \cdot 10^3 \cdot \left(1000N - \sum_{i=1}^N p_i\right)}, \quad (10)$$

where b_i is the total number of errors in the i -th second.

Fig. 3. BERT (E1) fixture and realization.

The STM-1 bit error rate tester for the speed of 155 Mbps is based on the same principle.

Fig. 4. BERT (STM-1) realization.

Fig. 5. BERT (STM-1) fixture.

5. INTEGRATION TIME AND THE BER MEASUREMENT PRECONDITIONS:

While calculating the *BER*, there is the problem how to choose the appropriate time of measurement in order to get the correct *BER* value with the minimal deviation. The mean times considering receiving of 10 errors for the speed of 2,048 Mbps are:

Tab. 1. Presumed time of measurement at 2,048 Mbps:

Presumed <i>BER</i>	Measurement time (s)	Measurement time (days)
$1 \cdot 10^{-15}$	$5 \cdot 10^9$	$56 \cdot 10^3$
$1 \cdot 10^{-12}$	$5 \cdot 10^6$	56
$1 \cdot 10^{-9}$	$5 \cdot 10^3$	$56 \cdot 10^{-3}$

To minimize the mean time, the *BER* tester for the speed of 155 Mbps was developed. If the optical link allows this speed increase, the measurement time will be much shorter. The required times for the same number of 10 errors are:

Tab. 2. Presumed time of measurement at 155 Mbps:

Presumed <i>BER</i>	Measurement time (s)	Measurement time (days)
$1 \cdot 10^{-15}$	$6,5 \cdot 10^7$	700
$1 \cdot 10^{-12}$	$6,5 \cdot 10^4$	0,7
$1 \cdot 10^{-9}$	$6,5 \cdot 10^1$	

Even that, the determined time for receiving of 10 errors is too long for the optical links, if the small *BER* is expected. The different measurement criteria have to be specified. In spite of that, we choose the time of 10 days, which (for the 155 Mbps speed) leads to the following mean error numbers:

Tab. 3. Number of errors in 10 days at 155 Mbps:

BER	10^{-14}	10^{-12}	10^{-9}
Number of errors	≈ 1	130	$130 \cdot 10^3$

This result says that we are able to verify the link error rate for the *BER* up to 10^{-14} or worst.

The year season is also significant. The preconditions for the link error rate determination must respect the season with the worst atmospheric conditions. These conditions became either at the hot cloudless weather or at the foggy days. The fog evokes the slow changes of attenuation; to the contrary the hot weather affects the laser beam scintillations which lead to the beam misspointing.

Probability of the fog appearance and the average temperature in CZ for the constituent months:

Tab. 4. Average month temperatures and frequency of foggy days:

Month	1	2	3	4	5	6
Fog appearance (days in month)	10,6	9,14	7,2	4,3	1,7	0,5
T_{average} (°C)	-2,4	-0,2	3,8	9,1	14,2	17,1
Month	7	8	9	10	11	12
Fog appearance (days in month)	1,2	3,5	8,9	10,6	8,07	7,29
T_{average} (°C)	18,6	18	14,3	9,1	3,7	-0,4

The best month for the error rate testing is September. The precondition of the ample amount of foggy days in combination with high temperatures is accomplished. If the measurement is impracticable, it should be capable to do it in the lab for simulated conditions. The measurement is divided into the three separate parts to be run for 80 hours (1/3 of 10 days) each:

- 1) The simulation of fog: We imitate the middle fog with visual range of 0.5 km, using the 40 dB attenuation per km.
- 2) The turbulent atmosphere: Reached by the thermal heating to get the structural refraction index parameter C_n^2 equal to $10^{-13} \text{ m}^{-2/3}$ adequate to the medium turbulences.
- 3) The clear atmosphere: With no other attenuations.

6. CONCLUSIONS

This work deals with the optical wireless link (OWL) error rate. We point out effects increasing the link error rate. The link between the parameters *BER* and *CNR*, describing OWL quality, is shown.

The next part was focused on the problematic of *BER* and its measurement. The prospective error rate tester realization was presented. This tester works with pseudorandom sequence defined according to the ITU standards. The OWL error rate data are transmitted into the computer to be processed and stored. We showed the possible ways of *BER* calculation, the estimate percentage of link unavailability and the estimate percentage of link errorless run, according to the *BER* measurement. Finally, the advisement, how to measure the error rate corresponding with the real one, was shown.

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