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Recommendation ITU-R F.1605

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Error performance and availability estimation for synchronous digital hierarchy terrestrial fixed wireless systems

F Series

Fixed service

International Telecommunication Union

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Note: *This ITU-R Recommendation was approved in English under the procedure detailed in Resolution ITU-R 1.*

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RECOMMENDATION ITU-R F.1605*

Error performance and availability estimation for synchronous digital hierarchy terrestrial fixed wireless systems

(2003)

Scope

This Recommendation provides the error performance prediction methods for synchronous digital hierarchy (SDH) radio links (paths and sections) with capacities in synchronous transfer mode (STM) from 51 Mbit/s (STM-0) to 622 Mbit/s (STM-4). The prediction methods are based on a theoretically-derived relationship between bit error ratio (BER) and the SDH parameters based on errored blocks (EBs). The methods take into account system characteristics such as burst errors along with the parameters needed for predicting the outage time based on different BER thresholds.

The ITU Radiocommunication Assembly,

considering

a) that synchronous digital hierarchy (SDH) and plesiochronous digital hierarchy (PDH) systems play an important role in current fixed wireless systems;

b) that suitable path planning and systems design methods are needed to minimize the degradation of fixed radio system operation due to propagation effects,

recognizing

a) that Recommendation ITU-R F.1668 established the error performance objectives for real connections;

b) that Recommendation ITU-R F.1703 established the availability objectives for real connections;

c) that Recommendation ITU-R P.530 provides methods to allow the prediction of propagation parameters affecting the planning of terrestrial line-of-sight systems,

recommends

1 that the error performance prediction methods for SDH radio links (paths and sections) set out in Annex 1 should be adopted for planning terrestrial line-of-sight systems in the respective ranges of parameters indicated.

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* Radiocommunication Study Group 5 made editorial amendments to this Recommendation in 2009 in accordance with Resolution ITU-R 1.

Annex 1

Prediction of error performance and availability of line-of-sight SDH radio links

1 Introduction

SDH networks, or synchronous optical networks (SONET), currently allow radio link systems with capacities in synchronous transfer mode (STM) from 51 Mbit/s (STM-0) to 622 Mbit/s (STM-4). International Recommendations and Standards define the error performance and availability objectives for SDH networks. These objectives are media independent, and still have to be met whenever radio forms a part of the network.

The prediction methods given in this Annex are based on a theoretically-derived relationship between bit error ratio (BER) and the SDH parameters based on errored blocks (EBs). The methods take into account system characteristics such as burst errors along with the parameters needed for predicting the outage time based on different BER thresholds. The term “outage” in this Recommendation is defined as the probability that the BER is larger than a given threshold. It should be noted that the outage intensity (OI), defined in § 2.1 is a distinctly different parameter.

2 Error performance and availability objectives

ITU-T Recommendations G.826 and G.827 give the requirements for error performance and availability, respectively. Since these Recommendations give the end-to-end objectives, other recommendations are needed when dealing with actual radio links. In order to apportion the allowances to individual paths with actual hop lengths, operating radio frequency, etc., a number of additional recommendations have therefore been issued dealing with radio as an SDH network element.

2.1 Error performance and availability parameters

ITU-T Recommendations G.826 and G.828 define a set of block-based error performance events and parameters devoted to in-service error performance monitoring of an SDH path (see Note 1). An EB is one in which one or more bits are in error. An errored second (ES) occurs if there are one or more errored blocks or at least one defect such as a loss of pointer (LoP) during a one-second period. A severely errored second (SES) occurs if there are 30% or more EBs or a defect. SES is a subset of ES. Background block error (BBE) is an EB not occurring as part of an SES. Error performance parameters defined are severely errored second ratio (SESR), background block error ratio (BBER), and errored second ratio (ESR).

Each direction of a path can be in one of two states: available time or unavailable time. The criteria determining the transition between the two states are as follows: A period of unavailable time begins at the onset of 10 consecutive SES events. These 10s are considered to be part of unavailable time. A new period of available time begins at the onset of 10 consecutive non-SES events. These 10s are considered to be part of available time. A path is available if, and only if, both directions are available.

The availability parameters defined are: availability ratio (AR) and mean time between digital path outage (Mo). The converse of AR is the unavailability ratio (UR). Thus, $AR + UR = 1$. The reciprocal of Mo is defined as the outage intensity (OI). Thus, $OI = 1/Mo$. OI is regarded as the number of unavailable periods per year.

NOTE 1 – An SDH path is a trail carrying an SDH payload and associated overhead through the layered transport network between the path-terminating equipment. A digital path may be bidirectional or unidirectional and may comprise of both customer-owned portions and network-operator-owned portions (for more information see ITU-T Recommendations G.803, G.805 and G.828).

The definition of block size and error performance events for SDH multiplex section (MS) and regenerator section (RS) are presented in ITU-T Recommendation G.829. The error performance parameters and objectives for SDH MS and RS on individual digital fixed wireless links are given in the ITU-R F-Series Recommendations.

NOTE 2 – The threshold of 30% EBs is defined for SDH path in ITU-T Recommendations G.826 and G.828, while for SDH MS and RS the threshold value is defined in ITU-T Recommendation G.829.

2.2 Objectives for digital fixed wireless digital paths

The error performance objectives given for digital paths at or above the primary rate (2 048 or 1 544 Mbit/s) are different for national and international portions. The specified objectives must be met for any month. ITU-R has adopted objectives for both national and international paths. For the national portion there is a subdivision into three sections. These are: long haul, short haul and access network sections. The allocation of the error performance objectives for the short haul and access sections shall each make use of a fixed block allocation in the range of 7.5% to 8.5% of the end-to-end objectives. The allocation of the objectives for the long haul section shall make use of a distance-based allocation per 100 km and a fixed block allocation in the range of 1% to 2% of the end-to-end objectives. For apportioning these objectives to real digital fixed wireless links consisting of one or more hops, Recommendation ITU-R F.1668 should be used for the international and national portions.

The availability objectives are defined in ITU-T Recommendation G.827. For real digital fixed wireless links consisting of one or more hops the availability objectives for a link forming part of an SDH path at or above the primary rate are defined in Recommendation ITU-R F.1703 for the international and national portions.

3 Predicting error performance and availability

The relationship between the error performance parameters and BER is evaluated employing both random (Poisson) and burst error (Neyman-A) distributions. Modern radio transmission systems, which implement complex modulation schemes, error correction codes, equalizers, etc., tend to produce clusters or bursts of errors (see Note 1). Typical values for high level modulation (e.g. 128-trellis code modulation (128-TCM)) are 10 to 20 errors per burst.

NOTE 1 – A burst of errors is defined as a sequence of errors which starts and ends with an errored bit such that the time between two errors is less than the memory of the system (e.g. the constraint length of the convolutional code, the code size for block code, etc.).

The SDH prediction methods are based on theoretical assumptions relating BER, which is the fundamental parameter of existing prediction methods, to the error performance events ES, SES and BBE. Since the methods are based on BER, they automatically cover both multipath and rain attenuation. In the following paragraphs, some background information is given followed by step-by-step calculation procedures.

The prediction methods for SDH can also be used for PDH with the following choices:

– use the BER_{SES} closest to the transmission rate (Mbit/s), e.g. a VC-12 for a 2 Mbit/s PDH radio;
– use the BER_{SES} as given in Table 1 (the BER_{SES} is under study for PDH, but only minor differences are expected).

TABLE 1

***BER_{SES}* for various SDH paths and MS sections**

Path type	Bit rate supported (Mbit/s)	BER_{SES} (1), (2)	Blocks/s, *n* (2)	Bits/block, N_B (2)
VC-11	1.5	$5.4 \times 10^{-4}\ \alpha$	2 000	832
VC-12	2	$4.0 \times 10^{-4}\ \alpha$	2 000	1 120
VC-2	6	$1.3 \times 10^{-4}\ \alpha$	2 000	3 424
VC-3	34	$6.5 \times 10^{-5}\ \alpha$	8 000	6 120
VC-4	140	$2.1 \times 10^{-5}\ \alpha$	8 000	18 792
STM-1	155	$2.3 \times 10^{-5}\ \alpha$ $1.3 \times 10^{-5}\ \alpha + 2.2 \times 10^{-4}$	8 000 192 000	19 940 801

(1) $\alpha = 1$ indicates a Poisson distribution of errors.

(2) The blocks/s are defined in ITU-T Recommendations ITU-T G.826 and G.828 for SDH path, in ITU-T Recommendation G.829 for SDH sections. Some STM-1 equipment might be designed with 8 000 blocks/s (19 940 bits/block), but ITU-T Recommendation G.829 defines the block rate and size to be 192 000 blocks/s and 801 bits/block, respectively.

3.1 Prediction of SESR

The procedure for predicting SESR is based on the relationship between SES and BER, where the methods for predicting outage defined by a specified BER are given in Annex 1 of Recommendation ITU-R P.530. Generally the SESR is predicted by:

$$SESR = \int_{BER_A}^{BER_B} f_{SES}(x) \quad g_{BER}(x) \ \mathrm{d}x \tag{1}$$

where:

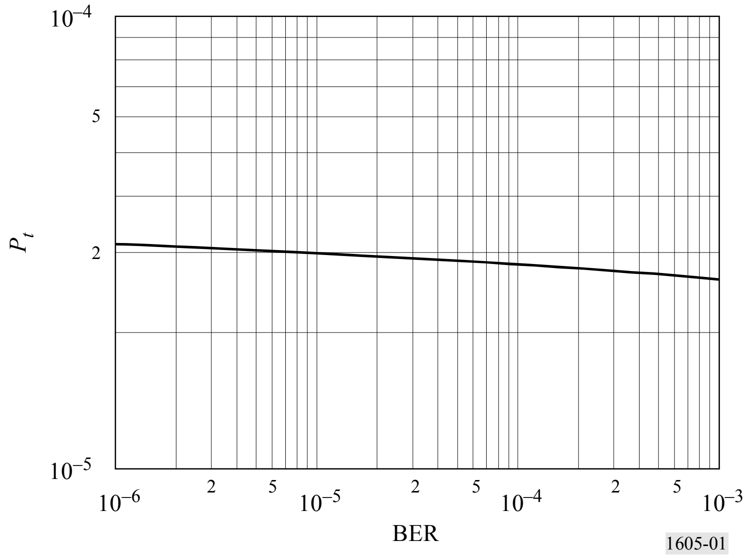
- $f_{SES}(x)$: relationship between SES and the BER
- $g_{BER}(x)$: probability density function (PDF) of BER
- BER_A and BER_B: integration limits (typical values are 1×10^{-9} and 1×10^{-3}).

3.1.1 Prediction of SESR due to multipath propagation effects

The SESR parameter is given by equation (1) where the second term is the PDF of BER. In the case of multipath propagation, the BER is strictly connected to the outage probability P_t, evaluated by the methods in Annex 1 of Recommendation ITU-R P.530. Using appropriate methods for the transmission system considered, the outage probability P_t versus BER can be derived (see Fig. 1 for an example). The function g_{BER} is derived from the applicable figure, similar to Fig. 1 i.e. $g_{BER} = \mathrm{d}P_t/\mathrm{d}_{BER}$.

FIGURE 1

An example of outage probability, P_t, versus BER, due to multipath propagation



In general, the values of outage probability are obtained for only a few values of BER where equipment signature and threshold are known. If an extended set of BER values are available, a more precise curve can be obtained.

The SESR evaluation is made in two steps, first to determine the amount of SES due to EB, and the second to obtain the usually negligible part corresponding to LoP.

The curve of SES due to EB can be approximated by a step function. The BER value, where the SES probability changes from 0 to 1 is denoted BER_{SES}.

$$f_{SES}(x) = \begin{cases} 0 & \text{for } BER < BER_{SES} \\ 1 & \text{for } BER \geq BER_{SES} \end{cases} \tag{2}$$

The value of BER_{SES} normalized to the mean number of errors per bursts α ($\alpha = 1$ for Poisson distribution) is given in Table 1.

Considering equation (2), in the case of SES due to EB, equation (1) becomes:

$$SESR = \int_{BER_A}^{BER_B} f_{SES}(x) \quad g_{BER}(x) \; \mathrm{d}x = P_t(BER_{SES}) \tag{3}$$

Upper limit for SES due to LoP

To evaluate the upper limit, $SESR_{LoPu}$, it is assumed that the probability of SES for BER values less than BER_{SES} is a constant. Then:

$$SESR_{LoPu} = P(SES \mid BER = BER_{SES}) \; (1 - P_t(BER_{SES})) \tag{4}$$

NOTE 1 – The contribution from LoP has been found to be small, and can therefore be ignored.

3.1.1.1 Step-by-step procedure for calculation of SESR due to multipath

Step 1: Calculate the outage probability P_{tSES} for $BER = BER_{SES}$ for the appropriate system, using the outage prediction methods described in Annex 1 of Recommendation ITU-R P.530.

$$SESR = P_{tSES} = P_t\,(BER_{SES}) \tag{5}$$

where BER_{SES} is given in Table 1.

3.1.2 Prediction of SESR due to rain attenuation

Rain may introduce severe attenuation. Most of the time X% when rain attenuation exceeds the threshold A_{SES}, an unavailability condition will occur. The remaining time $100 - X\% = Y\%$ is considered as available time giving rise to SES. The division between available and unavailable time for any climatic region has to be found from experimental measurements.

The process of obtaining the SESR due to rain implies finding the attenuation margin, A_{SES}, of the radio link for a BER, BER_{SES}, where all seconds are SES. Then it is possible to evaluate the percentage of time in the worst month that the rain attenuation exceeds this margin, and finally to evaluate the corresponding annual percentage of time. The SESR value due to rain will be Y% of this probability.

3.1.2.1 Step-by-step procedure for calculation of SESR due to rain attenuation

In the following, a step-by-step procedure for evaluating SESR due to rain is given. The input parameters are: frequency, hop length, polarization, rain zone, transmission power, gain of transmitting antenna, gain of receiving antenna, relationship between received power and BER, SDH path type, and error burst length.

Step 1: Calculate the rain attenuation exceeded for 0.01% of time, $A_{0.01}$, using the method in Annex 1 of Recommendation ITU-R P.530.

Step 2: Calculate the nominal received power without rain attenuation, $P_{RXnominal}$.

Step 3: Using the relationship between the received power and BER (usually obtained from equipment manufacturers) obtain the value of A_{SES}, where A_{SES} is the attenuation margin of the radio link for $BER = BER_{SES}$ (see Table 1).

Step 4: Calculate the annual time percentage, p_{aSES}, that the rain attenuation is larger than A_{SES}, using the method in Annex 1 of Recommendation ITU-R P.530.

Step 5: Translate the annual time percentage, p_{aSES}, to worst-month percentage, p_{wSES}, using the method in Recommendation ITU-R P.841.

Step 6: Calculate SESR from:

$$SESR = Y(\%)\ P_{wSES} \tag{6}$$

where P_{wSES} is the worst-month probability ($P_{wSES} = p_{wSES} / 100$).

NOTE 1 – The value of X is under study; for the time being $Y = 0\%$ is suggested, that is, rain attenuation results in an unavailability of P_{wSES} in the worst month.

3.2 Prediction of BBER

The BBER is evaluated for multipath and rain conditions from:

$$BBER = \int_{BER_A}^{BER_B} f_{BBER}(x) \quad g_{BER}(x) \ \mathrm{d}x \tag{7}$$

where:

$f_{BBER}(x)$: relationship between BBE and BER

$g_{BER}(x)$: PDF of BER

BER_A and BER_B: integration limits (typical values are 1×10^{-12} and 1×10^{-3}).

3.2.1 Prediction of BBER due to multipath

Two alternative methods can be used: a complete one based on the analytical solution of the integral in equation (7), where $g_{BER}(x)$ is derived from the outage prediction model (the applicable figure, similar to Fig. 1) and $f_{BBER}(x)$ is the theoretical relationship for BBE due to BER, and a simplified method based on approximation of $f_{BBER}(x)$ and of $g_{BER}(x)$.

3.2.1.1 Step-by-step procedure for calculation of BBER due to multipath

In this section, a step-by-step procedure based on the simplified prediction model is given.

Step 1: Calculate the outage probability, P_{tR}, for the residual BER (RBER) (typically in the range from $1 \times 10^{-10}$and 1×10^{-13} for the bit rates of 2 to 155 Mbit/s, respectively), using the outage prediction methods described in Annex 1 of Recommendation ITU-R P.530 for the appropriate system:

$$P_{tR} = P_t(RBER) \tag{8}$$

Step 2: Calculate the outage probability at $BER = BER_{SES}$ as in Step 1:

$$P_{tSES} = P_t(BER_{SES}) \tag{9}$$

BER_{SES} is given in Table 1.

Step 3: Calculate the SESR as in Step 1 for multipath (see § 3.1.1.1):

$$SESR = P_{tSES} = P_t(BER_{SES}) \tag{10}$$

Step 4: Calculate the BBER from:

$$BBER = SESR \frac{\alpha_1}{2.8\,\alpha_2(m - 1)} + \frac{N_B\ RBER}{\alpha_3} \tag{11}$$

where:

α_1 = 10 to 30, number of errors per burst for the BER in the range from 1×10^{-3} to BER_{SES}

α_2 = 1 to 10, number of errors per burst for the BER in the range from BER_{SES} to RBER

α_3 = 1, number of errors per burst for the BER lower than RBER

N_B: number of bits/block (see Table 1)

m: slope of the BER distribution curve on a log-log scale for BER in the range from BER_{SES} to RBER, given by:

$$m = \left| \frac{\log_{10}(RBER) - \log_{10}(BER_{SES})}{\log_{10}(P_{tR}) - \log_{10}(P_{tSES})} \right| \tag{12}$$

3.2.2 Prediction of BBER due to rain attenuation

The prediction model for BBER due to rain is based on the relationship between the ITU-R rain attenuation model and the relationship between the received power and BER of the transmission system being considered.

3.2.2.1 Step-by-step procedure for the calculation of BBER due to rain attenuation

The input parameters are: frequency, hop length, polarization, rain zone, transmission power, gain of transmitting antenna, gain of receiving antenna, relationship between received power and BER, SDH path type, and error burst length.

Step 1: Calculate the rain attenuation exceeded for 0.01% of time, $A_{0.01}$, using the method in Annex 1 of Recommendation ITU-R P.530.

Step 2: Calculate the nominal received power without rain attenuation, $P_{RXnominal}$.

Step 3: Using the relationship between received power and BER (usually obtained from equipment manufacturers) obtain the value of A_{SES}, where A_{SES} is the attenuation margin of the radio link for $BER = BER_{SES}$ (see Table 1).

Step 4: Calculate the annual time percentage, p_{aSES}, that the rain attenuation is larger than A_{SES}, using the method in Annex 1 of Recommendation ITU-R P.530.

Step 5: Translate the annual time percentage, p_{aSES}, to worst-month percentage, p_{wSES}, using the method in Recommendation ITU-R P.841.

Step 6: Using the relationship between received power and BER (usually obtained from equipment manufacturers) obtain the value of A_R, where A_R is the attenuation margin of the radio link for RBER).

Step 7: Calculate the annual time percentage, p_{aR}, that the rain attenuation is larger than A_R, using the method in Annex 1 of Recommendation ITU-R P.530.

Step 8: Translate the annual time percentage, p_{aR}, to worst-month percentage, p_{wR}, using the method in Recommendation ITU-R P.841.

Step 9: Transform the worst-month percentages, p_{wSES}, and p_{wR}, into the corresponding probabilities, P_{wSES} and P_{wR}, where: ($P_{wSES} = p_{wSES}/100$ and $P_{wR} = p_{wR}/100$).

Step 10: Calculate BBER from:

$$BBER = SESR \frac{\alpha_1}{2.8\,\alpha_2 (m - 1)} + \frac{N_B\ RBER}{\alpha_3} \tag{13}$$

where SESR is attained from equation (6)

and

$\alpha_1 =$ 1 to 30, number of errors per burst for the BER in the range from 1×10^{-3} to BER_{SES}

$\alpha_2 =$ 1 to 20, number of errors per burst when the BER is in the range from BER_{SES} to RBER, for $\alpha_1/\alpha_2 \leq 2$

$\alpha_3 =$ 1, number of errors per burst for the BER equal to or lower than RBER

N_B: number of bits/block (see Table 1)

m: slope of the BER distribution curve on a log-log scale for BER in the range from BER_{SES} to RBER given by:

$$m = \left| \frac{\log_{10}(RBER) - \log_{10}(BER_{SES})}{\log_{10}(P_{wR}) - \log_{10}(P_{wSES})} \right| \tag{14}$$

3.3 Prediction of ESR

The ESR is evaluated for multipath and rain conditions from:

$$ESR = \int_{BER_A}^{BER_B} f_{ESR}(x) \quad g_{BER}(x) \;\, \mathrm{d}x \tag{15}$$

where:

$f_{ESR}(x)$: relationship between ES and BER

$g_{BER}(x)$: PDF of BER

BER_A and BER_B: integration limits (typical values are 1×10^{-12} and 1×10^{-3}).

3.3.1 Prediction of ESR due to multipath

The method of predicting ESR is based on an approximation for the integral (equation (15)).

3.3.1.1 Step-by-step procedure for calculation of ESR due to multipath

In the following, a step-by-step procedure for evaluating ESR due to multipath is given.

Step 1: Calculate the outage probability, P_{tR}, for the RBER, using the outage prediction methods described in Annex 1 of Recommendation ITU-R P.530 for the appropriate system:

$$P_{tR} = P_t(RBER) \tag{16}$$

Step 2: Calculate the outage probability at $BER = BER_{SES}$ as in Step 1:

$$P_{tSES} = P_t(BER_{SES}) \tag{17}$$

where BER_{SES} is given in Table 1.

Step 3: Calculate SESR from:

$$SESR = P_{tSES} = P_t(BER_{SES}) \tag{18}$$

Step 4: Calculate ESR from:

$$ESR = SESR \sqrt[m]{n} + \frac{n \, N_B \; RBER}{\alpha_3} \tag{19}$$

where:

$\alpha_3 =$ 1, number of errors per burst for BER lower than RBER

N_B: number of bits/block (see Table 1)

n: number of blocks/s (see Table 1)

m: slope of the BER distribution curve on a log-log scale for BER in the range from BER_{SES} to RBER, given by:

$$m = \left| \frac{\log_{10}(RBER) - \log_{10}(BER_{SES})}{\log_{10}(P_{tR}) - \log_{10}(P_{tSES})} \right| \tag{20}$$

3.3.2 Prediction of ESR due to rain attenuation

The prediction model for ESR due to rain is based on the relationship between the ITU-R rain attenuation model and the relationship between the received power and BER of the transmission system being considered.

3.3.2.1 Step-by-step procedure for the calculation of ESR due to rain

The input parameters are: frequency, hop length, polarization, rain zone, transmission power, gain of transmitting antenna, gain of receiving antenna, relationship between received power and BER, SDH path type, error burst length.

Step 1: Calculate the rain attenuation exceeded for 0.01% of time, $A_{0.01}$, using the method in Annex 1 of Recommendation ITU-R P.530.

Step 2: Calculate the nominal received power without rain attenuation, $P_{RXnominal}$.

Step 3: Using the relationship between received power and BER (usually obtained from equipment manufacturers) obtain the value of A_{SES}, where A_{SES} is the attenuation margin of the radio link for $BER = BER_{SES}$ (see Table 1).

Step 4: Calculate the annual time percentage, p_{aSES}, that the rain attenuation is larger than A_{SES} using Annex 1 of Recommendation ITU-R P.530.

Step 5: Translate the annual time percentage, p_{aSES}, to the worst-month percentage, p_{wSES}, using the method in Recommendation ITU-R P.841.

Step 6: Using the relationship between received power and BER (usually obtained from equipment manufacturers) obtain the value of A_R, where A_R is the attenuation margin of the radio link for RBER.

Step 7: Calculate the annual time percentage, p_{aR}, that the rain attenuation is larger than A_R using Annex 1 of Recommendation ITU-R P.530.

Step 8: Translate the annual time percentage, p_{aR}, into worst-month percentage, p_{wR}, using the method in Recommendation ITU-R P.841.

Step 9: Transform the worst-month percentages, p_{wSES} and p_{wR}, into the corresponding probabilities, P_{wSES} and P_{wR} such that:

$$P_{wSES} = p_{wSES}/\,100 \text{ and } P_{wR} = p_{wR}/\,100$$

Step 10: Calculate ESR from:

$$ESR = SESR\ \sqrt[m]{n} + \frac{n\ N_B\ RBER}{\alpha_3} \tag{21}$$

where SESR is attained from equation (6)

and

$\alpha_3 =$ 1, number of errors per burst, for BER lower than RBER

N_B: number of bits/block (see Table 1)

n: number of blocks/s (see Table 1)

m: slope of the BER distribution curve on a log-log scale for BER in the range from BER_{SES} to RBER, given by:

$$m = \left| \frac{\log_{10}(RBER) - \log_{10}(BER_{SES})}{\log_{10}(P_{wR}) - \log_{10}(P_{wSES})} \right| \tag{22}$$

3.4 Prediction of unavailability due to propagation effects

According to the current definition, the unavailability is caused by long SES periods. A radio system is either in the available state or in the unavailable state. If the system is in an available state, and a period of SES occurs that is longer than 10 consecutive seconds, the system will change to an unavailable state, and the period of SES becomes unavailable time. If the system is in an unavailable state, the requirement for changing to an available state is a period of ten consecutive seconds with non-SES. At the moment, it is assumed that it is only fades due to rain that causes unavailable time. It is therefore straightforward to calculate unavailability due to rain attenuation by using the method for SESR due to rain (see § 3.1.2 and 3.1.2.1).

If $Y = 0\%$ (see Note 1 in § 3.1.2.1), then $UR = P_{aSES}$ for rain attenuation, where $P_{aSES} = p_{aSES}/100$ (see Step 4 in § 3.1.2.1).

It is well-known that multipath fading can also contribute to unavailability events. However, for the moment, no accepted unavailability prediction method due to multipath propagation, or other clear air effects, exist.