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SERIES E: OVERALL NETWORK OPERATION, TELEPHONE SERVICE, SERVICE OPERATION AND HUMAN FACTORS

Quality of service, network management and traffic engineering – Traffic engineering – Determination of the number of circuits in automatic and semi-automatic operation

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Dimensioning at a circuit group with multi-slot bearer services and overflow traffic

ITU-T Recommendation E.527

(Formerly CCITT Recommendation)

ITU-T E-SERIES RECOMMENDATIONS

OVERALL NETWORK OPERATION, TELEPHONE SERVICE, SERVICE OPERATION AND HUMAN FACTORS

OPERATION, NUMBERING, ROUTING AND MOBILE SERVICES	
INTERNATIONAL OPERATION	
Definitions	E.100–E.103
General provisions concerning Administrations	E.104–E.119
General provisions concerning users	E.120–E.139
Operation of international telephone services	E.140–E.159
Numbering plan of the international telephone service	E.160–E.169
International routing plan	E.170–E.179
Tones in national signalling systems	E.180–E.189
Numbering plan of the international telephone service	E.190–E.199
Maritime mobile service and public land mobile service	E.200–E.229
OPERATIONAL PROVISIONS RELATING TO CHARGING AND ACCOUNTING IN THE INTERNATIONAL TELEPHONE SERVICE	
Charging in the international telephone service	E.230–E.249
Measuring and recording call durations for accounting purposes	E.260–E.269
UTILIZATION OF THE INTERNATIONAL TELEPHONE NETWORK FOR NON-TELEPHONY APPLICATIONS	
General	E.300–E.319
Phototelegraphy	E.320–E.329
ISDN PROVISIONS CONCERNING USERS	
International routing plan	E.350–E.399
QUALITY OF SERVICE, NETWORK MANAGEMENT AND TRAFFIC ENGINEERING	
NETWORK MANAGEMENT	
International service statistics	E.400–E.409
International network management	E.410–E.419
Checking the quality of the international telephone service	E.420–E.489
TRAFFIC ENGINEERING	
Measurement and recording of traffic	E.490–E.505
Forecasting of traffic	E.506–E.509
Determination of the number of circuits in manual operation	E.510–E.519
Determination of the number of circuits in automatic and semi-automatic operation	**E.520–E.539**
Grade of service	E.540–E.599
Definitions	E.600–E.699
ISDN traffic engineering	E.700–E.749
Mobile network traffic engineering	E.750–E.799
QUALITY OF TELECOMMUNICATION SERVICES: CONCEPTS, MODELS, OBJECTIVES AND DEPENDABILITY PLANNING	
Terms and definitions related to the quality of telecommunication services	E.800–E.809
Models for telecommunication services	E.810–E.844
Objectives for quality of service and related concepts of telecommunication services	E.845–E.859
Use of quality of service objectives for planning of telecommunication networks	E.860–E.879
Field data collection and evaluation on the performance of equipment, networks and services	E.880–E.899

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

ITU-T RECOMMENDATION E.527

DIMENSIONING AT A CIRCUIT GROUP WITH MULTI-SLOT BEARER SERVICES AND OVERFLOW TRAFFIC

Summary

This Recommendation deals with dimensioning methods for a set of circuit groups handling multi-slot bearer services which consist of first-choice groups and an overflow group to which overflow traffic from the first-choice groups are offered. For this purpose, this Recommendation provides example methods for calculating peakedness of the overflow traffic and example methods for calculating individual call blocking probabilities of the overflow group.

Source

ITU-T Recommendation E.527 was revised by ITU-T Study Group 2 (1997-2000) and was approved under the WTSC Resolution No. 1 procedure on 13 March 2000.

FOREWORD

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NOTE

In this Recommendation, the expression "Administration" is used for conciseness to indicate both a telecommunication administration and a recognized operating agency.

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CONTENTS

		Page
1	Scope of this Recommendation	1
2	References	1
3	Terms and definitions	1
4	Introduction	1
5	Modelling for dimensioning of circuit groups	2
5.1	Modelling of offered traffic	2
5.2	Categories of circuit groups	2
5.3	GOS objectives	2
6	Characterization of overflow traffic from a first-choice group	3
6.1	Calculating traffic intensity of individual overflow	3
6.2	Calculating peakedness of individual overflows	3
7	Dimensioning methods for an overflow group	3
7.1	Principles	3
7.2	Calculating individual call blocking probabilities	3
8	History	4
9	Bibliography	4
Annex A – Example methods for calculating overflow variances from a first-choice group		4
A.1	Assumptions and notations	4
A.2	Variance calculation methods	5
	A.2.1 Exact solution method	5
	A.2.2 Approximation method	6
Annex B – Example method for calculating individual call blocking probabilities of an overflow group		7
B.1	Reduced network method	7
B.2	Notations	7
B.3	Determination of equivalent capacity n_i	8
B.4	Time congestion Π	8
B.5	Blocking probability B_i	9
B.6	The second overflow	9
B.7	Field of application	9
B.8	Processing time and programming effort	9

Recommendation E.527

DIMENSIONING AT A CIRCUIT GROUP WITH MULTI-SLOT BEARER SERVICES AND OVERFLOW TRAFFIC

(revised in 2000)

1 Scope of this Recommendation

This Recommendation deals with dimensioning methods for a set of circuit groups handling multi-slot bearer services which consist of first-choice groups and an overflow group to which overflow traffic from the first-choice groups are offered. For this purpose, this Recommendation provides example methods for calculating peakedness of the overflow traffic and example methods for calculating individual call blocking probabilities of the overflow group.

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; all 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.

– ITU-T Recommendation E.524 (1999), *Overflow approximations for non-random inputs*.

– ITU-T Recommendation E.526 (1993), *Dimensioning a circuit group with multi-slot bearer services and no overflow inputs.*

– CCITT Recommendation E.731 (1992), *Methods for dimensioning resources operating in circuit switched mode*.

– ITU-T Recommendation E.737 (1997), *Dimensioning methods for B-ISDN*.

3 Terms and definitions

Recommendation E.600 provides general terminology in traffic engineering used in this Recommendation.

4 Introduction

This Recommendation presents methods for dimensioning a circuit group with multi-slot bearer services and overflow traffic. Methods for dimensioning a circuit group with multi-slot bearer services and no overflow traffic are presented in Recommendation E.526. Thus this Recommendation complements Recommendation E.526.

This Recommendation treats an overflow group to which multiple overflow traffic streams from the first-choice groups. It is assumed that both overflow groups and first-choice groups are operated with full availability (see Recommendation E.731).

Individual traffic streams will be expressed, on the one hand, in calls as in Recommendation E.524, and on the other in busy circuits as in Recommendation E.526.

This Recommendation is also related to Recommendations E.731 and E.737 in that the dimensioning methods presented in these Recommendations are based on the technique of multi-slot traffic modelling of a circuit-switched network which handles a mixed traffic with different bandwidth requirements.

5 Modelling for dimensioning of circuit groups

5.1 Modelling of offered traffic

For traffic engineering purpose, multi-slot bearer traffic is often characterized by the following parameters:

- traffic stream identification, denoted by i;
- call arrival rate for traffic stream i, denoted by λ_i;
- mean holding time for traffic stream i, denoted by $1/\mu_i$;
- number of circuits occupied by a call for traffic stream i, denoted by d_i;
- traffic intensity measured in number of calls for traffic stream i, denoted by A_i ($A_i = \lambda_i/\mu_i$);
- peakedness factor for traffic stream i, denoted by Z_i.

5.2 Categories of circuit groups

In this Recommendation, the following two categories of circuit groups with multi-slot bearer services are considered.

a) *First-choice group*

A first-choice group is a circuit group to which fresh traffic is offered. The fresh traffic is modelled by a Poisson arrival process and thus its peakedness factor is one. The first-choice group with multi-slot bearer services may handle various traffic streams of calls which hold different numbers of time slots when accepted.

Following the definitions and notations in Recommendation E.526, the size of the first-choice group is represented by the number of circuits in the group.

b) *Overflow group*

An overflow group is a circuit group to which overflow traffic from the first-choice groups is offered. It may handle fresh traffic which is offered to it as well.

The size of the overflow group is also represented by the number of circuits in the group.

5.3 GOS objectives

For the purpose of dimensioning circuit groups with multi-slot bearer services, call blocking probabilities are considered as an important GOS parameter. Thus, the objectives of link call blocking probabilities and/or end-to-end call blocking probabilities are often used in a dimensioning process of a network which consists of circuit groups. Since end-to-end call blocking probabilities are often calculated from the link call blocking probabilities and routing patterns as described in Recommendation E.737, it is important to evaluate individual call blocking probabilities at a circuit group. This Recommendation, therefore, focuses on methods for calculating individual call blocking probabilities at the circuit group level.

6 Characterization of overflow traffic from a first-choice group

6.1 Calculating traffic intensity of individual overflow

Once individual call blocking probabilities are obtained at a first-choice group, the traffic intensities O_i of individual overflows can be evaluated as follows:

$$O_i = A_i B_i \tag{6-1}$$

where B_i denotes the call blocking probability of the i-th traffic stream at the first-choice group. Example methods for calculating the call blocking probability B_i are given in Recommendations E.526, E.731 and E.737.

6.2 Calculating peakedness of individual overflows

To characterize the overflow traffic for the purpose of dimensioning the overflow group, the peakednesses of the individual overflow traffic offered to the overflow group are often used. The peakedness Z_i is defined as:

$$Z_i = V_i / O_i \tag{6-2}$$

where V_i denotes the variance of the overflow traffic.

Example methods for calculating the variances and thus peakednesses of individual overflow are given in Annex A.

7 Dimensioning methods for an overflow group

7.1 Principles

The basic problem of dimensioning an overflow group is to determine the size of the group and the parameter values of service protection schemes such as a trunk reservation (see Recommendations E.731 and E.737), if applied, under the constraint of call blocking objectives in an economical way for a given offered traffic condition. Note that the overflow traffic streams offered to the group may be characterized by its traffic intensity and peakedness. If the overflow traffic is directly offered from a first-choice group, its intensity and peakedness may be calculated by using the methods given in clause 6.

To dimension the overflow group, in principle, the following iterative procedure is used:

Step 1: Start with an initial set of values of the group size and, if applied, of parameters of service protection schemes.

Step 2: Evaluate individual blocking probabilities of the calls at the group for the current set of group size and parameter values to check if the blocking objectives are satisfied.

Step 3: If the objectives are all met and a certain optimization criterion is met as well, end the procedure. Otherwise, modify the group size and/or the parameter values of service protection schemes and return to Step 2.

As seen in Step 2 above, it is needed to calculate all the call blocking probabilities for the group.

7.2 Calculating individual call blocking probabilities

Several methods are available for calculating approximate individual call blocking probabilities at the overflow group. Table A.1/E.737 gives a (not exhaustive) list of available methods.

Annex B gives another example method which is not included in Table A.1/E.737.

8 History

The first issue in 1995, revised in 2000.

9 Bibliography

[1] ODA (T.): Moment Analysis for Traffic Associated with Markovian queueing Systems, *IEEE Transactions on Communications*, Vol. 39, No. 5, pp. 737-746, May 1991.

[2] LE GALL (P.): Overflow traffic combination and cluster engineering, *Proceedings of ITC*-11, paper 2.2 B-1, Kyoto 1985.

[3] de PAZ (C.): A non-linear dynamic analysis of overflow traffic, *Comunicaciones de Telefónica I + D*, No. 19, December 2000.

ANNEX A

Example methods for calculating overflow variances from a first-choice group

A.1 Assumptions and notations

Consider a first-choice group with multi-slot bearer services to which Poisson traffic streams are input. It is assumed that the circuit group is operated in full availability. The following notations are used.

Model parameters

N capacity of the group (number of slots in the group).

I number of traffic streams.

i identifier of traffic stream, $i = 1, 2, \ldots, I$.

λ_i arrival rate of traffic stream i.

μ_i reciprocal of mean holding time of calls in stream i.

A_i traffic intensity measured in number of calls, $A_i = \lambda_i/\mu_i$.

d_i number of circuits used by a call in stream i.

B_i call blocking probability of traffic stream i at the first-choice group.

O_i mean of overflow i.

V_i variance of overflow i.

Z_i peakedness of overflow i.

Notations for calculation

n_i number of calls in stream i in progress.

$\boldsymbol{n}$ state of the group, $\boldsymbol{n} = (n_1, n_2, \ldots, n_I)$.

E state space of the group $E = (\boldsymbol{n})$.

$|E|$ total number of states in the state space E.

$\boldsymbol{Q}$ $|E| \times |E|$ coefficient matrix of steady state equations.

π steady state probabilities vector of the group.

$\boldsymbol{R}_i$ $|E| \times |E|$ overflow rate matrix of traffic stream i.

$\boldsymbol{f}_i$ the first moment vector of overflow i.

F_i the first moment of overflow i.

S_i the second moment of overflow i.

$\boldsymbol{e}$ $|E| \times 1$ vector with all the element equal to unity.

$\boldsymbol{I}$ $|E| \times |E|$ diagonal matrix with all the diagonal elements equal to unity.

Note that the steady state probabilities π are given as a solution of $\pi\boldsymbol{Q} = 0$ and $\pi\boldsymbol{e} = 1$ and that it has the product-form solution in special cases, as stated in Recommendations E.526, E.731 and E.737.

The overflow rate matrix $\boldsymbol{R}_i = [r_i(\boldsymbol{n}_1, \boldsymbol{n}_2)]$ is a diagonal matrix whose $\boldsymbol{n}$-th diagonal element $r_i(\boldsymbol{n}, \boldsymbol{n})$ is given as follows:

$$r_i(\boldsymbol{n},\boldsymbol{n}) = \begin{cases} \lambda_i & : \text{ if an arriving call in stream } i \text{ is rejected at state } \boldsymbol{n}, \\ 0 & : \text{ otherwise.} \end{cases} \qquad \text{(A.1-1)}$$

A.2 Variance calculation methods

A.2.1 Exact solution method

The mean and variance of stream i overflow can be calculated by the following procedure.

Exact calculation procedure

Step 1) Calculate π and B_i.

Step 2) Calculate the mean O_i from $O_i = A_i B_i$.

Step 3) Solve the following system of linear equation for the vector $\boldsymbol{f}_i$:

$$\boldsymbol{f}_i(\mu_i \boldsymbol{I} - \boldsymbol{Q}) = \pi \boldsymbol{R}_i \qquad \text{(A.2-1)}$$

Step 4) Calculate F_i and S_i by:

$$F_i = O_i \qquad \text{(A.2-2)}$$

$$S_i = \left(\frac{1}{\mu_i}\right) \boldsymbol{f}_i \boldsymbol{R}_i e + F_i \qquad \text{(A.2-3)}$$

Step 5) Calculate the variance V_i and peakedness Z_i by:

$$V_i = S_i - (F_i)^2 \qquad \text{(A.2-4)}$$

$$Z_i = V_i / O_i \qquad \text{(A.2-5)}$$

Derivation of the equations (A.2-1) to (A.2-3) and numerical examples can be found in [1]. The above calculation procedure for the variances can also be applied to the multi-slot groups where a service protection scheme such as trunk reservation described in Recommendations E.526, E.731 and E.737 is used.

It should be remarked that, when the size of group and/or the number of traffic streams are large, computational complexity of solving the above equation (A.2-1) in Step 3) becomes considerably large due to high dimensionality.

A.2.2 Approximation method

In order to lessen the computational complexity to calculate the second moment S_i, the following approximation method may be used when the circuit group is operated in full availability.

The principle of the approximation method is to establish a hypothetical stochastic process whose state space size is tractably smaller than that of the original state space E. Consider a state space $E' = (j : 0 \leq j \leq N)$. Assuming that the group is operated by complete sharing policy and the probabilities π are known and also letting Ej denote a subspace of E of the group such that $J = (\boldsymbol{n} : \Sigma_{i=1,2,\ldots,I} d_i n_i = j)$, the state transition rates $q(j_1, j_2)$ in the state space E' are set as follows:

$$q(j_1, j_2) = \begin{cases} \lambda_i & : \ 0 \leq j_1 \leq N - d_i, j_2 = j_1 + d_i, \text{ for all } i, \\ \xi_i(j_i) & : \ d_i \leq j_1 \leq N, j_2 = j_1 - d_i, \quad \text{for all } i, \\ 0 & : \ \text{otherwise} \end{cases} \tag{A.2-6}$$

where $\xi_k(j)$ is given by:

$$\xi_i(j) = \mu_i E\left[n_i \middle| \sum_{i=1,2,\ldots,I} d_i n_i = j \right] = \mu_i \left\{ \sum_{n \in Ej} n_i \pi(\boldsymbol{n}) \right\} / \left\{ \sum_{n \in Ej} \pi(\boldsymbol{n}) \right\} \tag{A.2-7}$$

The following notations are used as regards to the state transition model:

- $\boldsymbol{Q'}$ — $N \times N$ coefficient matrix of the steady state equations, $\boldsymbol{Q'} = [q(j_1, j_2)]$.
- π' — $N \times 1$ vector with N element that satisfies the system of equations $\pi'\boldsymbol{Q'} = 0$ and $\pi' e = 1$.
- $\boldsymbol{R}_i'$ — $N \times N$ overflow rate matrix of traffic stream i.
- $\boldsymbol{f}_i'$ — the first moment vector of overflow i.
- S_i' — approximate second moment of overflow i.

Note that it holds that $\pi'(j) = \Sigma_{\boldsymbol{n} \in Ej} \pi(\boldsymbol{n})$. The matrix $\boldsymbol{R}_i' = [r_i'(j_1, j_2)]$ is a diagonal matrix whose j-th diagonal element $r_i'(j, j)$ is given as follows:

$$r_i'(j, j) = \begin{cases} \lambda_i & : \ \text{if an arriving call in stream } i \text{ is rejected at state } j, \\ 0 & : \ \text{otherwise.} \end{cases} \tag{A.2-8}$$

The calculation procedure for an approximation to the variance of each overflow can be constructed as follows:

Approximation procedure

Step 1) Calculate π and B_i.

Step 2) Calculate the mean O_i from $O_i = A_i B_i$.

Step 3) Solve the following system of linear equation for the vector $\boldsymbol{f}_i'$:

$$\boldsymbol{f}_i' (\mu_i \boldsymbol{I} - \boldsymbol{Q'}) = \pi' \boldsymbol{R}_i' \tag{A.2-9}$$

Step 4) Calculate F_i and S_i' by:

$$F_i = O_i \tag{A.2-10}$$

$$S_i' = (1/\mu_i) \boldsymbol{f}_i' \boldsymbol{R}_i' \boldsymbol{e} + F_i \tag{A.2-11}$$

Step 5) Calculate the approximate variance V_i' and peakedness Z_i' by:

$$V_i' = S_i' - (F_i)^2 \tag{A.2-12}$$

$$Z_i' = V_i'/O_i \tag{A.2-13}$$

Numerical examples can be found in [1]. Especially, when all the service rates μ_i are the same and no trunk reservation is applied, the approximation is good.

ANNEX B

Example method for calculating individual call blocking probabilities of an overflow group

B.1 Reduced network method

This method is derived from [2].

B.2 Notations

For partial overflow traffic of $n^{0,i}$ (i = 1, ..., x)

- number of simultaneous time slots: d_i.
- traffic intensity (in calls): b_i.
- traffic intensity (in circuits): $(b_i \cdot d_i)$.
- overflow function: $\rho_i(n)$.
- peakedness factor: $z_i = \frac{\text{variance}}{\text{mean}}(\text{of traffic})$.
- equivalent capacity (in calls): n_i.

For the first-choice circuit group of $n^{0,i}$

- number of circuits: m_i.
- offered traffic intensity (in calls): a_i.
- probability of overflow: $p_i = E_{mi/di}(a_i)$ where $E_n(a)$ is the Erlang loss formula extended to the case where n need not be an integer. We have the relationship: $b_i = a_i p_i$.

For the overflow group

- number of circuits: N.
- total traffic intensity (in calls): $b = \sum_{i=1}^{x} b_i$
- total traffic intensity (in circuits): $M = \sum_{i=1}^{x} b_i d_i$
- reduction factor: Z_0.
- time congestion: Π
  - Second overflow traffic intensity (in calls): O_i.
  - Probability of partial blocking: $B_i = O_i/b_i$.

B.3 Determination of equivalent capacity n_i

The overflow function $\rho_i(n)$ is defined by the following recurrent process, derived from recurrent process (6-1) in E.524:

$$\rho_i(0) = p_i = E_{m_i/d_i}, \rho_i(0) = p_i = E_{m_i/d_i}(a_i), \frac{n}{\rho_i(n)} = \left(\frac{m_i}{d_i} + n - a_i\right) + a_i \rho_i(n-1) \qquad \text{(B-1)}$$

This recurrent process may produce numerical instabilities leading to values with significant numerical error when the following condition occurs:

$$\frac{\alpha_i(n) - \sqrt{a_i \cdot (n+1)}}{a_i} < \rho_i(n) < \frac{\alpha_i(n) + \sqrt{a_i \cdot (n+1)}}{a_i} \qquad \text{(B-2)}$$

with:

$$\alpha_i(n) = a_i - \frac{m_i}{d_i} - n - 1 \qquad \text{(B-3)}$$

To avoid this computational difficulty, the following tight upper bound to $\rho_i(n)$ can be used (see [3]):

$$\rho_i(n) < \frac{\sqrt{\alpha_i^2(n) + 4a_i \cdot (n+1)} - \alpha_i(n)}{2a_i} \qquad \text{(B-4)}$$

with $\alpha_i(n)$ given by formula (B-3). This upper bound has the following two properties:

a) The upper bound becomes tighter as n increases.

b) It is calculated directly from formula (B-4) without the recursive process.

The *equivalent capacity* n_i (in calls) is the solution of the following set of equations, derived from the set (6-2) of Recommendation E.524:

$$\frac{n_i}{N} = \frac{a_i \rho_i(n_i) / D_i(n_i + 1)}{\sum_{k=1}^{x} a_k d_k \rho_k(n_k) / D_k(n_k + 1)}, \; i = 1, ..., \text{x} \qquad \text{(B-5)}$$

with:

$$D_i(n) = 1 + a_i\,[\rho_i(n) - \rho_i(n-1)] \qquad \text{(B-6)}$$

The only modification is the insertion of the parameter d_k in the denominator of (6-2) in E.524. The *peakedness factor* z_i is given by the expression:

$$z_i = D_i(1) \qquad \text{(B-7)}$$

NOTE – For direct traffic we have: $m_i = 0, b_i = a_i, \rho_i(n) = D_i(n) = 1$.

B.4 Time congestion Π

The expression (A-3) in Annex A/E.526 becomes:

$$\Pi = B_1 \approx \left(\frac{1}{Z_0}\right) \cdot E_{N/Z_0}\left(M/Z_0\right) \qquad \text{(B-8)}$$

the reduction factor becoming:

$$Z_0 = \frac{\sum_{i=1}^{x} a_i d_i^2 \rho_i(n_i)}{\sum_{i=1}^{x} b_i d_i} \quad \text{(B-9)}$$

$E_n(a)$ is the Erlang loss formula with n fractional. It will be remembered that Π is equal to the blocking probability B_1 of a direct traffic (m_i = 0) with simple time slots (d_i = 1) and arrivals conforming to Poisson's law.

B.5 Blocking probability B$_i$

The factor $H_i(d_i)$ is the same as the factor H_i in Annex A/E.526. We thus obtain, for the blocking probability of partial traffic stream $n^{0,\,i}$:

$$B_i = B_1 \cdot \frac{\rho_i(n_i)}{E_{m_i/d_i}(a_i)} \cdot H_i(d_i) \quad \text{with} \quad H_i(d_i) = \frac{K^{d_i} - 1}{K - 1} \quad \text{(B-10)}$$

where the term K is defined as:

$$K = \left[\frac{N}{M}\right]^{1/Z} \text{ with : } V = \sum_{i=1}^{x} b_i d_i^2 \text{ and } Z = \frac{V}{M} \quad \text{(B-11)}$$

B.6 The second overflow

Formula (6-4) in E.524 now gives, for the intensity of *the second partial overflow* O_i (in calls):

$$O_i = a_i \rho_i(n_i) H_i(d_i) \times \Pi \quad \text{(B-12)}$$

Similarly, formula (6-5) in E.524 modified gives, for the partial grade of service equalization:

$$\rho_i(n_i) \cdot H_i(d_i) = C \quad \text{(B-13)}$$

where C is an economically suitable constant.

NOTE – This equalization is only possible for a fairly low d_i. For video communications (large d_i), it is necessary to have recourse to service protection methods.

B.7 Field of application

This approximate method may be used for:

$$d \leq 10, z \leq 3 \quad \text{(B-14)}$$

B.8 Processing time and programming effort

The values given in Table 2/E.524 hold approximately.

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