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SERIES G: TRANSMISSION SYSTEMS AND MEDIA,
DIGITAL SYSTEMS AND NETWORKS

Digital networks – Quality and availability targets

Availability performance parameters and objectives for end-to-end international constant bit-rate digital paths

ITU-T Recommendation G.827

ITU-T G-SERIES RECOMMENDATIONS

TRANSMISSION SYSTEMS AND MEDIA, DIGITAL SYSTEMS AND NETWORKS

INTERNATIONAL TELEPHONE CONNECTIONS AND CIRCUITS	G.100–G.199
GENERAL CHARACTERISTICS COMMON TO ALL ANALOGUE CARRIER-TRANSMISSION SYSTEMS	G.200–G.299
INDIVIDUAL CHARACTERISTICS OF INTERNATIONAL CARRIER TELEPHONE SYSTEMS ON METALLIC LINES	G.300–G.399
GENERAL CHARACTERISTICS OF INTERNATIONAL CARRIER TELEPHONE SYSTEMS ON RADIO-RELAY OR SATELLITE LINKS AND INTERCONNECTION WITH METALLIC LINES	G.400–G.449
COORDINATION OF RADIOTELEPHONY AND LINE TELEPHONY	G.450–G.499
TESTING EQUIPMENTS	G.500–G.599
TRANSMISSION MEDIA CHARACTERISTICS	G.600–G.699
DIGITAL TERMINAL EQUIPMENTS	G.700–G.799
DIGITAL NETWORKS	G.800–G.899
General aspects	G.800–G.809
Design objectives for digital networks	G.810–G.819
Quality and availability targets	**G.820–G.829**
Network capabilities and functions	G.830–G.839
SDH network characteristics	G.840–G.849
Management of transport network	G.850–G.859
SDH radio and satellite systems integration	G.860–G.869
Optical transport networks	G.870–G.879
DIGITAL SECTIONS AND DIGITAL LINE SYSTEM	G.900–G.999
QUALITY OF SERVICE AND PERFORMANCE – GENERIC AND USER-RELATED ASPECTS	G.1000–G.1999
TRANSMISSION MEDIA CHARACTERISTICS	G.6000–G.6999
DIGITAL TERMINAL EQUIPMENTS	G.7000–G.7999
DIGITAL NETWORKS	G.8000–G.8999

For further details, please refer to the list of ITU-T Recommendations.

ITU-T Recommendation G.827

Availability performance parameters and objectives for end-to-end international constant bit-rate digital paths

Summary

This Recommendation defines network performance parameters and objectives for the path elements and end-to-end availability of international constant bit-rate digital paths. These parameters are independent of the type of physical network supporting the end-to-end path, e.g., optical fibre, radio relay or satellite. Guidance is included on methods for improving availability and calculating the end-to-end availability of a combination of network elements.

Source

ITU-T Recommendation G.827 was approved on 13 September 2003 by ITU-T Study Group 13 (2001-2004) under the ITU-T Recommendation A.8 procedure.

Keywords

Availability, availability objectives, availability performance, availability ratio, unavailability ratio.

FOREWORD

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The World Telecommunication Standardization Assembly (WTSA), which meets every four years, establishes the topics for study by the ITU-T study groups which, in turn, produce Recommendations on these topics.

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In some areas of information technology which fall within ITU-T's purview, the necessary standards are prepared on a collaborative basis with ISO and IEC.

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CONTENTS

ITU-T Recommendation G.827

Availability performance parameters and objectives for end-to-end international constant bit-rate digital paths

1 Introduction

This Recommendation is part of a set of Recommendations that define the end-to-end transmission performance of the international telecommunications transport network. The performance definitions are based upon a 27 500 km Hypothetical Reference Path (HRP) defined in ITU-T Rec. G.826.

1.1 Scope

This Recommendation specifies the availability parameters and their objectives for path elements and end-to-end international constant bit rate (CBR) digital paths. These paths are based on the Plesiochronous Digital Hierarchy (PDH) as defined in ITU-T Rec. G.705, the Synchronous Digital Hierarchy (SDH) as defined in ITU-T Rec. G.707 or the Optical Transport Network (OTN) technology as defined in ITU-T Rec. G.709.

Future revisions of this Recommendation may consider the availability specification of other transmission technologies.

The availability parameters and their objectives are independent of the transmission media supporting the path, e.g., optical fibre, radio relay or satellite.

The availability objectives are considered to be complementary to the error performance objectives defined in ITU-T Recs G.821, G.826, G.828 and G.8201.

Packet or cell-based transport technologies are covered by other ITU-T Recommendations such as X.137 and I.357. The availability performance for switched connections in the ISDN is defined in ITU-T Rec. I.355.

The objectives given in this Recommendation may be used as a basis for the negotiation of enhanced performance, between the customer and the service provider, via a Service Level Agreement (SLA) as described in ITU-T Recs E.800 and E.801.

This Recommendation calls up other Recommendations for details about particular transport technologies such as measurement points and conditions and testing strategies. These Recommendations are

- for networks in general, including path protection arrangements: ITU-T Rec. G.805;
- for terrestrial optical fibre cable systems: ITU-T Recs G.872 and G.911;
- for microwave radio-relay transmission systems: ITU-R Recs F.1492 and F.1493;
- for satellite systems: ITU-R Rec. S.579-5;
- for details of the control protocol employed to switch between main and protection paths in SDH transport systems: ITU-T Recs G.841 and G.842.

1.2 Purpose

This Recommendation is intended to be useful to:

- purchasers of telecommunication capacity;
- transmission-network-planners, to determine the required infrastructure to support the telecommunication service offering;

- organizations responsible for the supply of capacity, to determine what additional end-to-end support may be needed (such as end-to-end protection switching) to fulfil the contracted quality of service objectives;
- network operators providing the network elements, to ensure that the contracted availability objectives are met;
- national public network supervisory bodies.

1.3 Application of this Recommendation

This Recommendation defines the availability of international end-to-end CBR digital paths based upon the availability of their constituent path elements.

A path is constructed using path elements that meet availability objectives obtained using the principles specified in 7.2. The designer will assemble the path elements into the path such that the path will meet the Table 2 objectives. The path may include various protection topologies; examples are given in Annex A.

The characteristics of path elements depend upon their length, their location in the end-to-end circuit and their quality category. More detailed analysis of their availability down to network operator domains, server layers, subnetworks or access groups is outside the scope of this Recommendation.

Techniques for improving the end-to-end availability by employing additional protection network elements are described in Annex A.

The availability is calculated from unity minus the unavailability.

Note that one or both of the end-to-end path's end points may be located at the user's premises.

Annex A also gives detailed guidance on methodologies for evaluating the end-to-end availability.

In some cases, an international telecommunications circuit may be provided by a group of private network operators. Then, the customer must negotiate the availability objectives required between these network operators to establish a SLA contract possibly using the performance specified in this Recommendation as guidance.

2 References

The following ITU-T Recommendations and other references contain provisions which, through reference in this text, constitute provisions of this Recommendation. At the time of publication, the editions indicated were valid. All Recommendations and other references are subject to revision; users of this Recommendation are therefore encouraged to investigate the possibility of applying the most recent edition of the Recommendations and other references listed below. A list of the currently valid ITU-T Recommendations is regularly published. The reference to a document within this Recommendation does not give it, as a stand-alone document, the status of a Recommendation.

[1] ITU-T Recommendation E.800 (1994), *Terms and definitions related to quality of service and network performance including dependability*.

[2] ITU-T Recommendation E.801 (1996), *Framework for Service Quality Agreement*.

[3] ITU-R Recommendation F.1492 (2000), *Availability objectives for real digital radio-relay links forming part of the international portion constant bit rate digital path at or above the primary rate*.

[4] ITU-R Recommendation F.1493 (2000), *Availability objectives for real digital radio-relay links forming part of national portion constant bit rate digital path at or above the primary rate*.

[5] ITU-T Recommendation G.705 (2000), *Characteristics of plesiochronous digital hierarchy (PDH) equipment functional blocks*.

[6] ITU-T Recommendation G.707/Y.1322 (2000), *Network node interface for the synchronous digital hierarchy (SDH)*.

[7] ITU-T Recommendation G.709/Y.1331 (2003), *Interfaces for the Optical Transport Network (OTN)*.

[8] ITU-T Recommendation G.805 (2000), *Generic functional architecture of transport networks*.

[9] ITU-T Recommendation G.821 (2002), *Error performance of an international digital connection operating at a bit rate below the primary rate and forming part of an Integrated Services Digital Network*.

[10] ITU-T Recommendation G.826 (2002), *End-to-end error performance parameters and objectives for international, constant bit-rate digital paths and connections*.

[11] ITU-T Recommendation G.828 (2000), *Error performance parameters and objectives for international, constant bit-rate synchronous digital paths*.

[12] ITU-T Recommendation G.8201 (2003), *Error performance parameters and objectives for multi-operator international paths within the Optical Transport Network (OTN)*.

[13] ITU-T Recommendation G.841 (1998), *Types and characteristics of SDH network protection architectures*.

[14] ITU-T Recommendation G.842 (1997), *Interworking of SDH network protection architectures*.

[15] ITU-T Recommendation G.872 (2001), *Architecture of optical transport networks*.

[16] ITU-T Recommendation G.911 (1997), *Parameters and calculation methodologies for reliability and availability of fibre optic systems*.

[17] ITU-T Recommendation I.355 (2000), *ISDN 64 kbit/s connection type availability performance*.

[18] ITU-T Recommendation I.357 (2000), *B-ISDN semi-permanent connection availability*.

[19] ITU-R Recommendation S.579-5 (2001), *Availability objectives for a hypothetical reference circuit and a hypothetical reference digital path when used for telephony using pulse code modulation, or as part of an integrated services digital network hypothetical reference connection, in the fixed-satellite service*.

[20] ITU-T Recommendation X.137 (1997), *Availability performance values for public data networks when providing international packet-switched services*.

3 Abbreviations

This Recommendation uses the following abbreviations:

AR Availability Ratio

CBR Constant Bit Rate

CP Customer Premises

FS Frontier Station

HRP Hypothetical Reference Path

IB International Border

ICPCE	Inter-Country Path Core Element
IG	International Gateway
IPCE	International Path Core Element
Mo	Mean time between outages
MTTR	Mean Time To Restore
NPCE	National Path Core Element
NPE	National Path Element
OI	Outage Intensity
OTN	Optical Transport Network
PDH	Plesiochronous Digital Hierarchy
PE	Path Element
PEP	Path End Point
SA	Service Availability
SDH	Synchronous Digital Hierarchy
SES	Severely Errored Second
SLA	Service Level Agreement
TIC	Terminal International Centre
U	Unavailability
UR	Unavailability Ratio
λ	Failure rate
μ	Restoration rate

4 Definitions

4.1 Availability

For the full details of the availability definitions, refer to ITU-T Recs G.826, G.828 or Annex A/G.8201.

4.1.1 Criteria for a single direction

A period of unavailable time begins at the onset of ten consecutive Severely Errored Second (SES) events. These ten seconds are considered to be part of unavailable time. A new period of available time begins at the onset of ten consecutive non-SES events (a non-SES event is a second that is an errored second, but not an SES, or is error free). These ten seconds are considered to be part of available time. Figure 1 illustrates this definition.

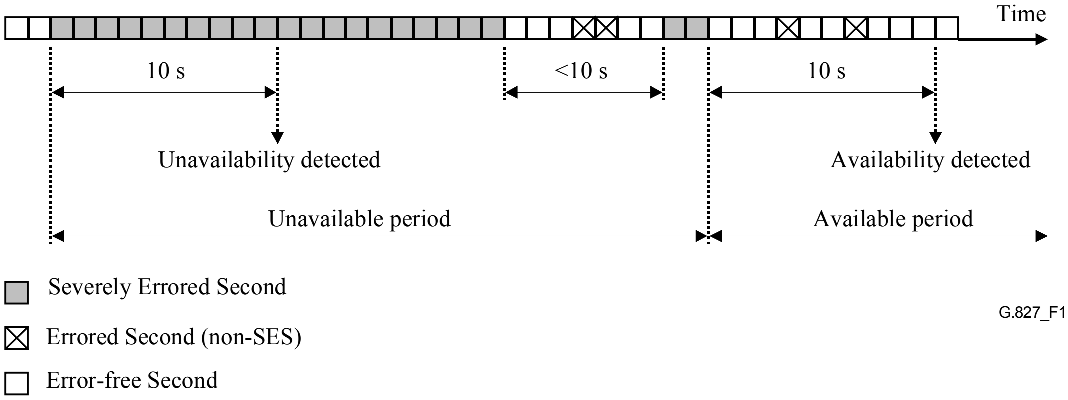


Figure 1/G.827 – Example of unavailability determination

The specification of SESs is dependent upon the system under consideration (please refer to the appropriate Recommendation).

4.1.2 Criterion for a bidirectional path or connection

A bidirectional path or connection is in the unavailable state if either one or both directions are in the unavailable state. This is shown in Figure 2.

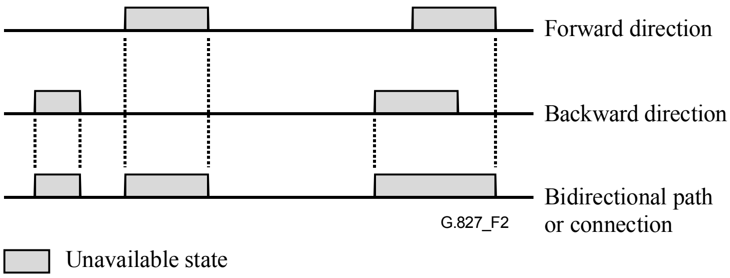


Figure 2/G.827 – Example of the unavailable state of a bidirectional path or connection

Available time is obtained by adding all the periods of available time from the observation period in a generic observation period.

Unavailable time is derived by adding all the periods of unavailable time during a generic observation period.

Availability is defined as the percentage of available time (to total time) in a generic observation period. This is also known as the Availability Ratio (AR).

Unavailability is defined as the percentage of unavailable time (to total time) in a generic observation period. This is also known as the Unavailability Ratio (UR).

4.2 End-to-end paths

An end-to-end path is a transport entity responsible for the integrity of client information transfer between path end points. End-to-end paths are made up of a combination of path elements.

4.3 Path elements

A Path Element (PE) is defined in this Recommendation as a portion of an end-to-end path for the purpose of availability specification.

PEs are defined by geographical rather than architectural considerations and their boundaries are not necessarily at the bit rate of the end-to-end path under consideration. For example, a 2 Mbit/s path may only physically exist at 140 Mbit/s at an international boundary.

4.4 Path element categories

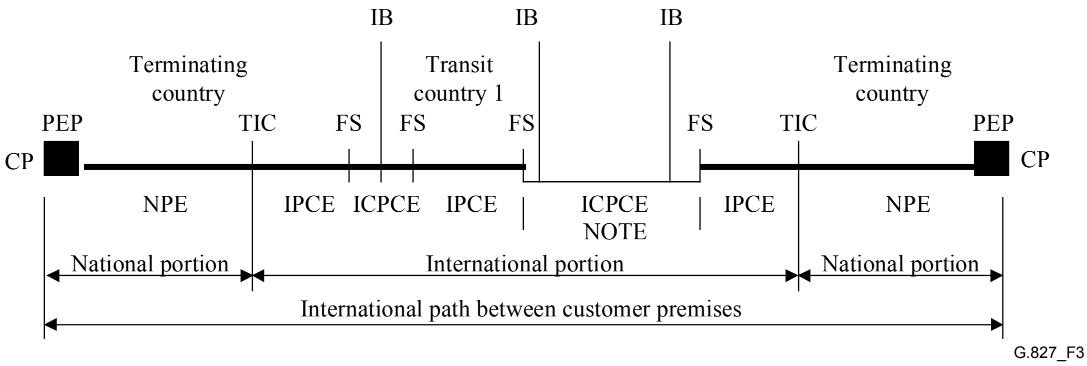
PEs are categorized according to:

1) their location in the network;
2) their length;
3) their performance level.

This Recommendation identifies three different geographical categories of PEs:

- Inter-Country Path Core Element (ICPCE);
- International Path Core Element (IPCE);
- National Path Element (NPE).

The conceptual location of these path element types is shown in Figure 3.



NOTE – This ICPCE crosses two international borders and is typically supported by a satellite or undersea cable transmission system.

CP	Customer Premises	IPCE	International Path Core Element
FS	Frontier Station	NPE	National Path Element
IB	International Border	PEP	Path End Point
ICPCE	Inter-Country Path Core Element	TIC	Terminal International Centre

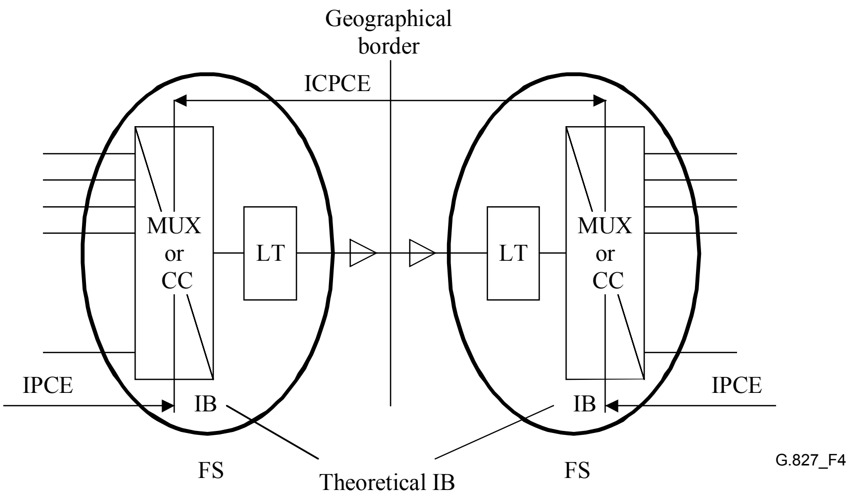
Figure 3/G.827 – Conceptual location of the elements of an end-to-end international path between customer premises

4.4.1 Inter-country path core elements

The ICPCE is the PE carried on the highest order digital path across the geographical border between two countries.

This element is limited by the Frontier Stations (FSs) where the highest order inter-country path may be terminated. When the highest order inter-country path is not terminated in the FS, the ICPCE is limited by the supporting inter-country section access point. An example of an ICPCE is given in Figure 4.

An ICPCE may be transported on a satellite, a terrestrial or an undersea cable transmission system. In the case of a satellite transmission system, the FS is considered to be located at the earth station.



CC	Cross Connect	IPCE	International Path Core Element
FS	Frontier Station	LT	Line Terminal
IB	International Border	MUX	Multiplexer
ICPCE	Inter-Country Path Core Element		

Figure 4/G.827 – An example of an ICPCE

4.4.2 International path core elements

The IPCE is the PE used in the core network within one country. The boundary of this element depends on its application. For a transit country, this element is limited by the two FSs. For a terminating country, this element is limited by the International Gateway (IG) and the FS.

4.4.3 National path elements

The NPE is a PE used in a terminating country to connect the international portion and the Path End Points (PEPs).

4.5 Performance level categories

Three performance level categories are defined in this Recommendation:

a) standard priority level;

b) high priority level;

c) pre-emptible priority level.

The "pre-emptible" priority level does not have a defined availability performance but it might be interrupted to provide protection capacity when required for another path. The "standard" performance category is the minimum requirement. The "high" performance category is a level of performance above the "standard" level.

Customers may negotiate any level of availability for any particular end-to-end path via a SLA.

5 Length categories

Length categories are defined by the following rules:

$$100\times(i-1) \leq L < 100\times i \quad (5\text{-}1)$$

where $i = 1, 2, ...$

This formula specifies length categories, in 100 km intervals. Each category is associated to an integer variable "k" which is used in the following formulas of 7.3 to determine the availability performance objectives for a PE of length L. Table 1 gives the values of "k" for each length category up to 10 000 km.

Except for PEs carried on undersea cables, the lengths refer to the actual route lengths or the air-route distance multiplied by a routing factor, whichever is smaller.

The routing factor is as follows:

- if the air-route distance is less than 1000 km, then the routing factor is 1.5;
- if the air-route distance is larger than 1000 km and less than 1200 km, then the calculated route length is taken to be 1500 km;
- if the air-route distance is larger or equal to 1200 km, then the routing factor is 1.25.

For a PE carried on an undersea cable, the actual cable route length is used.

Table 1/G.827 – Values of k as a function of the PE length

Km	**0**	**100**	**200**	**300**	**400**	**500**	**600**	**700**	**800**	**900**
0		1	2	3	4	5	6	7	8	9
1000	10	11	12	13	14	15	16	17	18	19
2000	20	21	22	23	24	25	1	2	3	4
3000	5	6	7	8	9	10	11	12	13	14
4000	15	16	17	18	19	20	21	22	23	24
5000	25	1	2	3	4	5	6	7	8	9
6000	10	11	12	13	14	15	16	17	18	19
7000	20	21	22	23	24	25	1	2	3	4
8000	5	6	7	8	9	10	11	12	13	14
9000	15	16	17	18	19	20	21	22	23	24
10000	25	26	27	28	29	30	31	32	33	34

The correct value to be used is contained in the cell corresponding to the lowest sum between row and column index that is greater than the PE length.

Examples:

Length = 3250 km, k = 8 (row 3000, column 300);

Length = 3300 km, k = 9 (row 3000, column 400).

6 Availability parameters

The duration of unavailable time must be greater than 10 seconds to meet the definition of unavailability. Shorter periods of corruption should be categorized under "Errored seconds" or SES and are not part of the availability performance.

6.1 Availability ratio and unavailability ratio

The term "availability" refers to the availability ratio (AR), which is the proportion of time that a path is in the available state during an observation period. AR is calculated by dividing the total available time during the observation period by the duration of the observation period.

The converse of AR, the unavailability ratio (UR), is the proportion of time that an end-to-end path is in the unavailable state during an observation period. UR is calculated by dividing the total unavailable time during the observation period by the duration of the observation period.

$$AR + UR = 1 \qquad (6\text{-}1)$$

The observation period is recommended to be one year.

The allocation of availability objectives to observation periods shorter than one year is outside the scope of this Recommendation.

The discussion of methods of obtaining realistic availability figures by employing various sampling schemes is outside the scope of this Recommendation.

Planned Available Time

If the connection is not planned to be a permanent connection, then the periods when the connection is not in service do not count in the calculation of its availability. This may impact on the choice of the observation period.

6.2 Mean time between outages and outage intensity

A period of unavailability is also known as an "Outage". The mean time between outages (Mo) is the average duration of intervals when the PE is available during a measurement period. The number of outages per measurement period is called the "Outage Intensity" (OI).

If the measurement period is one year and Mo is expressed in fractions of a year, then OI is the reciprocal of Mo.

NOTE – This relation assumes that the periods of unavailability are small compared to the periods of availability.

7 Availability objectives

7.1 End-to-end availability

The end-to-end availability of a path is normally based upon the long-term accumulated performance measurements of PEs. In a new network, the network planners will have based their plans on a working assumption about availability, so this figure may be adopted until more practical values can be collected.

The availability is usually calculated as the unavailability subtracted from unity (see Annex A for examples). However, if there is an overlap in the timing of any period of unavailability, then, from the perspective of the end-to-end path, this only counts as one period of unavailability. Such an overlap may be due to a major incident, such as a fire in an exchange, that would affect both the incoming and outgoing network elements.

Availabilities are normally collected for large ensembles of PEs rather than individual pairs or fibres. For the purposes of this Recommendation, it has been assumed that all PEs of a given type (defined by length and performance) within one domain (such as a country) will be covered by one target objective. Any particular network operator may hold more detailed information, but this point is outside the scope of this Recommendation.

7.2 End-to-end objectives

Table 2 specifies the end-to-end objectives for a 27 500 km HRP. An international digital path at or above the primary rate shall meet the objectives of Table 2 for all parameters concurrently.

The objectives apply to observation periods of one year (~365 consecutive days), using a sliding window with 24-hour granularity.

To meet these requirements in the longer term, it may be necessary to use more stringent values at the design stage.

Table 2/G.827 – End-to-end availability performance objectives for a 27 500 km international digital HRP at or above the primary rate

Rate	1.5 Mbit/s to 40 Gbit/s	
	AR	OI
High priority	98%	70
Standard priority	91%	250
Pre-emptible priority	F.F.S.	F.F.S.
NOTE – Values for OI are based on an MTTR of 4 hours.		

7.3 Availability objectives for path elements

7.3.1 Path elements availability ratio objectives

The PE availability ratio objectives are determined by the following equations:

$$AR_{jS} = 1 - (A_{jS} + k \times X_{jS}) \text{ for the standard priority} \quad (7\text{-}1)$$

$$AR_{jH} = 1 - (A_{jH} + k \times X_{jH}) \text{ for the high priority} \quad (7\text{-}2)$$

where:

parameter X is a variable to multiply length quanta and A is a constant for each different type of PE; these values are given in Table 3,

j = 1 for PE length < 2500 km

j = 2 for 2500 km < PE length < 5000 km

j = 3 for 5000 km < PE length < 7500 km

j = 4 for PE length > 7500 km.

subscript S indicates standard priority,

subscript H indicates high priority,

the variable "k" is from Table 1.

Table 3/G.827 – Values for PEs availability ratio calculations ($\times 10^{-4}$)

Path element	Perfor-mance level	A_1	X_1	A_2	X_2	A_3	X_3	A_4	X_4
Length		< 2500 km	< 2500 km	2500 up to 5000 km	2500 up to 5000 km	5000 up to 7500 km	5000 up to 7500 km	≥ 7500 km	≥ 7500 km
IPCE	Standard	0	3	75	4	150	5	250	5
	High	0	0.6	15	0.8	30	1	50	1
NPE	Standard	0	5	100	8	275	5	375	5
	High	0	0.8	20	1.6	55	1	75	1
ICPCE	Standard	0	25	100	40	275	25	375	25
	High	0	0.8	20	1.6	55	1	75	1
NOTE – Satellite links may be deployed in any single PE or any contiguous combination of them.									

7.3.2 Path elements outage intensity objectives

The PE outage intensity objectives are determined by the following equations:

$$OI_{jS} = B_{jS} + k \times Y_{jS} \text{ for the standard priority} \quad (7\text{-}3)$$

$$OI_{jH} = B_{jH} + k \times Y_{jH} \text{ for the high priority} \quad (7\text{-}4)$$

where:

j =1 for PE length < 2500 km

j = 2 for 2500 km ≤ PE length < 5000 km

j = 3 for 5000 km ≤ PE length < 7500 km

j = 4 for PE length ≥ 7500 km.

subscript S indicates standard priority,

subscript H indicates high priority,

values of B_{jS}, Y_{jS}, B_{jH}, Y_{jH} are given in Table 4,

the variable "k" is from Table 1.

Table 4/G.827 – Values for PEs outage intensity calculations (outages/year)

Path element	Perfor-mance level	B_1	Y_1	B_2	Y_2	B_3	Y_3	B_4	Y_4
Length		**< 2500 km**	**< 2500 km**	**2500 up to 5000 km**	**2500 up to 5000 km**	**5000 up to 7500 km**	**5000 up to 7500 km**	**≥ 7500 km**	**≥ 7500 km**
IPCE	Standard	4	0.6	14	1	35	1.4	65	2
	High	1	0.2	3	0.3	8	0.4	15	0.6
NPE	Standard	5	0.6	18	1	40	1.6	75	2
	High	1	0.4	4	0.4	10	0.4	16	0.6
ICPCE	Standard	5	0.6	18	1	40	1.6	75	2
	High	1	0.4	4	0.4	10	0.4	16	0.6
NOTE – OI objectives in Tables 2 and 4 are based on a MTTR value of 4 hours. It is recognized that some events due to anomalous working conditions, such as propagation impairments for radio applications, can give rise to self-healing unavailability events; such events, usually much shorter, are not taken into account. In any case, the overall AR given in Tables 2 and 3 should not be exceeded.									

8 Related availability parameters

Four other parameters are commonly used in describing availability performance. These are generally defined as follows:

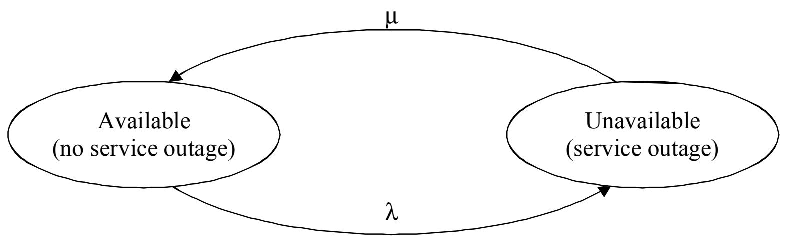
a) Mean Time To Restore (*MTTR*) is the average duration of unavailable service time intervals;

b) Failure rate (λ) is the average number of transitions from the available state to the unavailable state per unit available time;

c) Restoration rate (μ) is the average number of transitions from the unavailable state to the available state per unit unavailable time;

d) Unavailability (*U*) is the long-term ratio of unavailable service time to scheduled service time, expressed as a percentage.

Under the exponential distribution assumption of failure and restoration, the mathematical values for any of these parameters may be estimated from the values for AR (denoted by SA for "Service Availability" in Figure 5 and Mo as summarized in Figure 5.



a) State diagram

$$Mo = \frac{1}{\lambda} \qquad MTTR = \frac{1}{\mu}$$

$$SA = 100\left[\frac{Mo}{Mo + MTTR}\right] = 100\left[\frac{\mu}{\lambda + \mu}\right]$$

$$U = 100 - SA = 100\left[\frac{MTTR}{Mo + MTTR}\right] = 100\left[\frac{\lambda}{\lambda + \mu}\right]$$

b) Parameter relationships

Figure 5/G.827 – Basic availability model and parameters

The MTTR may be reduced by deploying a comprehensive network management system with a fast response time which is sometimes called "resource allocation" to distinguish it from management which is traditionally a slower system.

The extra complexity introduced by the management system should not degrade the availability due to false alarms if it is carefully designed.

Annex A

Examples of path topologies and end-to-end path availability calculations

A.1 Purpose

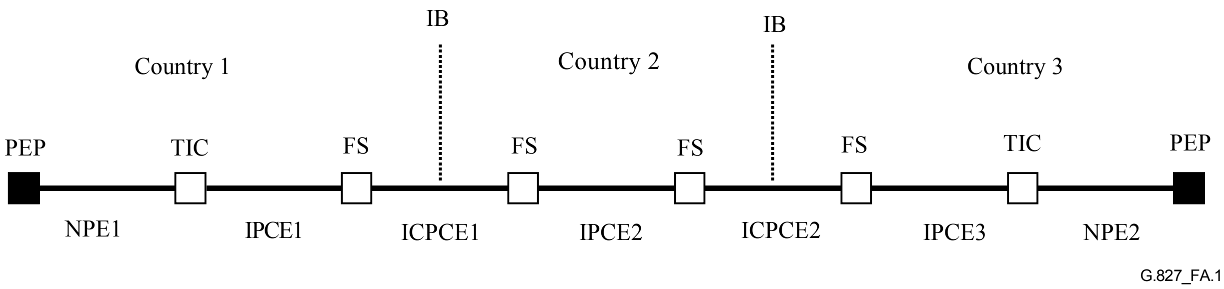
The purpose of this Annex is to provide guidance on the calculation of the end-to-end performance of a path from the objectives of the PEs, using example topologies.

More complex topologies may result from negotiations between customers and suppliers, but the principles of calculation given in these examples should still apply.

In practice, for any particular PE, some adjustment based upon local knowledge would be applied.

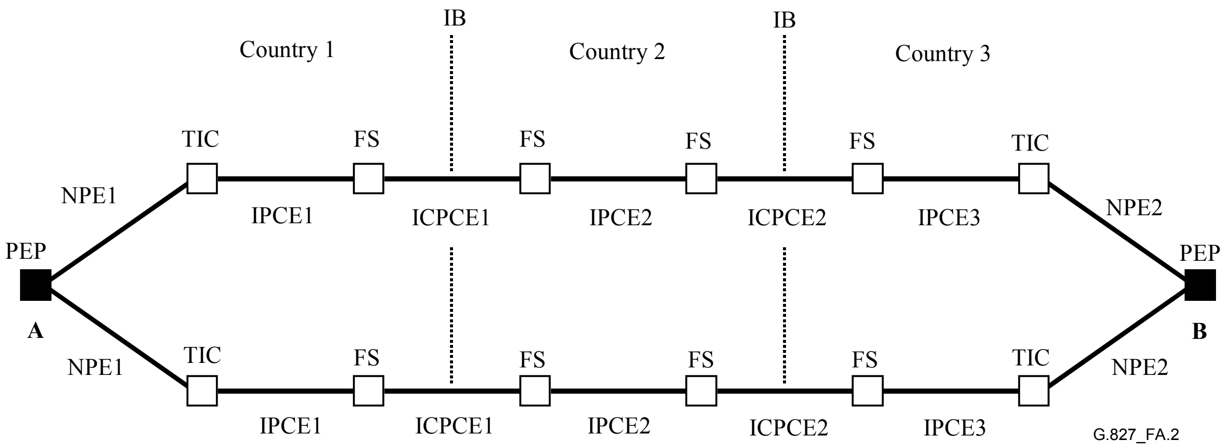
A.2 Path topologies

Figures A.1 and A.2 illustrate the basic path topologies that can be built using the PEs defined in this Recommendation.



FS	Frontier Station	NPE	National Path Element
IB	International Border	PEP	Path End Point
ICPCE	Inter-Country Path Core Element	TIC	Terminal International Centre
IPCE	International Path Core Element		

Figure A.1/G.827 – Example of a simple basic path without protection



FS	Frontier Station	NPE	National Path Element
IB	International Border	PEP	Path End Point
ICPCE	Inter-Country Path Core Element	TIC	Terminal International Centre
IPCE	International Path Core Element		

Figure A.2/G.827 – Example of a path with end-to-end protection

Figure A.1 shows a simple basic path without protection and Figure A.2 shows the addition of an end-to-end protection path which should have a separate routing for maximum protection.

This form of protection is called 1+1. Each path is a two-way connection with the transmit signal from each end permanently connected to both paths and a switching device at each receiver to select the best signal.

A more economical arrangement is to use one protection path to protect several other paths. This is known as a 1:n arrangement and requires selection switches at both transmitters and receivers.

A.3 End-to-end unavailability calculations

For the purposes of end-to-end availability calculations, it is more convenient to use the unavailability ratio.

For the purposes of illustration, it will be assumed that the unavailability performance of the constituent PEs follows a normal or Gaussian distribution and that it is small so that the contribution of each PE can, therefore, be considered to be independent, i.e., no overlap in the duration of the periods of unavailability.

A.3.1 Simple basic path

This corresponds to the topology shown in Figure A.1, where the path is made of i PEs.

Unavailability ratio

For the purposes of end-to-end availability calculations, it is more convenient to use the unavailability ratio than the availability ratio.

End-to-end unavailability ratio is simply the sum of the unavailability ratio of the constituent PEs.

Expressing this in mathematical terminology, the following notations apply:

ur: Unavailability ratio of a PE,

UR: Unavailability ratio of an end-to-end path,

Thus:

$$UR = \sum_i \left(ur_i \right) \tag{A-1}$$

The end-to-end availability is simply unity minus the results from Equations (A-1) and (A-2).

If other distributions are considered to be necessary (perhaps because they more closely represent the measured results obtained from the field), then these results may still apply as they are of a general nature, but calculating the results of a mixture of distributions would require more careful consideration.

Outage intensity

For the purposes of end-to-end calculations, it is more convenient to use the outage intensity than the mean time between service outage.

The outage intensity of the end-to-end path is simply the sum of the corresponding outage intensities of the PEs assuming that the outage intensity in each PE is small and the outages are, therefore, independent and do not overlap:

$$OI = \sum OI_j \tag{A-2}$$

A.3.2 1+1 end-to-end protection topology

In a topology such as that shown in Figure A.2 which uses two parallel paths and a protection switch at one end (for each direction of transmission), the calculations are as follows:

Unavailability

The unavailability of the end-to-end protected path is:

$$UR_{end\text{-}to\text{-}end} = \left(UR_1 \times UR_2 \right) + UR_A + UR_B \tag{A-3}$$

where UR_1, UR_2 are the unavailability ratios of each parallel path, UR_A and UR_B are the unavailability ratios of protection switches A and B.

Given that the two connections are independent of each other, this would result in a large improvement in the availability of the end-to-end path because typical values of the unavailability should be much less than one.

Outage intensity

The outage intensity of the protected path between points A and B in Figure A.2 is dependent upon the way the protection circuit is used.

The end-to-end outage intensity is given by the formula:

$$OI_{end\text{-}to\text{-}end} = \left(OI_1 \times UR_2 \right) + \left(OI_2 \times UR_1 \right) + OI_A + OI_B \tag{A-4}$$

where OI_1 and OI_2 are the outage intensity of each parallel path, OI_A and OI_B are the outage intensity of the protection switches A and B.

A.3.3 1:n protection ratio topology

There are two situations that must be covered by this analysis:

a) the protection channel is faulty when one of the working channels suffers an outage;

b) the protection channel is in use when a second working channel suffers an outage.

Situation a is the same as the 1+1 case so the unavailability is $= UR_w \times UR_p$, if protection switches are not considered (UR_w is the unavailability of the working channel, and UR_p is the unavailability of the protection channel).

Situation b has to consider the unavailability of all the other channels, plus the contention for the protection channel when two working channels suffer a simultaneous outage.

Therefore,

$$\mathrm{U} = \left\{UR_w \times \left(\sum UR_{w\text{-}remaining\text{-}channels}\right)\right\} \times \frac{1}{2}$$

$$= \left\{UR_w \times \left(UR_w(n-1)\right)\right\} \times \frac{1}{2}$$

The resulting unavailability UR is the sum of cases a and b.

$$UR = UR_w \times UR_p + \left\{UR_w \times \left(UR_w(n-1)\right)\right\} \times \frac{1}{2}$$

$$= UR_w\left[UR_p + UR_w \frac{(n-1)}{2}\right]$$

If all channels have the same unavailability U, then the result is:

$$UR = U^2 + \left\{U \times U(n-1)\right\} \times \frac{1}{2}$$

$$UR = U^2\left\{\frac{n+1}{2}\right\}$$

A.3.4 More complex topologies

Ring topologies

Figure A.3 illustrates an SDH ring topology showing that traffic can be rerouted around a failed link but the protection route depends upon the switching capabilities of the various nodes on the ring and may not be the shortest distance between two nodes.

ITU-T Rec. G.841 contains great detail on the many intricacies of ring topologies, structure (two or four fibre rings) and node functionality as economic considerations do not allow all nodes on the ring to have switching capability.

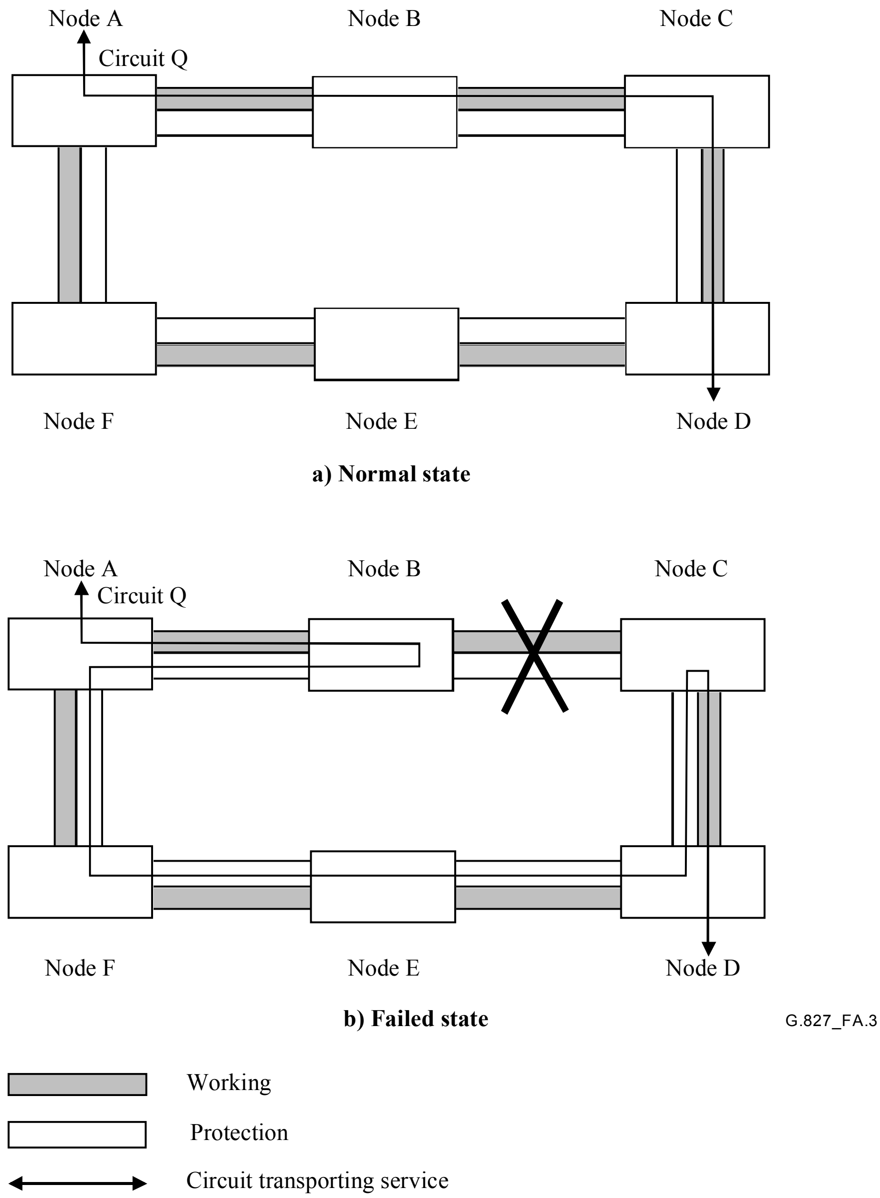


Figure A.3/G.827 – Ring topology in working and failed condition

A.4 Large-scale telecommunication networks

When alternative routings are sought in nationwide networks, the problem is rather complex. Several papers such as [B-3] and [B-11] from the Bibliography (Appendix I) address this type of issue.

Appendix I

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Appendix II

Calculations and service levels supporting the end-to-end availability objectives

Examples of calculations

The following calculations for AR and OI of PEs are based on:

– A simple serial arrangement of all PEs;

– 2 NPEs of 450 km each;

– 2 IPCEs of 850 km each and 2 IPCEs of 3500 km each;

– 3 ICPCEs of 1450 km each.

Assuming all Standard PEs, we obtain the following end-to-end results:

$$AR = 1-[2\times25\times10^{-4} + 2\times27\times10^{-4} + 2\times139\times10^{-4} + 3\times75\times10^{-4}]$$

$$= 1-[607\times10^{-4}] = 0.939 = 93.9\%$$

$$OI = (2\times8 + 2\times9.4 + 2\times30 + 3\times14) = 137$$

Service Levels

Information on service levels normally provided by network operators can be found in operators' websites.

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