



ATIS-0100514.2009(S2019)

**Network Performance Parameter and Objectives for
Dedicated Digital Services – SONET Bit Rates**

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ATIS-0100514.2009(S2019), *Network Performance Parameters and Objectives for Dedicated Digital Services - SONET Bit Rates*

Is an American National Standard developed by the **Quality of Service (QoS) Task Force** under the **ATIS Network Performance, Reliability and Quality of Service Committee (PRQC)**.

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Network Performance Parameters and Objectives for Dedicated Digital Services – SONET Bit Rates

Alliance for Telecommunications Industry Solutions

Approved March 23, 2009

American National Standards Institute, Inc.

Abstract

This standard defines the parameters and establishes objectives for assessing the performance of dedicated digital services operating at the nominal 51.84 Mbit/s, 155.52 Mbit/s, 622.08 Mbit/s, 2.488 Gbit/s, and 9.865 Gbit/s interface rates of the SONET (Synchronous Optical Network) digital hierarchy. Rates above 9.865 Gbit/s and SONET virtual tributaries are for further study.

The standard defines the framework for specifying accuracy and availability performance and the allocation of end-to-end performance objectives among service providers. The performance objectives are applicable to each direction of the service between network interfaces. Performance impairments originated outside the network interfaces, such as those due to end-user actions are not included in evaluating performance. The standard further provides acceptance and repair verification test limits for SONET services. The parameter definitions are block based, making in-service measures convenient.

FOREWORD

The information contained in this Foreword is not part of this American National Standard (ANS) and has not been processed in accordance with ANSI's requirements for an ANS. As such, this Foreword may contain material that has not been subjected to public review or a consensus process. In addition, it does not contain requirements necessary for conformance to the standard.

The Alliance for Telecommunication Industry Solutions (ATIS) serves the public through improved understanding between providers, customers, and manufacturers. The Network Performance, Reliability, and Quality of Service Committee (PRQC) develops and recommends standards, requirements, and technical reports related to the performance, reliability, and associated security aspects of communications networks, as well as the processing of voice, audio, data, image, and video signals, and their multimedia integration. PRQC also develops and recommends positions on, and foster consistency with, standards and related subjects under consideration in other North American and international standards bodies.

This standard will be useful to providers and users of digital communications services and also to designers of network and terminal equipment and service applications. This standard provides error performance parameters, measurement methods, numerical specifications, and allocations for dedicated digital communications services operating at specific rates of the SONET (Synchronous Optical Network) digital hierarchy. This standard provides the means to verify the accuracy and availability performance of dedicated digital services operating at nominal interface rates of 51.84 Mbit/s, 155.52 Mbit/s, 622.08 Mbit/s, 2.488 Gbit/s, and 9.865 Gbit/s. Included mappings of performance measures to SONET monitoring functions allow establishing compliance with this standard on an in-service basis.

ANSI guidelines specify two categories of requirements: mandatory and recommendation. The mandatory requirements are designated by the word *shall* and recommendations by the word *should*. Where both a mandatory requirement and a recommendation are specified for the same criterion, the recommendation represents a goal currently identifiable as having distinct compatibility or performance advantages.

There are four annexes in this standard. Annex A is normative and is considered part of this standard. Annexes B through D are informative, and are not considered part of this standard.

Suggestions for improvement of this standard are welcome. They should be sent to: Alliance for Telecommunications Industry Solutions, Suite 500, 1200 G Street NW, Washington, DC 20005.

M. Neibert, PRQC Chair (Telcordia)

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The **QoS** Task Force was responsible for the development of this document.

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American National Standard for Telecommunications –

Network Performance Parameters and Objectives for Dedicated Digital Services – SONET Bit Rates

1 SCOPE, PURPOSE, & APPLICATION

This standard defines the parameters and establishes objectives for assessing the performance of dedicated digital services operating at the nominal 51.84 Mbit/s, 155.52 Mbit/s, 622.08 Mbit/s, 2.488 Gbit/s, and 9.865 Gbit/s interface rates of the SONET (Synchronous Optical Network) digital hierarchy. Rates above 9.865 Gbit/s and SONET virtual tributaries are for further study.

This standard defines the framework for specifying accuracy and availability performance and the allocation of end-to-end performance objectives among service providers. The performance objectives are applicable to each direction of the service between network interfaces. Performance impairments originated outside the network interfaces, such as those due to end-user actions are not included in evaluating performance. The parameter definitions are block based, making in-service measures convenient. The mappings given in Annex A shall be sufficient for establishing in-service or out-of-service conformance to this standard.

2 NORMATIVE REFERENCES

The following standards contain provisions which, through reference in the text, constitute provisions of this American National Standard. At the time of publication, the editions indicated were valid. All standards are subject to revision, and parties to agreements based on this American National Standard are encouraged to investigate the possibility of applying the most recent editions of the standards listed below.

ATIS-0900105.2008, *Telecommunications – Digital hierarchy – Synchronous Optical Network (SONET) - Basic Description including Multiplex Structure, Rates and Formats.*¹

ATIS-0300231.2003(R2007), *Telecommunications – Digital Hierarchy – Layer 1 In-Service Digital Transmission Performance Monitoring.*¹

ATIS-0100503.2002(R2011), *Telecommunications – Network Performance Parameters for Dedicated Digital Services – Definitions and Measurements.*¹

ATIS-0100510.1999(R2008), *Telecommunications – Network Performance Parameters for Dedicated Digital Services – Specifications.*¹

ANSI/IEEE 1007-1991, *Methods and equipment for measuring the transmission characteristics of pulse-code modulation (PCM) telecommunications circuits and systems.*²

¹ This document is available from the Alliance for Telecommunications Industry Solutions, 1200 G Street N.W., Suite 500, Washington, DC 20005. <<http://www.atis.org>>.

² This document is available from the Institute of Electrical and Electronic Engineers. <<http://www.ieee.org>>.

3 DEFINITIONS, ACRONYMS, & ABBREVIATIONS

3.1 Definitions

The definitions, which have been taken from various other standards where appropriate, have been abbreviated in some cases. In the context of this standard, the following definitions apply:

3.1.1 Available State: A state in which a (bi-directional or unidirectional) service is usable (see clause A.6).

NOTE – Each direction of a service is assumed to be in the available state unless a transition to the unavailable state is observed without a subsequent transition to the available state. In this standard the transitions between the available and unavailable states are³:

- transition to the unavailable state occurs at the beginning of 10 consecutive SES;
- transition to the available state occurs at the beginning of 10 consecutive seconds, none of which is an SES.

3.1.2 Background Block Error (BBE): An errored block not occurring as part of an SES.

3.1.3 Bit Error Ratio (BER): The ratio of the number of bit errors to the total number of bits transmitted in a given time interval.

3.1.4 Block: A block is a set of consecutive bits associated with the connection; each bit belongs to one and only one block. See clause 5 for block sizes used in accessing performance.

3.1.5 Errored Block (EB): A block in which one or more bits are in error. See Annex A for estimators.

3.1.6 Errored Second (ES): A one second period with one or more errored blocks. SES defined in 3.1.11 is a subset of ES. See Annex A for estimators.

NOTE – A period of loss of signal shall be considered a period of errored blocks.

3.1.7 Error Free Second (EFS): A one second interval in which no errored blocks are received.

NOTE – In general, measurement is over time and is stated as a percentage, i.e., % EFS.

3.1.8 Inter-Network Interface (INI): The point of demarcation between access and transit portions of the network.

NOTE – Where a Point of Termination (POT) exists, it coincides with an INI.

3.1.9 Network Interface (NI): The point of demarcation between the service provider facilities and the customer's installation.

NOTE – Customer, in this definition, refers to the end user.

3.1.10 Pseudo-Random Binary Sequence (PRBS): A binary sequence that approximates a random signal. The PRBS pattern is $2^n - 1$ bits in length and generates every combination of n -bit words as defined in ANSI/IEEE 1007.

3.1.11 Severely Errored Period (SEP): A sequence of between 3 to 9 consecutive SES. The sequence is terminated by a second which is not an SES.

3.1.12 Severely Errored Second (SES): A one-second period that contains $\geq 30\%$ errored blocks or at least one severely disturbed period.

A severely disturbed period occurs when, over a period of time equivalent to 1 ms, all the contiguous blocks are affected by a high bit error density. See Annex A for estimators.

³ Other indicators are for further study.

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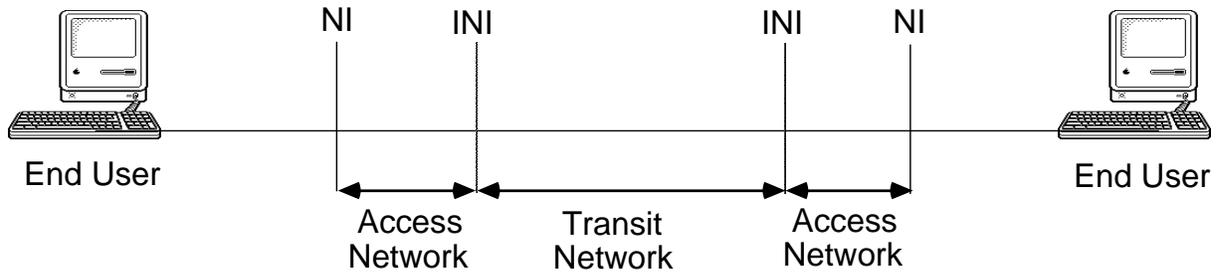
NOTE – A period of loss of signal or a bit error density of $\geq 10^{-2}$ shall be considered a period of errored blocks with high bit error density. It is not required to verify this BER by an actual in-service or out-of-service measurement.

3.2 Acronyms & Abbreviations

AIS	Alarm Indication Signal
ANSI	American National Standards Institute
ATIS	Alliance for Telecommunications Industry Solutions
BBE	Background Block Error
BBER	Background Block Error Ratio
BIP	Bit Interleaved Parity
BER	Bit Error Ratio
EB	Errored Block
ES	Errored Second
EFS	Error Free Second
FEBE	Far End Block Error
INI	Inter-Network Interface
LOP	Loss Of Pointer
NI	Network Interface
OC	Optical Carrier
PDH	Plesiochronous Digital Hierarchy
POT	Point Of Termination
PRBS	Pseudo-Random Binary Sequence
RDI	Remote Defect Indication
RFI	Remote Failure Indication
SEP	Severely Errored Period
SEPI	Severely Errored Period Intensity
SES	Severely Errored Second
SPE	Synchronous Payload Envelope
STS	Synchronous Transport Signal
UAS	Unavailable Seconds

4 REFERENCE MODEL

The performance of dedicated digital networks shall be specified in terms of the reference model in Figure 1. End-to-end performance shall be specified from NI-to-NI with performance allocated for NI-to-*INI* (access) and *INI*-to-*INI* (transit). For intra-network connections (no *INIs*), end-to-end performance shall apply. Since dedicated digital services are characterized by established connections (i.e., no access or disengagement phases) with a constant rate of data transfer, entry and exit events consist solely of user information bits crossing a network interface.



NOTES

NI – Network Interface

INI – Inter-Network Interface: INIs are only present when the service is provided across multiple networks. Where a point of termination (POT) exists, it will coincide with an INI.

Figure 1 - Reference Model - SONET Dedicated Digital Service

5 ERROR PERFORMANCE PARAMETERS AND BLOCK SIZES

5.1 Block sizes for assessing performance

This standard is based upon the error performance measurement of blocks. As defined in 3.1.4, a block is a set of consecutive bits associated with the connection; each bit belongs to one and only one block.

The following block sizes are given in assessing performance. (See Table 1.)

Table 1 - Block Size

Rate (Mbit/s)	51.84 (STS-1)	155.52 (STS-3c)	622.08 (STS-12c)	2,488.32 (STS-48c)	9,865.28 (STS-192c)
Bits/block	6,264	18,792	75,168	300,672	1,202,688

The block size corresponds to the number of bits in 125 microseconds for the SONET path (equivalent to synchronous payload envelope (SPE)); 50.112 Mbit/s, 150.336 Mbit/s, 601.344 Mbit/s, 2.405 Gbit/s, and 9.622 Gbit/s for STS-1, STS-3c, STS-12c, STS-48c, and STS-192c paths, respectively. A path that is multiplexed to a higher rate should be measured at its demultiplexed, original rate. Performance objectives apply at these rates to the SONET path that is not constrained to a particular physical signal type (i.e., objectives apply for electrical (STS-n) or optical (OC-n) signals). See Annex A for further details on block measurement with SONET path measures.

5.2 Error Performance Parameters

Performance parameters include:

5.2.1 Percent Errored Seconds (% ES): $100 \times$ the ratio of ES to total seconds in available time during a fixed measurement period.

5.2.2 Percent Severely Errored Seconds (% SES): $100 \times$ the ratio of SES to total seconds in available time during a fixed measurement period.

5.2.3 Background Block Error Ratio (BBER): The ratio of Background Block Errors (BBE) to total blocks in available time during a fixed measurement interval. No blocks that occur during an SES shall be used for the computation of BBER.

5.2.4 Severely Errored Period Intensity (SEPI): The number of SEP events in available time, divided by the total available time.

NOTE - The SEPI parameter has a unit of (1/s). This is to enable any SEPI objective to be easily translated to the equivalent number of SEP events over a specific measurement interval. It should be noted that the SEP event has no significance over a time interval of less than three seconds.

6 DERIVATION OF END-TO-END OBJECTIVES

Because of the variability of performance, objectives must be determined with due consideration of the statistical distribution of the impairments in the individual provider portions. In general, error performance distributions have two components:

- a Poisson-like distributed background bit error rate;
- episodes of clustered error events superimposed on the above.

Most modern digital systems have been engineered such that the Poisson component is low relative to objectives. The episodic component is difficult to model, but for today's architecture, facilities, and equipment, certain statistical properties are observed. There is a low probability that all provider portions would simultaneously operate at the worst end of their individual performance distribution. Thus, it follows that the end-to-end performance objectives will be greater than the largest objective among the carrier portions, but less than the linear sum of the objectives of all portions.

The end-to-end objective in each case was chosen between these bounds according to current network behavior. For example, in the case where the accuracy objectives are all the same on all three portions, an end-to-end objective equal to a factor 2 times the objective on the individual carrier portions was chosen.

7 PERFORMANCE OBJECTIVES

Accuracy and availability performance objectives provide a measure for evaluating performance of digital services. They can be used as an aid in designing, developing, and maintaining the networks providing digital services, and also, should be considered in the design of terminal equipment and service applications.

7.1 *Rationale*

Objectives are provided for the performance parameters defined in clause 5. Services in aggregate provided in accordance with this standard should perform better than the objective. However, individual circuit performance may vary as a result of factors such as technology mix, system architecture (including protection strategies) and complexity, geographic factors, isolated events, etc., and may be time variant (i.e., could exceed objectives one or two days per month).

Many factors were taken into account in deriving these objectives: customer needs, analytical estimates of performance, empirically observed network performance, performance requirements of the service and its applications, and the practicality of implementing and maintaining a desired quality of service.

7.2 *Accuracy objectives*

Accuracy performance objectives are stated in terms of the parameters provided in Table 2. Accuracy performance should be evaluated relative to a measurement period of 30 days or more. As determination of compliance with the performance objectives would require excessively long test periods, the objectives are used to derive limits for timed tests. Background Block Error Ratio (BBER),

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Percent Errored Second (% ES), and Percent Severely Errored Second (% SES) characterize the transmission quality of the service and are used to derive the test limits. Specific intervals and values are identified in clause 9.

The long term accuracy objectives are expressed as a ratio (or percentage) because they apply over long periods of time. For convenience, percentage values may be converted to a mean number of events/day through multiplication by 864 (86,400 sec/day÷100).

Table 2 - Long-term Accuracy Objectives

Segment	Parameter	51.84 Mbit/s (STS-1)	155.52 Mbit/s (STS-3c)	622.08 Mbit/s (STS-12c)	2.488 Gbit/s (STS-48c)	9,865 Gbit/s (STS-192c)
End-to-End	BBER	(Note 1)	(Note 1)	10-5	10-5	10-4
	% ES	0.25	0.5	(Note 2)	(Note 2)	(Note 2)
	% SES	0.035	0.035	0.035	0.035	0.035
	SEPI (Monthly)	FFS	FFS	FFS	FFS	FFS
Transit	BBER	(Note 1)	(Note 1)	5 x 10-6	5 x 10-6	5 x 10-5
	% ES	0.125	0.25	(Note 2)	(Note 2)	(Note 2)
	% SES	0.025	0.025	0.025	0.025	0.025
	SEPI (Monthly)	FFS	FFS	FFS	FFS	FFS
Access	BBER	(Note 1)	(Note 1)	5 x 10-6	5 x 10-6	5 x 10-5
	% ES	0.125	0.25	(Note 2)	(Note 2)	(Note 2)
	% SES	0.01	0.01	0.01	0.01	0.01
	SEPI (Monthly)	FFS	FFS	FFS	FFS	FFS
(There may be periods of time when these objectives are not met.)						
<p>NOTES</p> <p>1 BBER is only specified for rates above 160 Mbit/s.</p> <p>2 Percent ES objectives tend to lose significance for applications at high bit rates and are therefore not specified for paths operating at bit rates above 160 Mbit/s. Nevertheless, it is recognized that the observed performance of synchronous digital paths is error free for long periods of time even at Gigabit/s rates; and that significant ESR indicates a degraded transmission system. Therefore, for maintenance purposes ES monitoring should be implemented within any error performance measuring devices operating at these rates.</p> <p>3 SEPI is a new parameter, with little history. As such, specific objectives are for future study (FFS).</p>						

7.3 Availability Objectives

Availability objectives are stated in terms of the parameter provided in Table 3. Percent (%) Availability characterizes the usability of the service over time. See 3.1.1 for available state definition and transitions.

Table 3 - Service Availability Objectives

Segment	Parameter	51.84 Mbit/s (STS-1)	155.52 Mbit/s (STS-3c)	622.08 Mbit/s (STS-12c)	2.488 Gbit/s (STS-48c)	9,865 Gbit/s (STS-192c)
End-to-End	% Availability (Annual)	99.830	99.830	99.830	99.830	99.830
Transit	% Availability (Annual)	99.930	99.930	99.930	99.930	99.930
Access	% Availability (Annual)	99.950	99.950	99.950	99.950	99.950

8 TEST DESIGN

8.1 Rationale

Test procedures described in this standard are intended to indicate, by comparing measured performance against threshold values, whether or not a particular circuit is likely to meet the service performance objectives specified in this standard. A circuit that passes these tests is considered “acceptable”; if it does not pass these tests, it is considered “unacceptable.”

For the test specified, all measurements are to be made at the bit rate of the service. Non-intrusive measurement methods may be used where available. Out-of-service tests conducted intrusively in accordance with clause 9 should employ block based measurements with the appropriate rate PRBS for the payload.⁴

These procedures take into account the duration of a test trial and the number of trials to be run. Both long duration and short duration tests are specified. Test limits are derived from long term accuracy objectives through statistical and empirical procedures. Tests are provided for bringing an overall circuit⁵ into service, either on completion of a new installation (acceptance) or after repair activity (repair verification).

Performance studies of current transmission technologies have shown that error distributions are such that long observation periods (i.e., 30 or more days) are required to indicate long term accuracy performance with a high degree of statistical confidence. However, practical considerations require much shorter duration tests (i.e., 24 hours or less) which provide a prediction of long term performance.

For short duration (1 to 2 hour) tests, limits are provided for stages of a sequential test procedure. If at the conclusion of any stage in the procedure, the test result is less than or equal to the test limit, the service performance shall be considered acceptable and the test terminated. If at any stage in the procedure the test result is greater than the test limit for the final stage, the service performance shall be considered unacceptable and the test similarly terminated. If the test result at any stage is between these two limits, the test is thus far inconclusive and shall be continued to the second stage.

For long term tests (24 hours), only a single test limit is provided; if the test result is less than or equal to the test limit, the service performance shall be considered acceptable. If at any time during the test this limit is exceeded, the service performance shall be considered unacceptable.

Extended analysis using in-service monitoring, following the successful completion of a test, can provide a practical and economical method of confirming the long term accuracy performance of the service.

⁴ The appropriate PRBS is 2²³-1 inverted pattern.

⁵ Testing subsections of access and transit segments is beyond the scope of this standard.

8.1.1 Acceptance Tests

Acceptance test measurements are made upon completion of a new service installation. Threshold levels for these tests are generally more stringent than the pro-rated levels derived from the associated long term objective, to provide a greater assurance that a circuit meets a specified performance level. This approach minimizes the probability that the circuit will require corrective maintenance.

8.1.2 Repair Verification Tests

Repair verification tests are made upon completion of a repair activity. Threshold levels for these tests are the same as acceptance test levels to ensure that a circuit will meet specified performance levels.

8.1.3 Trouble Verification Tests

Trouble verification tests are made in response to a trouble indication. Trouble verification is an internal responsibility of the provider and is, therefore, not covered in this standard.

8.2 Performance Determination

8.2.1 Parameters Measured

For digital services operating at rates of 51.84 and 155.52 Mbit/s, the appropriate measures are percent ES and percent SES. For the 622.08 Mbit/s rate and higher rates, the appropriate measures are BBER and percent SES. The appropriate block size (number of bits per block) for each bit rate is given in Table 1.

8.2.2 Test Duration

Test durations have been specified in this standard from 1 hour to 24 hours. For the shorter test durations, sequential tests are specified; for the longer 24 hour duration, only one test is specified. In-service monitoring, where available, may be used over longer periods of time to confirm conformance to long term objectives.

9 SERVICE PERFORMANCE TESTING

For each service included in this clause, the following is provided: test criteria, sequential test procedures and test limit tables. The specified procedure applies to acceptance and repair verification tests (not trouble verification). Each procedure includes the following: the parameters to be measured, the duration of a single test stage, the number of sequential stages to be conducted, and performance determination criteria. Test criteria are provided in Table 4 and test limits for each service are provided in Tables 5, 6, 7, 8 and 9. These test limits were derived using the mathematical models and techniques described in Annex B. Different models and techniques may result in different limits.

The sequential short duration tests are structured in stages with one of three outcomes after each stage: *acceptable performance*, indicating confidence that the circuit under test will satisfy the long-term objective; *unacceptable performance*, indicating confidence that the circuit under test will not satisfy the long-term objective; or *inconclusive*, indicating insufficient evidence at this stage to predict the long-term performance (i.e., marginal). If at any stage the test indicates acceptable or unacceptable performance, the test is terminated. If the test is inconclusive at the first stage, the procedure shall be continued to the second stage. Testing for longer periods such as 24 hours or continuous monitoring will provide greater confidence and should be considered for marginal circuits.

9.1 Tests for 51.84, 155.52, 622.08 Mbit/s, 2.488 Gbit/s, and 9.865 Gbit/s Services

These are services with actual user payload capacity of up to 49.536, 149.760, 600.768 Mbit/s, 2.404 Gbit/s, and 9.621 Gbit/s respectively. Payload capacity is 576 kbit/s less than the SPE capacity to allow for the nine path overhead bytes in each 125 microsecond block. Test criteria are provided in Table 4.

Table 4 - Test Criteria

Bit Rate	51.84 Mbit/s (STS-1)	155.52 Mbit/s (STS-3c)	622.08 Mbit/s (STS-12c)	2.488 Gbit/s (STS-48c)	9.865 Gbit/s (STS-192c)
Parameters	ES, SES, SEP	ES, SES, SEP	BBE, SES, SEP	BBE, SES, SEP	BBE, SES, SEP
Test stage duration Short Long	1 Hour 24 Hour	1 Hour 24 Hour	1 Hour 24 Hour	1 Hour 24 Hour	1 Hour 24 Hour
Number of stages Short duration Long duration	1 or 2 1	1 or 2 1	1 or 2 1	1 or 2 1	1 or 2 1
Test limits	Table 5	Table 6	Table 7	Table 8	Table 9
NOTE: Use of the SEP parameter for test criteria is for further study.					

9.2 Test Procedures

9.2.1 Short Duration Tests

Up to two sequential 1 hour stages shall be conducted to validate the general performance of the service.

The service performance shall be considered acceptable and the test terminated if, after 1 hour, the test results for all parameters do not exceed the limits for the 1 hour tests in the table for the service (Table 5, 6, 7, 8, or 9). The service performance shall be considered unacceptable if any test result is greater than the 2 hour limit. If the test result is between these two limits, continue the test.

After two hours, the service performance shall be considered acceptable if the test results do not exceed the limits in the table for the service (Table 5, 6, 7, 8 or 9) for the 2 hour test. The service performance shall be considered unacceptable if the test result is greater than the 2 hour limit. Testing for longer periods, such as 24 hours or continuous monitoring, will provide greater confidence and should be considered for marginal circuits.

9.2.2 Long Duration Tests

Long duration (i.e., 24 hour) tests are an option. If a 24 hour test is performed, the service performance shall be considered acceptable if the results for each parameter measured do not exceed the 24 hour limits in the table for the service (Table 5, 6, 7, 8, or 9).

9.3 Acceptance and Repair Verification Test Limit Tables

The test limits in Tables 5 to 9 are designed to support the accuracy objectives given in Table 2. While some of the entries are "0", it should be noted that an isolated error event is not necessarily indicative of a service affecting problem. From the "weight of evidence" tables in Annex B, all the short duration test limits for SES would be 0 or 1. Because many SES are known to occur in pairs (protection switch and restoral switch), it is unreasonable to set a limit at one SES. Test limits for 51.84, 155.52, 622.08 Mbit/s, 2.488, and 9.865 Gbit/s are provided in Tables 5, 6, 7, 8, and 9, respectively.

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Table 5 - Acceptance and Repair Verification Test Limits for 51.84 Mbit/s Service

Parameter limit for:	Short duration tests (1 hour stages)				Long duration test (24 hour)	
	ES		SES		ES	SES
	1 hour	2 hour	1 hour	2 hour	24 hour	24 hour
End-to-end	≤ 6	≤ 12	0	≤ 2 (Note 1)	≤ 150	≤ 20
Transit	≤ 3	≤ 6	0	≤ 2 (Note 1)	≤ 75	≤ 14
Access	≤ 3	≤ 6	0	≤ 2 (Note 1)	≤ 75	≤ 5
NOTES 1 Accept at 2 only if the cause of the SES is identified as an isolated event. 2 This standard does not provide trouble verification test limits; see 8.1.3 .						

Table 6 - Acceptance and Repair Verification Test Limits for 155.52 Mbit/s Service

Parameter limit for:	Short duration tests (1 hour stages)				Long duration test (24 hour)	
	ES		SES		ES	SES
	1 hour	2 hour	1 hour	2 hour	24 hour	24 hour
End-to-end	≤ 12	≤ 24	0	≤ 2 (Note 1)	≤ 300	≤ 20
Transit	≤ 6	≤ 12	0	≤ 2 (Note 1)	≤ 150	≤ 14
Access	≤ 6	≤ 12	0	≤ 2 (Note 1)	≤ 150	≤ 5
NOTES 1 Accept at 2 only if the cause of the SES is identified as an isolated event. 2 This standard does not provide trouble verification test limits, see 8.1.3 .						

Table 7 - Acceptance and Repair Verification Test Limits for 622.08 Mbit/s Service

Parameter limit for	Short duration tests (1 hour stages)				Long duration test (24 hour)	
	BBE		SES		BBE	SES
	1 hour	2 hour	1 hour	2 hour	24 hour	24 hour
End-to-end	≤ 199	≤ 399	0	≤ 2 (Note 1)	≤ 4792	≤ 20
Transit	≤ 99	≤ 199	0	≤ 2 (Note 1)	≤ 2396	≤ 14
Access	≤ 99	≤ 199	0	≤ 2 (Note 1)	≤ 2396	≤ 5
<p>NOTES</p> <p>1 Accept at 2 only if the cause of the SES is identified as an isolated event.</p> <p>2 This standard does not provide trouble verification test limits, see 8.1.3.</p> <p>3 FFS = For Future Study.</p> <p>4 In the absence of test equipment and network elements that measure and report Background Block Errors, the SES parameter is used here as a measure of acceptance and repair verification. As an interim alternative, bilateral agreements could be established to use ES as a measure of acceptance and repair verification.</p>						

Table 8 - Acceptance and Repair Verification Test Limits for 2.488 Gbit/s Service

Parameter limit for	Short duration tests (1 hour stages)				Long duration test (24 hour)	
	BBE		SES		BBE	SES
	1 hour	2 hour	1 hour	2 hour	24 hour	24 hour
End-to-end	≤ 199	≤ 399	0	≤ 2 (Note 1)	≤ 4792	≤ 20
Transit	≤ 99	≤ 199	0	≤ 2 (Note 1)	≤ 2396	≤ 14
Access	≤ 99	≤ 199	0	≤ 2 (Note 1)	≤ 2396	≤ 5
<p>NOTES</p> <p>1 Accept at 2 only if the cause of the SES is identified as an isolated event.</p> <p>2 This standard does not provide trouble verification test limits, see 8.1.3.</p> <p>3 FFS = For Future Study.</p> <p>4 In the absence of test equipment and network elements that measure and report Background Block Errors, the SES parameter is used here as a measure of acceptance and repair verification. As an interim alternative, bilateral agreements could be established to use ES as a measure of acceptance and repair verification.</p>						

Table 9 - Acceptance and Repair Verification Test Limits for 9.865 Gbit/s Service

Parameter limit for	Short duration tests (1 hour stages)				Long duration test (24 hour)	
	BBE		SES		BBE	SES
	1 hour	2 hour	1 hour	2 hour	24 hour	24 hour
End-to-end	≤ 1996	≤ 3993	0	≤ 2 (Note 1)	47930	≤ 20
Transit	≤ 998	≤ 1996	0	≤ 2 (Note 1)	≤ 23965	≤ 14
Access	≤ 998	≤ 1996	0	≤ 2 (Note 1)	≤ 23965	≤ 5
<p>NOTES</p> <p>1 Accept at 2 only if the cause of the SES is identified as an isolated event.</p> <p>2 This standard does not provide trouble verification test limits, see 8.1.3.</p> <p>3 FFS = For Future Study.</p> <p>4 In the absence of test equipment and network elements that measure and report Background Block Errors, the SES parameter is used here as a measure of acceptance and repair verification. As an interim alternative, bilateral agreements could be established to use ES as a measure of acceptance and repair verification.</p>						

ANNEX A IN-SERVICE AND OUT-OF-SERVICE MEASUREMENTS USING THE SONET PATH PERFORMANCE MEASURES

A.1 Estimating Errored Blocks

A.1.1 Direct Estimation of Errored Blocks using the B3 Byte⁶

Since the standard defines blocks as consecutive bits associated with a connection, one or more BIP errors within a single B3 byte (i.e., 1 to 8 individual BIP errors) shall indicate one Errored Block.⁷ At the time of the writing of this standard, there were no current implementations for direct measurement of Errored Blocks. Therefore, A.1.2 provides an approximation methodology implementable with current systems.

A.1.2 Approximation of Errored Blocks Using Individual BIP Counts

This subclause offers guidance for use of equipment designed to count individual BIP violations over the entire second. The following provides the relationship between block errors and individual BIP counts:

$$E = \frac{P}{k}$$

where:

E = number of Errored Blocks in the measurement period

P = number of individual parity violations in the measurement period

k = conversion factor ($1 \leq k \leq 4$) representing the average number of individual BIP parity violations per Errored Block

The value of ' k ' is for further study. Initially the use of $k = 1$ is recommended even though it may overestimate Errored Blocks (e.g., three BIP errors in a single BIP-8 byte would estimate three Errored Blocks). In the case of high error rates, the BIP parity violation efficiency approaches 50 percent. Therefore, the value of ' k ' has a maximum expected value of 4, not 8. For information on values of ' k ' for paths using end-to-end forward error correction (FEC), see Annex C.

A.2 Estimating Errored Seconds

An Errored Second shall be estimated by the observation of one or more Errored Blocks as described in clause A.1 above, or by observing a defect as described in A.3.2.

NOTE – As described in ATIS-0300231.2003(R2007), defects can sometimes occur in a second where no Errored Blocks are observed.

A.3 Estimating Severely Errored Seconds

Subclause 3.1.11 defines a Severely Errored Second as a one second period which contains $\geq 30\%$ Errored Blocks or at least one Severely Disturbed Period. These two conditions are estimated using the methods described in the following subclauses respectively.

⁶ See ATIS-0900105.2008

⁷ The direct measurement of Errored Blocks is recommended.

A.3.1 Use of BIP Counts

The BIP count (x) for determination of an SES is shown in Table A-1 for each SONET path type. The value of (x) should be settable⁸ within the SONET equipment. These values are recommended even though it is likely that Severely Errored Seconds will be overestimated.

Table A.1 - Count of x for SES

Path type	(x) *
STS-1	≥ 2400 *
STS-3c	≥ 2400 *
STS-12c	≥ 2400 *
STS-48c	≥ 2400 *
STS-192c	≥ 2400 *

* NOTE - These values and the conversion factor 'k' are under study.

A.3.2 Use of Path Performance Defects

For in-service measurements and practical out-of-service measurements, a severely disturbed period can be estimated by the occurrence of path performance defects. A defect is considered to be a condition under which the path has momentarily lost its ability to transport bits.

Path performance defects include Loss of Pointer-Path (LOP-P) defect and Alarm Indication Signal-Path (AIS-P) defect (see ATIS-0300231.2004(R2007) for definitions of these defects). Use of other defects (e.g., connectivity defects)⁹ are under study.

A.4 Estimation of Performance Events at the Far-end of a Path

The area is for further study.

A.5 Availability Philosophy

Current implementations for path monitoring employ an availability philosophy which considers each direction of transmission independently and, therefore, do not require bi-directional coordination. However, recognizing the need in some cases to determine total unavailable time for a *service* using a path, the following principles for evaluating performance are offered:

- a) Accuracy performance objectives are applied *independently* to each direction of a path, and measurements, including detection of thresholds which define the transition to the unavailable state, are evaluated independent of the state of the opposite direction of transmission;
- b) Error performance *for an individual path direction* should only be evaluated while that path *direction* is in the available state (i.e., error performance measurement is inhibited during time in the unavailable state).

⁸ The ability to program this value may be useful in case future standards activities change the definition of SES. This does not imply that this number is an arbitrary variable.

⁹ For example, the relationship of TIM (Trace Identifier Mismatch) and UNEQ (Unequipped) to SES is under study.

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- c) Bi-directional (i.e., total) *service* unavailable time, is determined from the union of the time in the unavailable state for the two directions of transmission. This determination can be done by post processing of monitored data.

ANNEX B DERIVATION OF TEST LIMITS

The test limits used in clause 9 were derived using the mathematical models and techniques described below. Different models and techniques will result in different limits. Final validation of these test procedures and limits requires practical field experience.

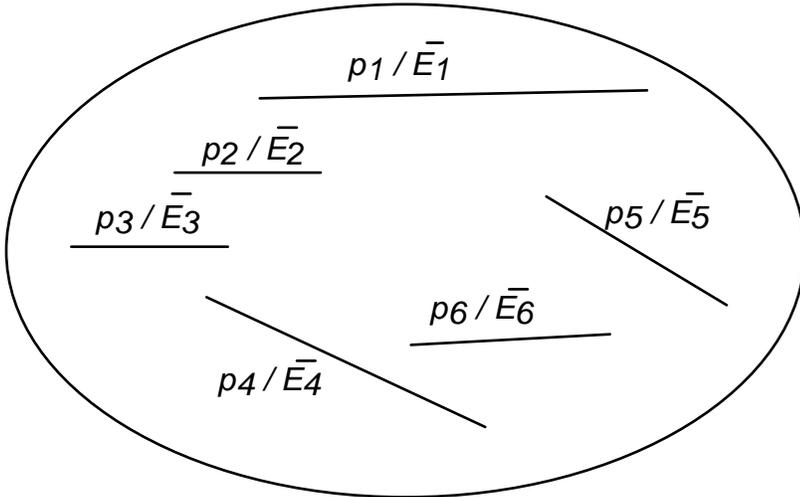


Figure B.1 - A Population of Circuits, Each Characterized by a Value of p

B.1 Introduction

Consider a network consisting of a population of circuits as shown in Figure B-1. We assume that errors (errored or severely-errored seconds) are generated by a very simple mechanism: At each second, a circuit flips a coin with probability p of coming up heads and $1-p$ tails; if the coin comes up heads, an error occurs. Therefore, p is the probability that a particular second is errored.¹⁰ (There will be different p 's for ES and for SES, but for now think of a generic p .) Imagine that each circuit in the population has a tag on it, giving its value of p . Since we don't know these tags, we can characterize the population by defining a *probability distribution* (p.d.) for p . With the coin-flipping model for error generation, a particular p corresponds to an average number \bar{E} of errors in 24 hrs., and one may think of the circuits as labeled by \bar{E} instead.¹¹

Further, we are interested in classifying the error performance of these circuits as "good" or "bad". This can be done by defining two p.d.'s, one for the "good" (low) p 's and one for the "bad" (high) p 's, such that some mixture of them equals the p.d. defining the entire population.¹² Defining "good" and "bad" by distributions of probabilities (instead of by sharp thresholds) allows for the stochastic nature of error performance of a given circuit as well as the variation in performance over the circuit population.

¹⁰ At this point we use "errored" to refer to either errored or severely-errored.

¹¹ $\bar{E} = 86400p$, 86400 being the number of seconds in a day.

¹² A mixture of the p.d.'s, $f_1(x)$ and $f_2(x)$, is the p.d., $f(x) = \alpha f_1(x) + (1-\alpha)f_2(x)$, where α is between 0 and 1.

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Now we randomly choose a circuit from this population, perform a test of some duration on it, measure k errors, and from this we want to deduce whether the circuit's unknown p value belongs to (came from) the "good" or to the "bad" sub-population.

In clause B.3 we define the binomial model used for the error generation process, and choose the *beta* probability density to model the p.d. for each subpopulation. The binomial (coin-flipping) model holds when the value of p is known. When p is unknown and described by a beta p.d., the errors have what is known as a *beta-binomial* distribution. In clause B.4 we extend these models to the mixture of the two subpopulations. Now let H_g be the hypothesis that the circuit under test belongs to the "good" subpopulation, and H_b the hypothesis that it belongs to the "bad" subpopulation. The first question we ask is "How does the result k of a test change our initial belief about the likelihood of H_g vs. H_b ?" (This initial belief is defined by the value of the population-mixing constant α .) In other words, "How do the test results, the 'weight of evidence', change the odds favoring one hypothesis over the other?" This is the subject of clause B.5. An extension to multi-stage (sequential) testing is given in ATIS-0100510.1999(R2008).

The second question is "How do we decide what weight of evidence is sufficient to accept H_g (or H_b)?" Clause B.6 deals with this question by introducing the *costs*, or penalties, associated with each decision and then showing how the decision that minimizes the expected cost can be chosen.

Finally, in clause B.7 we give the probability distributions characterizing the "good" and "bad" subpopulations for the defined SONET services, weight of evidence tables, and examples of using the methodology of clause B.6 with these tables.

B.2 Summary of Procedure

This clause is aimed at the "bottom line-oriented" reader. We list the parameters used by the decision procedure, and classify them into *objective* and *subjective*.¹³ We then list the steps involved in going from the inputs to the decision. References are given to later clauses in which interested readers may indulge.

B.2.1 Objective Parameters

Let O be an objective for a certain service class, expressed as a daily count. For example, 216 ES/day (corresponding to 0.25% errored seconds in a day) for STS-1 end-to-end performance, or 21.6 SES/day (corresponding to 0.025% severely-errored seconds per day) for STS-3 transit performance.

O is the only objective input. We do not concern ourselves here with how it is arrived at.

B.2.2 Subjective Parameters

- Parameters a_1, b_1 and a_2, b_2 . These are numbers ≥ 1 , characterizing the "good" and "bad" circuit populations. In clause B.7 we suggest a method for choosing these numbers based on the objective O .
- A parameter α , which is a number between 0 and 1. The circuit population is assumed to consist of a proportion α of "good" circuits and a proportion $1 - \alpha$ of "bad" circuits. Another way of looking at it is that α is the *prior* (before any test) belief of the tester in hypothesis H_g . The value

¹³ To some extent, this classification is itself subjective.

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of α is network-dependent. The weight of evidence is independent of α , but the final decision about H_g and H_b does depend on it. See clauses B.6 and B.7.

- A number $L \geq 1$, describing the relative “loss” (cost) associated with erroneously accepting a “bad” circuit. See clause B.6.

B.2.3 The Steps

The required steps are simple:

- a) Given an objective O for a certain service class, select a_1, b_1 and a_2, b_2 , as suggested in, clause B.7.
- b) If k errors (ES or SES) were measured in a test of duration d , where d is the number of 15-minute intervals in the test, the weight of evidence W is found by equation (B.5.3) in clause B.5.
- c) Using W , the mixing constant α and the loss, L , compute the expected costs of the actions “accept H_g ” and “accept H_b ” by equation (B.6.2) in clause B.6.
- d) Choose the action with least expected cost.

B.3 Error Probability Distributions

Assume that within a 15-minute interval (chosen because error performance data is commonly summarized every 15 minutes), errored or severely-errored seconds occur according to a binomial model with parameters n and p . So

$$\Pr(e = k | p) = \binom{n}{k} p^k (1-p)^{n-k} = \text{Bi}(k | n, p), \quad (\text{B.3.1})$$

where $n = 900$ is the number of seconds in 15 minutes. Now let $N = 96$ be the number of 15-minute intervals in a day. Then the number of ES that occur in a day is

$$E = e_1 + \dots + e_N$$

Assuming that the e_i are independent, it can be shown that E also has a binomial density, with parameters nN and p :

$$\Pr(E = m | p) = \binom{nN}{m} p^m (1-p)^{nN-m} = \text{Bi}(m | nN, p). \quad (\text{B.3.2})$$

Now assume that our knowledge about the unknown parameter p , which is the probability that a particular second is an ES, is represented by a beta “prior” density with parameters a and b :

$$\pi(p | a, b) = \text{Be}(p | a, b) = \frac{1}{B(a, b)} p^{a-1} (1-p)^{b-1}, \quad a, b \geq 1, \quad (\text{B.3.3})$$

where $B(a, b)$ is the Beta function. The beta density is chosen because of its flexible shape; the densities assumed for SONET services are shown in Figures B-2 and B-3. The issue of what the values of a and b are is taken up in clause B.4.

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It follows from equations (B.3.2) and (B.3.3) that the probability density of E is

$$\Pr(E = m | a, b) = \binom{nN}{m} \frac{B(a+m, b+nN-m)}{B(a, b)} = \text{BeBi}(m | nN, a, b). \quad (\text{B.3.4})$$

This probability density is known as the “beta-binomial”. If the parameters a, b that characterize p are known, equation (B.3.4) gives the probability that a circuit produces m ES or SES in a day. Equation (B.3.4) describes our *prior* knowledge of E , that is, it summarizes what we can say about E before making any tests. Now we will see how this knowledge is modified after the result of the 15-minute test becomes available.

Suppose that we do a 15-minute test and observe $e = k$. This modifies our knowledge (see equation (B.3.3)) of the parameter p : the *posterior* (after the test) density for p is

$$\pi'(p | a, b, e = k) = \text{Be}(p | a + k, b + n - k). \quad (\text{B.3.5})$$

(This follows by Bayes’ formula from equations (B.3.1) and (B.3.3).) Now since

$$\Pr(E = m | a, b, e = k) = \int_0^1 \Pr(E = m | p) \Pr(p | a, b, e = k) dp,$$

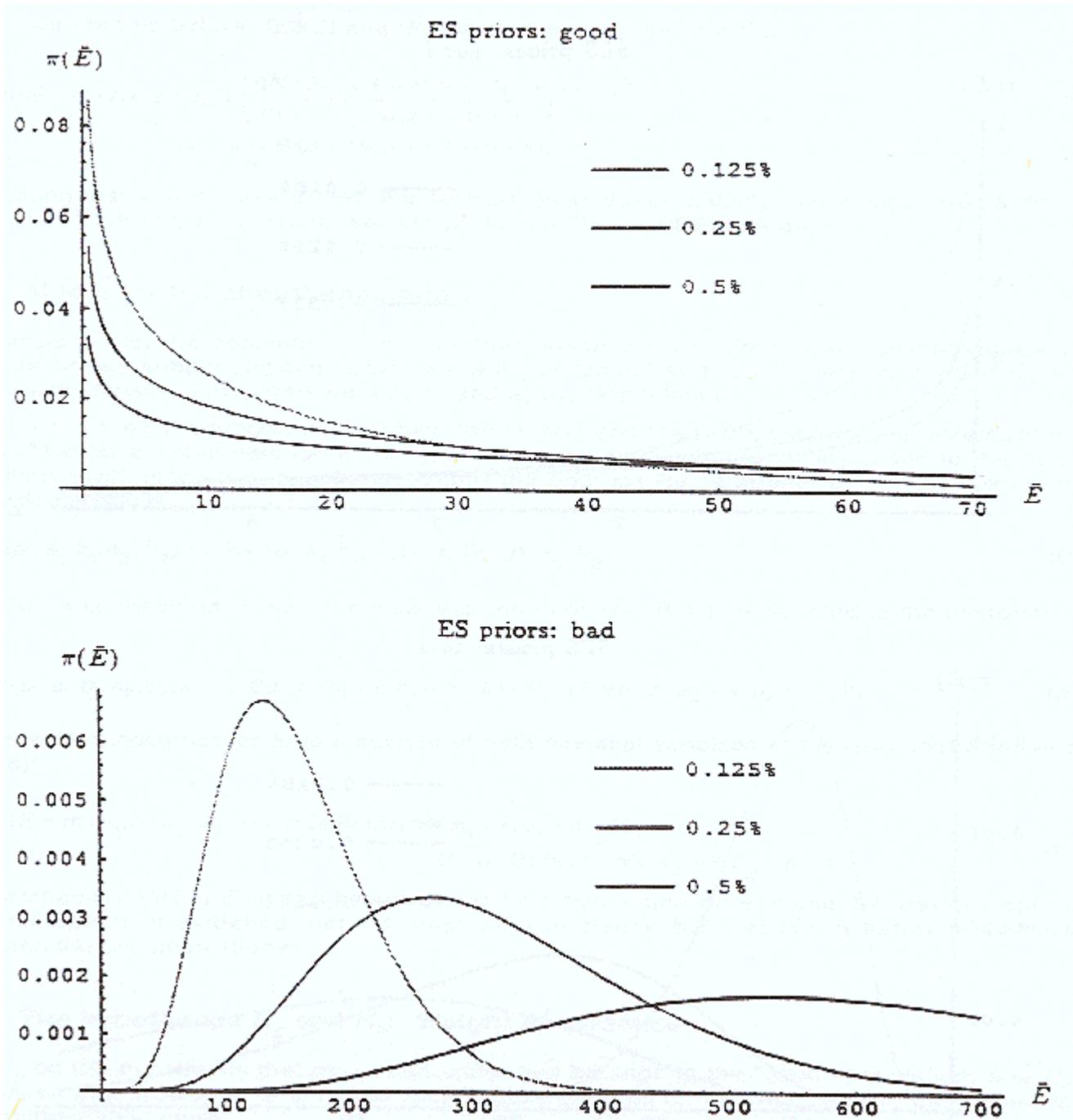
it follows from equations (B.3.5) and (B.3.4) that the posterior for E is

$$\begin{aligned} \Pr(E = m | a, b, e = k) &= \binom{nN}{m} \frac{B(a+k+m, b+nN+n-k-m)}{B(a+k, b+n-k)} \\ &= \text{BeBi}(m | nN, a+k, b+n-k). \end{aligned} \quad (\text{B.3.6})$$

Assuming that a and b are known, this formula gives the probability that a circuit that produced k ES (or SES) during a 15-minute test will produce m ES (or SES) in a day.

Figure B.2- Errored Seconds: The Beta Priors for the Parameter E = nNp

Figure B.3 - Severely Errored Seconds: The Beta Priors for the Parameter E = nNp



B.4 Model for the Circuit Population

We assume that the population of circuits from which our test circuit was selected consists of a mixture of two subpopulations, which we will call "good" and "bad"; each is defined by a beta probability density, with parameters a_1, b_1 and a_2, b_2 , respectively.

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Let $0 \leq \alpha \leq 1$ be the proportion by which the “good” and “bad” populations are mixed in the network. That is, a circuit belongs to the good sub-population with probability α and to the bad sub-population with probability $1-\alpha$. Consequently the prior for the parameter p over the mixture of the two populations is

$$\pi(p | a_1, b_1, a_2, b_2) = \alpha \text{Be}(p | a_1, b_1) + (1-\alpha) \text{Be}(p | a_2, b_2). \quad (\text{B.4.1})$$

After $e = k$ is observed in the 15-minute test, the prior (see B.4.1) is updated to the posterior

$$\pi'(p | a_1, b_1, a_2, b_2, k) = \alpha \text{Be}(p | a_1 + k, b_1 + n - k) + (1-\alpha) \text{Be}(p | a_2 + k, b_2 + n - k). \quad (\text{B.4.2})$$

The resulting posterior for E is a mixture of beta-binomial densities of the type shown in equation B.3.6:

$$\begin{aligned} \Pr(E = m | a_1, b_1, a_2, b_2, k) = & \alpha \text{BeBi}(m | nN, a_1 + k, b_1 + n - k) \\ & + (1-\alpha) \text{BeBi}(m | nN, a_2 + k, b_2 + n - k). \end{aligned} \quad (\text{B.4.3})$$

B.5 The Hypotheses H_g and H_b : Weight of Evidence

Let H_g be the hypothesis that the circuit under test belongs to the “good” population, and H_b the hypothesis that it belongs to the “bad” population. In terms of the prior on (a, b) introduced at the beginning of this Annex:

$$\begin{aligned} H_g : (a, b) &= (a_1, b_1), \\ H_b : (a, b) &= (a_2, b_2). \end{aligned}$$

Our prior belief about these two hypotheses is given by α : the probability of H_g being true is α and that of H_b is $1-\alpha$. In other words, the initial odds of H_g vs H_b are $\alpha/(1-\alpha)$. We will work in terms of the logarithm of this number, the *log-odds* $\log_{10} \alpha/1-\alpha$. The *weight of evidence* provided by the observation $e = k$ on the question of H_g vs H_b is

$$W(H_g | H_b : k) = \log_{10} \frac{\Pr(e = k | H_g)}{\Pr(e = k | H_b)}.$$

(The r.h.s. without the log is also known as the Bayes factor of H_g vs H_b , and in classical statistics it is called the likelihood ratio.) This quantity has a natural significance: when it is 0, the data provides no evidence for one hypothesis vs. the other; however, a positive weight of evidence favors H_g , while a negative weight favors H_b . Further, the final (posterior) log-odds of H_g vs H_b are obtained by *adding* the weight of evidence to the initial log-odds:

$$\underbrace{\log_{10} \frac{\Pr(H_g | k)}{\Pr(H_b | k)}}_{\text{final log-odds}} = \underbrace{W(H_g / H_b : k) + \log_{10} \frac{\alpha}{1-\alpha}}_{\text{initial log-odds}} \quad (\text{B.5.1})$$

(This is simply a consequence of Bayes' formula.) Now noting that

$$\Pr(e = k | H_g) = \frac{\int_0^1 \Pr(e = k | p) \pi(p | a_1, b_1) dp}{\int_0^1 \pi(p | a_1, b_1) dp} = \int_0^1 \Pr(e = k | p) \text{Be}(p | a_1, b_1) dp,$$

where $\pi(p|a_1, b_1)$ is given by equation (B.3.3), and similarly for $\Pr(e = k|H_b)$, we find that the weight of evidence provided by the 15-minute test is

$$W(H_g | H_b : k) = \log_{10} \frac{B(a_1 + k, b_1 + n - k) B(a_2, b_2)}{B(a_2 + k, b_2 + n - k) B(a_1, b_1)}. \tag{B.5.2}$$

It is worth emphasizing that unlike the probabilities shown in equation (B.4.3), the weight of evidence is *independent* of the population-mixing constant α , which is merely the initial estimate of the odds of H_g vs H_b . The result of the test modifies this estimate according to equation (B.5.2).

Finally, if the test lasts for d 15-minute intervals, equation (B.5.2) generalizes to

$$W(H_g | H_b : k) = \log_{10} \frac{B(a_1 + k, b_1 + nd - k) B(a_2, b_2)}{B(a_2 + k, b_2 + nd - k) B(a_1, b_1)}. \tag{B.5.3}$$

B.6 Using the Test Results to Make Decisions

How does one decide what weight of evidence suffices to, let's say, accept H_g ? Is $W(H_g/H_b) = 1$ enough (odds of 10:1), or do we need $W(H_g/H_b) = 2$ (100:1 odds)? In classical statistics one chooses a "confidence level", say 95%.¹⁴ But this choice is quite arbitrary: why is 95% sufficient? On the other hand, how do we know that 90% isn't enough? Clearly, some assessment of the *consequences* of making an erroneous decision is needed. Error probabilities are meaningless in themselves.

Let G stand for the action (decision) "accept H_g ", and B for the action "accept H_b ". Let $C(a, h)$ be a function assigning a *cost* (penalty) to an action a taken when hypothesis h is true. Pretending that we know which of H_g, H_b holds, we can set up the following table for C :

Table B.1 - Specification of a Simple Cost (Loss) Function for the Test

	H_g	H_b
G	0	L
B	1	0

Table B-1 shows that the decision to adopt H_g when H_g is indeed true, costs nothing, but it costs an amount L (for loss) when H_b is true. On the other hand, adopting H_b when H_g is true costs one unit. (It

¹⁴ More sophisticated users will talk about type I and type II errors.

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will be seen shortly that all that matters here is the ratio of $C(G, H_b)$ to $C(B, H_g)$, so we don't lose anything by setting these costs to L and 1 , respectively.)

Now after performing a test, we know the (posterior) probabilities of H_g and H_b , so we can compute the *expected posterior cost* (commonly called the *expected posterior loss*). Generally, if a is one of the available actions and k is the test result, we have

$$\bar{c}(a | k) = \sum_{\text{all } h} C(a, h) \Pr(h | k).$$

Using Table B-1 it follows that

$$\bar{c}(G | k) = L \Pr(H_b | k), \quad \bar{c}(B | k) = \Pr(H_g | k). \tag{B.6.1}$$

These results make good intuitive sense, and they correspond to the expected costs of the classical type I and II errors. It remains to express the probabilities in the r.h.s.'s in terms of the weight of evidence. By equation (B.5.1),

$$\frac{\Pr(H_g | k)}{\Pr(H_b | k)} = w(H_g | H_b : k) \frac{\alpha}{1 - \alpha},$$

where w is the nonlogarithmic form of the weight of evidence (i.e., $w = 10^W$). Using this in equation (B.6.1) we obtain

$$\bar{c}(G | k) = L \frac{1}{1 + \frac{\alpha w}{1 - \alpha}}, \quad \bar{c}(B | k) = \frac{\frac{\alpha w}{1 - \alpha}}{1 + \frac{\alpha w}{1 - \alpha}}. \tag{B.6.2}$$

If the test result is k , choose the action G or B according to which of $\bar{c}(G | k)$, $\bar{c}(B | k)$ is smaller than the other. Note that these expected costs depend on (a) the test result k (via w), (b) the prior knowledge α about the circuit population, and (c) on the relative cost (loss) L .

It follows from equation (B.6.2) that the critical weight of evidence, at which G and B are equally preferable, is

$$\bar{w} = w(\hat{k}) = L \frac{1 - \alpha}{\alpha}. \tag{B.6.3}$$

So the $k = \hat{k}$ at which $w(k) = \bar{w}$ is the test result *threshold*, at which the test provides no evidence for or against H_g or H_b .

B.7 The Weight of Evidence Method Used for SONET Test Limits

B.7.1 The Subjective Parameters

B.7.1.1 a and b

To find values for the parameters *a* and *b* of the “good” and “bad” subpopulations that are reasonable for a certain performance objective, we adopt the general approach taken in ATIS-0100510.1999(R2008). Given an objective O_i , we determine the mean and standard deviation of the populations G_i and B_i by requiring that

$$\frac{\mu_{G_i}}{O_i} = 0.20, \quad \frac{\sigma_{G_i}}{\mu_{G_i}} = 1.2,$$

$$\frac{\mu_{B_i}}{O_i} = 1.5, \quad \frac{\sigma_{B_i}}{\mu_{B_i}} = 0.4.$$

These values of mean and standard deviation are for the distributions of SES and ES for the "good" and "bad" populations.

The idea is that the “good” mean is significantly below the objective, while the “bad” mean is somewhat above it. The standard deviations are chosen subjectively, to reflect our understanding of the tightness of the distributions around their means. We then use the expressions

$$\mu = \frac{a}{a+b}, \quad \sigma^2 = \frac{ab}{(a+b+1)(a+b)^2}$$

for the mean and variance of a beta p.d. to find the corresponding *a* and *b*. The answers are

$$a = \mu \frac{\mu - \mu^2 - \sigma^2}{\sigma^2}, \quad b = (1 - \mu) \frac{\mu - \mu^2 - \sigma^2}{\sigma^2}.$$

If μ and σ are in ES/SES per day, they must be divided by $nN = 86400$ before they are used in this formula.

Table B.2 - The Critical (non-log) Weight of Evidence for Various L and α

		L					
		1	2	3	4	5	10
α	0.5	1.	2.	3.	4.	5.	10.
	0.6	0.667	1.33	2.	2.67	3.33	6.67
	0.7	0.429	0.857	1.29	1.71	2.14	4.29
	0.8	0.25	0.5	0.75	1.	1.25	2.5
	0.9	0.111	0.222	0.333	0.444	0.556	1.11
	0.95	0.0526	0.105	0.158	0.211	0.263	0.526
Note: $W = \text{Log}_{10}(0.556) = -0.2549$							

B.7.1.2 α and L

To get an idea of the significance of α and L, Table B-2 lists the critical weight of evidence \hat{w} defined in equation (B.6.3) for various α and L. α should be chosen in accordance with the prior knowledge that one has of the network, and appropriately adjusted to reflect any additional knowledge about the particular testing situation. L has to be chosen by assuming the cost of rejecting a “good” circuit to be 1 unit, and then assessing how much bigger (if one is conservative) is the cost of accepting a “bad” one.

The values that we use in the rest of this subclause are $\alpha = 0.9$ and $L = 5$. These are merely reasonable values; they should not be taken as anything more than that.

Table B.3 - Weight of Evidence W

k	1 hr.	2 hrs.	k	24 hrs.
0	1.74	2.74	20	2.54
1	0.82	1.81	30	1.69
2	0.225	1.2	40	1.08
3	-0.225	0.736	50	0.599
4	-0.588	0.362	60	0.209
5	-0.891	0.046	70	-0.119
6	-1.15	-0.226	74	-0.237
7	-1.38	-0.465	75	-0.266
8	-1.58	-0.677	80	-0.402
9	-1.76	-0.869	90	-0.65
10	-1.92	-1.04	100	-0.869

B.7.2 Errored Second Tables

Figure B-2 shows the “good” and “bad” priors for errored seconds. Instead of plotting $\pi(p)$ of equation (B.3.3), we show the p.d. of the more intuitive quantity $\bar{E} = nNp$, the expected number of ES/day corresponding to p . \bar{E} is the mean of E defined in equation (B.3.2), and its p.d. is

$$\pi(\bar{E}) = \frac{1}{nN} \text{Be}\left(\frac{\bar{E}}{nN} \mid a, b\right)$$

Note that \bar{E} is *not* the same as the mean of the E in equation (B.3.4).

Given the population, shown in Figure B-2, tables B.3 to B.5 show the weight of evidence corresponding to the test result k .

As an example, Table B-3 can be used as follows. If we begin with an equal mix of good and bad circuits, reflecting the assumption that the tester has no prior knowledge about the circuit to be tested, the mixing factor α is 0.5. Hence the initial odds are 1:1 that the hypothesis H_g is true, that is, that the circuit under test belongs to the “good” subpopulation. After a 1 hr. test, if the result k was 1, the weight of evidence for H_g vs. H_b increases to 0.82, giving odds of $10^{0.82} = 6.61:1$. If the 1 result persists for a 2-hr. test, the odds increase to 65:1 that the circuit is good. If k were 3 in the 1-hr. test, however, the weight of evidence is negative, and the odds are 1:1.67, somewhat favoring H_b , i.e., that the circuit is

bad. At $k = 8$, the odds for H_g vs. H_b increase to 1:38, well in favor of the hypothesis that the circuit actually came from the bad sub-population.

From Table B-2, the critical weight of evidence for $\alpha = 0.9$ and $L = 5$ is -0.2553 (log form). The horizontal lines in tables B.3 to B.5 indicate the corresponding critical test results \hat{k} .

B.7.3 Severely-Errored Second tables

Figure B-3 shows the “good” and “bad” priors for severely-errored seconds. Again, instead of plotting $\pi(p)$ of equation (B.3.3), we show the p.d. of the more intuitive quantity $E = nNp$, the expected number of ES/day corresponding to p . Tables B.6 to B.8 give the weight of evidence for tests on these populations.

B.7.4 Background Block Error Tables

The above model applies to BBE by changing the basic time unit from 1 s to 125 μ s, i.e., the time interval for a BBE (a BBE can be considered to be an “errored 125 μ s interval). In the discussion of B.1 and Figure B-1, a circuit flips a coin every 125 μ s instead of every second. Following the results in B.5, the weight of evidence for Background Block Error is given by

$$W(H_g | H_b : k) = \log_{10} \frac{B(a_1 + k, b_1 + N - k)B(a_2, b_2)}{B(a_2 + k, b_2 + N - k)B(a_1, b_1)}$$

where H_g and H_b are the hypotheses that the circuit is in the “good” and “bad” populations, respectively, N is the total number of blocks in the measurement interval, and k is the number of BBEs out of the N blocks. The function $B(a, b)$ is the beta function. The subscripts 1 and 2 refer to the “good” and “bad” population beta distributions, respectively.

The quantity N is equal to the number of blocks in the respective interval, which is equal to 8000 times the number of seconds in the interval. Thus, $N = 2.88 \times 10^7$ for a 1-hour measurement interval, $N = 5.76 \times 10^7$ for a 2-hour measurement interval, and $N = 6.912 \times 10^8$ for a 24-hour measurement interval. The mean and variance of the beta distribution for the “good” and “bad” populations are given in B.7.1.1 above, where the quantity O_i is the respective BBER objective expressed as a pure fraction.

There are four BBER objective values we must consider: (1) 10^{-5} , which is the end-to-end objective for STS-12c and STS-48c, (2) 5×10^{-6} , which is the access and transit portion allocation for STS-12c and STS-48c, (3) 10^{-4} , which is the end-to-end objective for STS-192c, and (4) 5×10^{-5} , which is the access and transit portion allocation for STS-192c. In what follows, we refer to these as cases 1 – 4, respectively.

As above, the ratio of the cost of considering a “bad” circuit “good” to that of considering a “good” circuit “bad” (the quantity L) is taken to be 5 and the prior probability that a circuit is “good” (the quantity α) is taken to be 0.9. With these values, the critical weight of evidence is $\log_{10} (5/9) = -0.2552725$.

The BBER weight of evidence for cases 1 – 4 is given in Tables B-9, B-10, B-11, and B-12, respectively. Each table contains weight of evidence as a function of the number of block errors, k , for 1 hour, 2 hour, and 24 hour tests. In each table, the range of k is chosen such that the critical weight of evidence of -0.2552725 is included (this critical weight of evidence is computed to seven decimal places because, in some of the cases, the weight of evidence varies slowly with k in the vicinity of the critical value). In addition, the two consecutive values of k for which the weight of evidence decreases below the critical value are given for each case and each measurement interval.

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The acceptance and repair verification test limits may be read directly from Tables B-9 through B-12. For each measurement interval of each case, the limit is equal to the largest value of k for which the weight of evidence is above the critical value. The results are incorporated in Table 7 for STS-12c, Table 8 for STS-48c, and Table 9 for STS-192c.

We note that the results show an approximate scaling:

- for the same weight of evidence, the corresponding value of k increases in proportion to the measurement time
- for the same weight of evidence, the corresponding value of k increases in proportion to the objective value.

These scalings are consistent with the notion that the average number of errors increases proportionally with the measurement interval and with the average error rate. The scalings are only approximate, but the approximation is better for larger k .

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Table B.4 - Weight of Evidence W for Objective of 0.25% ES (216 ES/day)

<i>k</i>	1 hr.	2 hrs.	<i>k</i>	24 hrs.
0	2.74	3.98	50	2.15
1	1.81	3.04	60	1.75
2	1.2	2.43	70	1.41
3	0.736	1.95	80	1.12
4	0.362	1.57	90	0.855
5	0.0462	1.25	100	0.623
6	-0.226	0.964	110	0.413
7	-0.465	0.716	120	0.223
8	-0.677	0.494	130	0.048
9	-0.868	0.294	140	-0.113
10	-1.04	0.111	149	-0.248
11	-1.2	-0.0567	150	-0.262
12	-1.35	-0.212	160	-0.401
13	-1.48	-0.355	170	-0.531
14	-1.6	-0.489	180	-0.653
15	-1.72	-0.615	190	-0.767

Table B.5 - Weight of Evidence W for Objective of 0.5% ES (432 ES/day)

<i>k</i>	1 hr.	2 hrs.	<i>k</i>	24 hrs.
0	3.98	5.4	200	0.633
10	0.111	1.47	220	0.422
12	-0.211	1.14	240	0.229
13	-0.355	0.989	260	0.0527
14	-0.489	0.85	280	-0.11
15	-0.614	0.718	290	-0.186
20	-1.14	0.162	299	-0.253
24	-1.48	-0.195	300	-0.260
25	-1.55	-0.276	310	-0.331
26	-1.62	-0.353	320	-0.400
27	-1.69	-0.427	340	-0.531
30	-1.88	-0.635	360	-0.654

Table B.6 - Weight of Evidence W for Objective of 0.01% SES (8.64 SES/day)

<i>k</i>	1 hr.	2 hrs.	<i>k</i>	24 hrs.
0	0.195	0.376	3	0.672
1	-0.687	-0.512	4	0.298
2	-1.25	-1.08	5	-0.0172
3	-1.66	-1.5	6	-0.289
4	-1.99	-1.83	7	-0.527
5	-2.25	-2.1	8	-0.739

Table B.7 - Weight of Evidence W for Objective of 0.025% SES (21.6 SES/day)

<i>k</i>	1 hr.	2 hrs.	<i>k</i>	24 hrs.
0	0.461	0.849	13	-0.0194
1	-0.429	-0.0518	14	-0.155
2	-0.996	-0.629	15	-0.283
3	-1.42	-1.06	16	-0.403
4	-1.75	-1.41	17	-0.515
5	-2.03	-1.69	18	-0.622

Table B.8 - Weight of Evidence W for Objective of 0.035% SES (30.24 SES/day)

<i>k</i>	1 hr.	2 hrs.	<i>k</i>	24 hrs.
0	0.624	1.12	19	-0.085
1	-0.271	0.213	20	-0.184
2	-0.843	-0.371	21	-0.278
3	-1.27	-0.809	22	-0.369
4	-1.61	-1.16	23	-0.455
5	-1.89	-1.45	24	-0.537

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Table B.9 - Weight of Evidence for BBER Objective of 10-5 (Case 1, end-to-end objective for STS-12c and STS-48c)

<i>k</i>	1 hour test	<i>k</i>	2 hour test	<i>k</i>	24 hour test
0	10.2	0	11.9	0	17.8
25	4.34	50	4.45	600	4.57
50	2.83	100	2.88	1200	2.92
75	1.92	150	1.95	1800	1.97
100	1.27	200	1.29	2400	1.31
125	0.774	250	0.785	3000	0.796
150	0.369	300	0.376	3600	0.383
175	0.030	350	0.034	4200	0.037
199	-0.25044	399	-0.25443	4792	-0.25489
200	-0.26132	400	-0.25991	4793	-0.25535
225	-0.516	450	-0.516	4800	-0.2586
250	-0.741	500	-0.743	5400	-0.516

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Table B. 10 - Weight of Evidence for BBER Objective of 5×10^{-6} (Case 2, access and transit portion allocation for STS-12c and STS-48c)

<i>k</i>	1 hour test	<i>k</i>	2 hour test	<i>k</i>	24 hour test
0	8.56	0	10.2	0	16.2
20	3.20	40	3.32	480	3.45
40	1.72	80	1.77	960	1.82
60	0.841	120	0.865	1440	0.888
80	0.216	160	0.227	1920	0.237
99	-0.24248	199	-0.25044	2396	-0.25501
100	-0.26399	200	-0.26132	2397	-0.25593
120	-0.652	240	-0.654	2400	-0.259
140	-0.974	280	-0.980	2880	-0.656

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Table B. 11- Weight of Evidence for BBER Objective of 10⁻⁴ (Case 3, end-to-end objective for STS-192c)

<i>k</i>	1 hour test	<i>k</i>	2 hour test	<i>k</i>	24 hour test
0	15.7	0	17.4	0	23.4
250	4.55	500	4.56	6000	4.57
500	2.92	1000	2.92	12000	2.93
750	1.97	1500	1.97	18000	1.98
1000	1.31	2000	1.31	24000	1.31
1250	0.795	2500	0.796	30000	0.797
1500	0.382	3000	0.383	36000	0.383
1750	0.037	3500	0.037	42000	0.038
1996	-0.25433	3993	-0.25473	47930	-0.25523
1997	-0.25543	3994	-0.25528	47931	-0.25528
2000	-0.259	4000	-0.259	48000	-0.258
2250	-0.516	4500	-0.516	54000	-0.516

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Table B. 12 - Weight of Evidence for BBER Objective of 5×10^{-5} (Case 4, access and transit portion allocation for STS-192c)

<i>k</i>	1 hour test	<i>k</i>	2 hour test	<i>k</i>	24 hour test
0	14.1	0	15.7	0	21.7
200	3.43	400	3.44	4800	3.46
400	1.82	800	1.82	9600	1.83
600	0.885	1200	0.888	14400	0.890
800	0.236	1600	0.237	19200	0.238
998	-0.25463	1996	-0.25433	23965	-0.25525
999	-0.25683	1997	-0.25543	23966	-0.25534
1000	-0.259	2000	-0.259	24000	-0.258
1200	-0.656	2400	-0.656	28800	-0.656

Annex C

(informative)

ANNEX C APPROXIMATION OF ERRORED BLOCKS USING INDIVIDUAL BIP COUNTS FOR BURST ERROR CASES

In Annex A, the value $k = 1$ is recommended for the average number of parity violations per errored block in a measurement period, even though it may overestimate the number of errored blocks. The overestimation will occur in cases where the error process is bursty, and the value of k increases with increasing burst size. This is because a burst error process is more likely than a Poisson error process to produce multiple bit errors in the same block resulting in multiple code violations. This Annex provides information on the relation between k and average burst size, and information on situations where k is likely to be larger than 1. These situations are mainly cases where forward error correction (FEC) is used.

C.1 Relation between Average Burst Size and Average Number of Code Violations per Errored Block

In this section, the burst error process is modeled using the Neyman-A distribution. A detailed description of the Neyman-A distribution is given in [1]. The Neyman-A distribution has been used to model burst error processes in digital transmission systems; see, for example, [2]. The Neyman-A distribution models the occurrences of bursts as a Poisson process; in addition, the number of errors in a burst is assumed to have a Poisson distribution. In the following, the set of bits covered by a single BIP bit is referred to as a *thread*. Thus, the block defined for an STS-Nc contains 8 threads. The bits of the 8 threads are interleaved. The following two quantities must be calculated: (1) the probability of detecting an errored block, and (2) the probability of detecting an errored thread. These quantities are obtained as specializations of a more general case where a larger frame contains N blocks, and each block contains m threads. The blocks and threads are bit interleaved. This is often referred to as an $N \times BIP\text{-}m$ Error Detection Code (EDC) Usage. The probability of detecting an errored block is obtained by setting $N = 1$ and $m = 8$; the probability of detecting an errored thread is obtained by setting $N = 8$ and $m = 1$.

Let B_0 , B_{blk} and B_{th} be the total numbers of bits in a frame, block and thread, respectively, and let b be the average bit error ratio. Define

$$\begin{aligned} \mu &= \text{mean number of error bursts per frame} \\ \mu_1 &= \text{mean number of error bursts per block} \\ \mu_2 &= \text{mean number of bit errors per burst} \end{aligned} \tag{C-1}$$

The parameters μ , μ_1 and μ_2 are related to BER and block size by

$$\begin{aligned} \mu \frac{\mu_2}{N} &= B_{blk} b = \frac{B_0 b}{N} \\ \mu \mu_2 &= B_0 b \\ \mu_1 &= \mu \end{aligned} \tag{C-2}$$

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In equation (C-2), the average burst size $\overline{\mu_2}$ is divided by N to account for the interleaving of the blocks. However, also because of the interleaving, the average number of bursts per block, $\overline{\mu_1}$, is equal to the average number of bursts per frame, $\overline{\mu}$, because each burst is split among the N interleaved blocks.

The resulting expression for the average number of code violations, k , per errored block is given by equation (C-15), with an approximation for small BER given by equation (C-16). Numerical results for k , as a function of average burst size, are given in Table C-1. The reader interested only in the result should skip to equation (C-15). We now present the detailed derivation.

Derivation of the Result for the Average Number of Code Violations Per Errored Block

The probability that there will be k bit errors in a block of size B_{blk} is given by the Neyman-A distribution [1], [2]

$$p_{Ney}(k) = e^{-\mu_1} \frac{(\mu_2 / N)^k}{k!} \sum_{n=0}^{\infty} \frac{n^k}{n!} \mu^n e^{-n\mu_2 / N} \quad (C-3)$$

As explained above, in equation (C-3), the quantity μ_2 is divided by the number of blocks N in a frame because the bits of the various blocks are interleaved in groups of size m ; therefore, a burst covers bits of all N blocks. From equations (C-2) and (C-3), the probability of a block error is

$$\begin{aligned} P_{EB} &= 1 - p_{Ney}(0) = 1 - \exp\left[-\mu(1 - e^{-\mu_2 / N})\right] \\ &= 1 - \exp\left[-\frac{B_0 b}{\mu_2} (1 - e^{-\mu_2 / N})\right] \end{aligned} \quad (C-4)$$

It is seen from equation (C-4) that P_{EB} for the Neyman-A model depends on both average BER, b , and average burst size, μ_2 .

To determine the probability of detecting an errored block, the following approximation is used.[2] The probability of detecting an errored block may be written

$$P_{EB,det} = \Pr(\text{detect an EB} \mid \text{errored block}) P_{EB} = \eta P_{EB} \quad (C-5)$$

The conditional probability of detecting an errored block given that the block is errored is equal to 1 minus the conditional probability of not detecting the errored block given that it is errored. We approximate the conditional probability of not detecting the errored block given that the block is errored as the conditional probability of not detecting an errored thread given that the thread is errored, raised to the m^{th} power. That is, given that an error burst occurs, we assume the probability that the number of errored bits in one thread is even is independent of the probability that the number of errored bits in any other thread is even. This is a much better approximation than assuming complete independence among the threads, because here we at least account for dependence in the overall probability that the block is errored, P_{EB} . In addition, note that the calculation is exact for the case $m = 1$ (N x BIP-1), i.e., where we count individual code violations.

The conditional probability of not detecting an errored thread given that it is errored is equal to the probability that the number of errors in the thread is even and positive, p_{e+} , divided by the probability that the thread is errored. The latter is equal to the sum of p_{e+} and the probability that the number of errors in the thread is odd, p_o . We have already calculated the probability that a thread is errored (it is easily obtained from the result for the probability that a block is errored); therefore, if the probability that the number of errors in a thread is odd can be calculated, all the results will follow.

The probability that the number of errors in a thread is odd is obtained by summing the Neyman-A distribution over odd values

$$\begin{aligned}
 p_o &= \sum_{k=1}^{\infty} e^{-\mu} \frac{(\mu_2 / mN)^{2k-1}}{(2k-1)!} \sum_{n=0}^{\infty} \frac{n^{2k-1}}{n!} \mu^n e^{-n\mu_2 / mN} \\
 &= \sum_{n=0}^{\infty} e^{-\mu} \frac{\mu^n}{n!} e^{-n\mu_2 / mN} \sum_{k=1}^{\infty} \frac{(\mu_2 n / mN)^{2k-1}}{(2k-1)!} \\
 &= \sum_{n=0}^{\infty} e^{-\mu} \frac{\mu^n}{n!} e^{-n\mu_2 / mN} \sinh\left(\frac{\mu_2 n}{mN}\right) \\
 &= \sum_{n=0}^{\infty} e^{-\mu} \frac{\mu^n}{2n!} (1 - e^{-2n\mu_2 / mN}) \\
 &= \frac{e^{-\mu}}{2} \sum_{n=0}^{\infty} \frac{\mu^n - (\mu e^{-2\mu_2 / mN})^n}{n!} \\
 &= \frac{1}{2} \left[1 - \exp\left(-\mu \left(1 - e^{-2\mu_2 / mN}\right)\right) \right]
 \end{aligned} \tag{C-6}$$

Note that in equation (C-6), the upper limit of the sum over k is infinity rather than the maximum number of bits in the thread; this is because the Neyman-A distribution is normalized with an upper limit of infinity. This is a good approximation because the probabilities of such large numbers of errors (of order of the number of bits in the thread) is extremely small.

The quantity p_{e+} is now obtained as

$$p_{e+} = \text{Pr(errored thread)} - p_o \tag{C-7}$$

The probability of an errored thread is obtained from equation (C-4)

$$\text{Pr(errored thread)} = 1 - \exp[-\mu (1 - e^{-\mu_2 / mN})] \tag{C-8}$$

where now the average burst size μ_2 is divided by the number of threads in the frame mN to account for the interleaving. Substituting Eqs. (C-8) and (C-6) into equation (C-7) produces

$$p_{e+} = \frac{1}{2} + \frac{1}{2} \exp[-\mu (1 - e^{-2\mu_2 / mN})] - \exp[-\mu (1 - e^{-\mu_2 / mN})] \tag{C-9}$$

The detection efficiency is given by

$$\begin{aligned}\eta &= 1 - \left[\frac{P_{e+}}{\text{Pr}(\text{errored thread})} \right]^m \\ &= 1 - \left[\frac{P_{e+}}{1 - \exp\left[-\mu \left(1 - e^{-\mu_2 / mN}\right)\right]} \right]^m\end{aligned}\tag{C-10}$$

The detection efficiency and the probability of detecting an errored block may be evaluated using equation (C-2) to determine μ from the other quantities, and Eqs. (C-4), (C-5), (C-9), and (C-10). As noted earlier, the results are exact for the case $m = 1$, i.e., where we are counting individual code violations ($N \times \text{BIP-1}$). In this case, the probability of detecting an errored block (thread here) reduces to

$$P_{EB,\text{det}} = p_o = \frac{1}{2} \left[1 - \exp\left(-\mu \left(1 - e^{-2\mu_2 / N}\right)\right) \right] \quad (\text{for } m = 1)\tag{C-11}$$

Using the above results, the probability of detecting an errored block is

$$P_{EB,\text{det}} = \left\{ 1 - \left[\frac{\frac{1}{2} + \frac{1}{2} e^{-\mu(1-e^{-2\mu_2/8})} - e^{-\mu(1-e^{-\mu_2/8})}}{1 - e^{-\mu(1-e^{-\mu_2/8})}} \right]^8 \right\} \left[1 - e^{-\mu(1-e^{-\mu_2})} \right] \tag{C-12}$$

(for $N=1, m=8$)

Also, the probability of detecting an errored thread is

$$P_{Eth,\text{det}} = \frac{1 - \exp\left[-\mu \left(1 - e^{-2\mu_2 / 8}\right)\right]}{2} \tag{C-13}$$

(for $N=8, m=1$)

In equation (C-12) for the probability of detecting an errored block, the quantity in braces represents the detection efficiency. For the case here, this quantity is very close to 1. Then the probability of detecting an errored block may be approximated by

$$P_{EB,\text{det}} = 1 - e^{-\mu(1-e^{-\mu_2})} \tag{C-14}$$

Result for the Average Number of Code Violations Per Errored Block

Then the average number of code violations, k , is given by

$$k = \frac{P_{Eth,\text{det}}}{P_{EB,\text{det}}} = 4 \cdot \frac{1 - \exp\left[-\mu \left(1 - e^{-\mu_2 / 4}\right)\right]}{1 - \exp\left[-\mu \left(1 - e^{-\mu_2}\right)\right]} \tag{C-15}$$

where $\mu\mu_2 = B_{blk}b$. For small BER b , the quantity B_0b/μ_2 is small compared to 1, and equation (C-15) may be approximated by

$$k \cong 4 \cdot \frac{1 - e^{-\mu_2/4}}{1 - e^{-\mu_2}} \tag{C-16}$$

Values of k as a function of average burst size μ_2 are given in Table C-1.

Table C.1 - Average Number of Code Violations Per

Average burst size μ_2	k
1	1.40
2	1.82
3	2.22
4	2.58
5	2.87
8	3.46
10	3.67
20	3.97
30	4.00
40	4.00

The results in Table C-1 clearly show that the maximum value of k is 4 for large burst size. This is because, for large burst size, the probability of an odd number of errors in a thread is approximately equal to the probability of an even number of errors in a thread. Note that $k = 1.40$ for average burst size of 1 rather than $k = 1$ because, for the Neyman-A distribution, μ_2 represents the average burst size.

C.2 Cases where Forward Error Correction (FEC) is Used

One case where the error process is bursty is the case where Forward Error Correction (FEC) is used. This is because the types of FEC typically employed in digital transmission systems can correct up to some maximum number of errors. If the number of errors in the block exceeds this maximum, the FEC algorithm adds errors in addition to not correcting the errors that occur. Two types of FEC that may be used in server layers that support the transport of SONET paths are: (1) the shortened, systematic, binary-BCH code (derived from a (8192,8152) parent code) for OC-48 and OC-192 (see ITU-T Rec. G.707), and (2) the RS(255,239) FEC for the OTN. Both FECs use interleaved code blocks to increase the tolerance to burst errors. In the former, the code block is taken to be a single OC-48 row, interleaved 8 ways. The code can correct up to 3 errors; if more than 3 errors occur, the resulting incorrect block will contain at least 7 errors. Due to the interleaving, the FEC will fail only if the burst size exceeds $(8)(3) = 24$ errors, and the resulting number of errors in the incorrect block will be at least $(7)(8) = 56$. Table C-1 above shows that the average number of code violations per errored block is 4 for this case.

The latter FEC is a Reed-Solomon (255,239) code; this code can correct up to 8 symbol errors, where each symbol contains 8 bits. There are 16 interleaved codecs; therefore, for the FEC to fail there must be at least 128 symbol errors. The resulting incorrect code block will therefore contain at least 128 bit errors (it may have more, since each symbol contains 8 bits). Since an STS-48c or STS-192c frame spans more than one ODUk frame, the STS-48c or -192c will also have 128 or more bit errors. For this case, $k = 4$.

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The above discussion indicates that the effect of FEC is to increase k because the error process (after FEC) is bursty. If FEC is employed end-to-end, the value of k can be determined by considering the correction capability of the FEC. In cases where a SONET path traverses several segments (server layers), some of which use FEC and some of which do not, the net effect on k depends on the relative contribution of each segment and may be difficult to estimate.

C.3 References

- [1] ITU-T Rec. G.707/Y.1322 (10/00), *Network Node Interface for the Synchronous Digital Hierarchy (SDH)*.¹⁵
- [2] J. Neyman, *On a New Class of "Contagious" Distributions, Applicable in Entomology and Bacteriology*, *Annals of Mathematical Statistics*, Vol. 10, No. 1, March, 1939, pp. 35 – 57.
- [3] B. Cornaglia, P. Pane, and M. Spini, *Errored Block Detection with Bit Interleaved Parity Failures in SDH Network*, *IEEE Transactions on Communications*, Vol. 43, No. 12, December, 1995, pp. 2904 - 2906.²

¹⁵ This document is available from the International Telecommunications Union. <<http://www.itu.int/ITU-T/>>.

ANNEX D BIBLIOGRAPHY

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ITU-T Recommendation G.828 (03/00), *Error Performance Parameters and Objectives for International, Constant Bit Rate Synchronous Digital Paths*.¹⁵

ITU-T Recommendation M.2101 (06/00), *Performance Limits and Objectives for Bringing-into-service and Maintenance of International SDH Paths and Multiplex Sections*.¹⁵