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

Traffic engineering – Measurement and recording of traffic

Overview of Recommendations on traffic engineering

ITU-T Recommendation E.490.1

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ITU-T Recommendation E.490.1

Overview of Recommendations on traffic engineering

Summary

This Recommendation provides an overview of the Recommendations on Traffic Engineering, specifically those numbered between E.490 and E.799, which constitute the main body of ITU-T Recommendations on traffic engineering.

This Recommendation presents the four major traffic engineering tasks, classifies the traffic engineering Recommendations according to the task to which they are related, provides a brief overview of each Recommendation and describes the interrelation between Recommendations. It is intended as an introduction for those practitioners who wish to apply ITU-T Recommendations on traffic engineering.

Source

ITU-T Recommendation E.490.1 was prepared by ITU-T Study Group 2 (2001-2004) and approved under the WTSA Resolution 1 procedure on 13 January 2003.

History

This is the first issue of ITU-T Rec. E.490.1

FOREWORD

The International Telecommunication Union (ITU) is the United Nations specialized agency in the field of telecommunications. The ITU Telecommunication Standardization Sector (ITU-T) is a permanent organ of ITU. ITU-T is responsible for studying technical, operating and tariff questions and issuing Recommendations on them with a view to standardizing telecommunications on a worldwide basis.

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.

The approval of ITU-T Recommendations is covered by the procedure laid down in WTSA Resolution 1.

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.

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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As of the date of approval of this Recommendation, ITU had not received notice of intellectual property, protected by patents, which may be required to implement this Recommendation. However, implementors are cautioned that this may not represent the latest information and are therefore strongly urged to consult the TSB patent database.

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Overview of Recommendations on traffic engineering

1 Scope

This Recommendation provides an overview of the Recommendations on Traffic Engineering, specifically those numbered between E.490 and E.799, which constitute the main body of ITU-T Recommendations on traffic engineering. It is intended as an introduction for those practitioners who wish to apply ITU-T Recommendations on traffic engineering.

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.

All the Recommendations between E.490 and E.799 are referred to in this Recommendation. They are listed in Tables 1 to 7 and 9 to 12.

3 Definitions

The terms used in these Recommendations are consistent with the definitions made in the referred Recommendations on traffic engineering, especially with those made in ITU-T Rec. E.600 "Terms and definitions of traffic engineering".

4 Abbreviations

This Recommendation uses the following abbreviations:

ANM	Answer Message
ARIMA	Autoregressive Integrated Moving Average
ATM	Asynchronous Transfer Mode
B-ISDN	Broadband ISDN
CAC	Connection Admission Control
CPN	Customer Premises Network
DCME	Digital Circuit Multiplication Equipment
GoS	Grade of Service
HFC	Hybrid Fiber-Coaxial
IAM	Initial Address Message
IN	Intelligent Network
IP	Internet Protocol
ISDN	Integrated Services Digital Network
N-ISDN	Narrowband ISDN

NP	Network Performance
PSTN	Public Switched Telephone Network
QoS	Quality of Service
SS No.7	Signalling System No.7
STP	Signal Transfer Point
UPT	Universal Personal Telecommunication
YRV	Yearly Representative Value

5 Major traffic engineering tasks

This Recommendation on traffic engineering can be classified according to the four major traffic engineer tasks:

- traffic demand characterization;
- Grade of Service (GoS) objectives;
- traffic controls and dimensioning;
- performance monitoring.

The interrelation between these four tasks is illustrated in Figure 1. The initial tasks in traffic engineering are to characterize the traffic demand and to specify the GoS (or performance) objectives. The results of these two tasks are input for dimensioning network resources and for establishing appropriate traffic controls. Finally, performance monitoring is required to check if the GoS objectives have been achieved and is used as a feedback for the overall process.

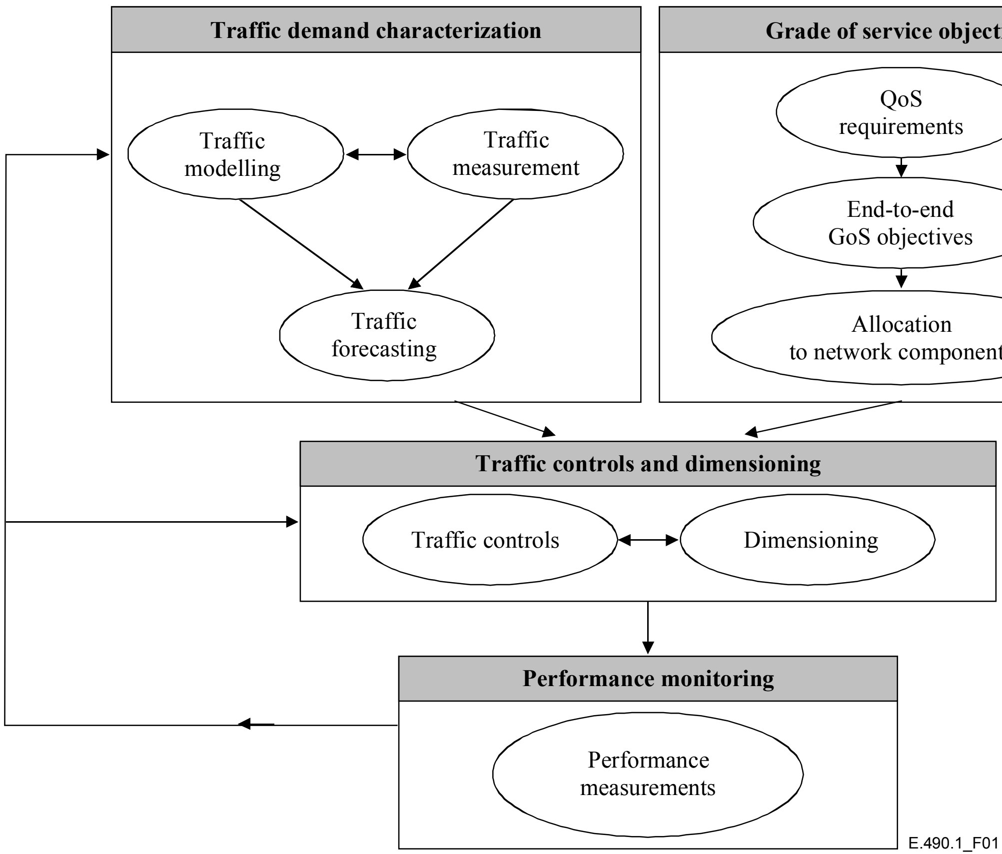

Figure 1/E.490.1 – Traffic engineering tasks

Clauses 6, 7, 8 and 9 describe each of the above four tasks. Each clause provides an overall view of the respective task and summarises the related Recommendations. Clause 10 summarizes a few additional Recommendations as their scope does not match the items considered in the classification.

6 Traffic demand characterization

Traffic characterization is done by means of models that approximate the statistical behaviour of network traffic in large population of users. Traffic models adopt simplifying assumptions concerning the complicated traffic processes. Using these models, traffic demand is characterized by a limited set of parameters (mean, variance, index of dispersion of counts, etc). Traffic modelling basically involves the identification of what simplifying assumptions can be made and what parameters are relevant from the viewpoint of the impact of traffic demand on network performance.

Traffic measurements are conducted to validate these models, with modifications being made when needed. Nevertheless, as the models do not need to be modified often, the purpose of traffic measurements is usually to estimate the values that the parameters defined in the traffic models take at each network segment during each time period.

As a complement to traffic modelling and traffic measurements, traffic forecasting is also required given that, for planning and dimensioning purposes, it is not enough to characterize present traffic demand, but it is necessary to forecast traffic demands for the time period foreseen in the planning process.

Thus the Recommendations cover these three aspects of traffic characterization: traffic modelling, traffic measurements and traffic forecasting.

6.1 Traffic modelling

Recommendations on traffic modelling are listed in Table 1. There are no specific Recommendations on traffic modelling for the classical circuit-switched telephone network. The only service provided by this network is telephony given that other services, as fax, do not have a significant impact on the total traffic demand. Every call is based on a single 64 kbit/s point-to-point bidirectional symmetric connection. Traffic is characterized by call rate and mean holding time at each origin-destination pair. Poissonian call arrival process (for first-choice routes) and negative exponential distribution of the call duration are the only assumptions needed. These assumptions are directly explained in the Recommendations on dimensioning.

Table 1/E.490.1 – Recommendations on traffic modelling

Rec. No.	Last issue date	Title
E.711	10/92	User demand modelling
E.712	10/92	User plane traffic modelling
E.713	10/92	Control plane traffic modelling
E.716	10/96	User demand modelling in Broadband-ISDN
E.760	03/00	Terminal mobility traffic modelling

The problem is much more complex in N- and B-ISDN and in IP-based network. There are more variety of services, each with different characteristics, different call patterns and different QoS requirements. **ITU-T Recs E.711 and E.716** explain how a call, in N-ISDN and B-ISDN respectively, must be characterized by a set of connection characteristics (or call attributes) and by a call pattern.

Examples of connection characteristics are the following: information transfer mode (circuit-switched or packet switched), communication configuration (point-to-point, multipoint, broadcast), transfers rate, symmetry (unidirectional, bidirectional symmetric or bidirectional asymmetric), QoS requirements, etc.

The call pattern is defined in terms of the sequence of events occurred along the call and of the times between these events. It is described by a set of traffic variables, which are expressed as statistical variables, that is, as moments or quantiles of distributions of random variables indicating number of events or times between events. The traffic variables can be classified into call-level (or connection-level) and packet-level (or transaction-level or, in ATM, cell-level) traffic variables.

The call-level traffic variables are related to events occurring during the call set-up and release phases. Examples are the mean number of re-attempts in case of non-completion and mean call-holding time.

The packet-level traffic variables are related to events occurring during the information transfer phase and describe the packet arrival process and the packet length. ITU-T Rec. E.716 describes a number of different approaches for defining packet-level traffic variables.

Once each type of call has been modelled, the user demand is characterized, according to ITU-T Recs E.711 and E.716, by the arrival process of calls of each type. Based on the user demand characterization made in ITU-T Recs E.711 and E.716, **ITU-T Recs E.712 and E.713** explain how to model the traffic offered to a group of resources in the user plane and the control plane, respectively.

Finally, **ITU-T Rec. E.760** deals with the problem of traffic modelling in mobile networks where not only the traffic demand per user is random but also the number of users being served at each moment by a base station or by a local exchange. The Recommendation provides methods to estimate traffic demand in the coverage area of each base station and mobility models to estimate handover and location updating rates.

6.2 Traffic measurements

Recommendations on traffic measurements are listed in Table 2. As indicated in the table, many of them cover both traffic and performance measurements. These Recommendations can be classified into those on general and operational aspects (E.490, E.491, E.502 and E.503), those on technical aspects (E.500 and E.501) and those specifying measurement requirements for specific networks (E.502, E.505 and E.745). ITU-T Rec. E.743 is related to the last ones, in particular to ITU-T Rec. E.505.

Let us start with the Recommendations on general and operational aspects. **ITU-T Rec. E.490** is an introduction to the series on traffic and performance measurements. It contains a survey of all these Recommendations and explains the use of measurements for short term (network traffic management actions), medium term (maintenance and reconfiguration) and long term (network extensions).

Table 2/E.490.1 – Recommendations on traffic measurements

Rec. No.	Last issue date	Title
E.490*	06/92	Traffic measurement and evaluation – General survey
E.491	05/97	Traffic measurement by destination
E.500	11/98	Traffic intensity measurement principles
E.501	05/97	Estimation of traffic offered in the network
E.502*	02/01	Traffic measurement requirements for digital telecommunication exchanges
E.503*	06/92	Traffic measurement data analysis
E.504*	11/88	Traffic measurement administration
E.505*	06/92	Measurements of the performance of common channel signalling network
E.743	04/95	Traffic measurements for SS No.7 dimensioning and planning
E.745*	03/00	Cell level measurement requirements for the B-ISDN
* These Recommendations cover both traffic and performance measurements.		

ITU-T Rec. E.491 points out the usefulness of traffic measurements by destination for network planning purposes and outlines two complementary approaches to obtain them: call detailed records and direct measurements.

ITU-T Rec. E.504 describes the operational procedures needed to perform measurements: tasks to be made by the operator (e.g., to define output routing and scheduling of measured results) and functions to be provided by the system supporting the man-machine interface.

Once the measurements have been performed, they have to be analysed. **ITU-T Rec. E.503** gives an overview of the potential application of the measurements and describes the operational procedures needed for the analysis.

Let us now describe ITU-T Recs E.500 and E.501 on general technical aspects. **ITU-T Rec. E.500** states the principles for traffic intensity measurements. The traditional concept of busy hour, which was used in telephone networks, cannot be extended to modern multiservice networks. Thus ITU-T Rec. E.500 provides the criteria to choose the length of the read-out period for each application. These criteria can be summarized as follows:

a) To be large enough to obtain confident measurements: the average traffic intensity in a period (t_1, t_2) can be considered a random variable with expected value A. The measured traffic intensity $A(t_1, t_2)$ is a sample of this random variable. As $t_2–t_1$ increases, $A(t_1, t_2)$ converges to A. Thus the read-out period length $t_2–t_1$ must be large enough so that $A(t_1, t_2)$ lies within a narrow confidence interval about A.

   An additional reason to choose large read-out periods is that it may not be worth the effort to dimension resources for very short peak traffic intervals.

b) To be short enough so that the traffic intensity process is approximately stationary during the period, i.e., that the actual traffic intensity process can be approximated by a stationary traffic intensity model. Note that in the case of bursty traffic, if a simple traffic model (e.g., Poisson) is being used, criterion b) may lead to an excessively short read-out period incompatible with criterion a). In these cases, alternative models should be used to obtain longer read-out period.

ITU-T Rec. E.500 also advises on how to obtain the daily peak traffic intensity over the measured read-out periods. It provides the method to derive the *normal load* and *high load* traffic intensities for each month and, based on them, the yearly representative values (YRV) for *normal* and *high loads*.

As offered traffic is required for dimensioning while only carried traffic is obtained from measurements, **ITU-T Rec. E.501** provides methods to estimate the traffic offered to a circuit group and the origin-destination traffic demand based on circuit group measurements. For the traffic offered to a circuit group, the Recommendation considers both circuit groups with only-path arrangement, and circuit groups belonging to a high-usage/final circuit group arrangement. The repeated call attempts phenomenon is taken into account in the estimation. Although the Recommendation only refers to circuit-switched networks with single-rate connections, some of the methods provided can be extended to other types of networks. Also, even though the problem may be much more complex in multiservice networks, advanced exchanges typically provide, in addition to circuit group traffic measurements, other measurements such as the number of total, blocked, complete and successful call attempts per service and per origin-destination pair, which may help to estimate offered traffic.

The third group of Recommendations on measurements includes **ITU-T Recs E.502, E.505 and E.745** which specify traffic and performance measurement requirements in PSTN and N-ISDN exchanges (E.502), B-ISDN exchanges (E.745) and nodes of SS No.7 Common Channel Signalling Networks (E.505).

Finally, **ITU-T Rec. E.743** is complementary to ITU-T Rec. E.505. It identifies the subset of the measurements specified in ITU-T Rec. E.505 that are useful for SS No.7 dimensioning and planning, and explains how to derive the input required for these purposes from the performed measurements.

6.3 Traffic forecasting

Traffic forecasting is necessary both for strategic studies, such as to decide on the introduction of a new service, and for network planning, that is, for the planning of equipment plant investments and circuit provisioning. The Recommendations on traffic forecasting are listed in Table 3. Although the title of the first two refers to international traffic, they also apply to the traffic within a country.

ITU-T Recs E.506 and E.507 deal with the forecasting of traditional services for which there are historical data. **ITU-T Rec. E.506** gives guidance on the pre-requisites for the forecasting: base data, including not only traffic and call data but also economic, social and demographic data are of vital importance. As the data series may be incomplete, strategies are recommended for dealing with missing data. Different forecasting approaches are presented: direct methods, based on measured traffic in the reference period, versus composite method based on accounting minutes, and top-down versus bottom-up procedures.

Table 3/E.490.1 – Recommendations on traffic forecasting

Rec. No.	Last issue date	Title
E.506	06/92	Forecasting international traffic
E.507	11/88	Models for forecasting international traffic
E.508	10/92	Forecasting new telecommunication services

ITU-T Rec. E.507 provides an overview of the existing mathematical techniques for forecasting: curve-fitting models, autoregressive models, autoregressive integrated moving average (ARIMA) models, state space models with Kalman filtering, regression models and econometric models. It also describes methods for the evaluation of the forecasting models and for the choice of the most appropriate one in each case, depending on the available data, length of the forecast period, etc.

ITU-T Rec. E.508 deals with the forecasting of new telecommunication services for which there are no historical data. Techniques such as market research, expert opinion and sectorial econometrics are described. It also advises on how to combine the forecasts obtained from different techniques, how to test the forecasts and how to adjust them when the service implementation starts and the first measurements are taken.

7 Grade of service objectives

Grade of Service (GoS) is defined in ITU-T Recs E.600 or E.720 as a number of traffic engineering parameters to provide a measure of adequacy of plant under specified conditions; these GoS parameters may be expressed as probability of blocking, probability of delay, etc. Blocking and delay are caused by the fact that the traffic handling capacity of a network or of a network component is finite and the demand traffic is stochastic by nature.

GoS is the traffic related part of network performance (NP), defined as the ability of a network or network portion to provide the functions related to communications between users. Network performance does not only cover GoS (also called trafficability performance) but also other non-traffic related aspects as dependability, transmission and charging performance.

NP objectives and in particular GoS objectives are derived from Quality of Service (QoS) requirements, as indicated in Figure 1. QoS is a collective of service performances that determine the degree of satisfaction of a user of a service. QoS parameters are user oriented and are described in network independent terms. NP parameters, while being derived from them, are network oriented, i.e., usable in specifying performance requirements for particular networks. Although they ultimately determine the (user observed) QoS, they do not necessarily describe that quality in a way that is meaningful to users.

QoS requirements determine end-to-end GoS objectives. From the end-to-end objectives, a partition yields the GoS objectives for each network stage or network component. This partition depends on the network operator strategy. Thus Recommendations only specify the partition and allocation of GoS objectives to the different networks that may have to cooperate to establish a call (e.g., originating national network, international network and terminating national network in an international call).

In order to obtain an overview of the network under consideration and to facilitate the partitioning of the GoS, Recommendations provide the so-called reference connections. A reference connection consists of one or more simplified drawings of the path a call (or connection) can take in the network, including appropriate reference points where the interfaces between entities are defined. In some cases a reference point define an interface between two operators. Recommendations devoted to provide reference connections are listed in Table 4.

Table 4/E.490.1 – Recommendations on reference connections

Rec. No.	Last issue date	Title
E.701	10/92	Reference connections for traffic engineering
E.751	02/96	Reference connections for traffic engineering of land mobile networks
E.752	10/96	Reference connections for traffic engineering of maritime and aeronautical systems
E.755	02/96	Reference connections for UPT traffic performance and GoS
E.651	03/00	Reference connections for traffic engineering of IP access networks

ITU-T Rec. E.701 provides reference connection for N-ISDN networks, **ITU-T Rec. E.751** for land mobile networks, **ITU-T Rec. E.752** for maritime and aeronautical systems, **ITU-T Rec. E.755** for UPT services and **ITU-T Rec. E.651** for IP-based networks. In the latter, general reference connections are provided for the end-to-end connections and more detailed ones for the access network in case of HFC systems. As an example, Figure 2 (taken from Figure 6-2/E.651) presents the reference connection for an IP-to-PSTN/ISDN or PSTN/ISDN-to-IP call.

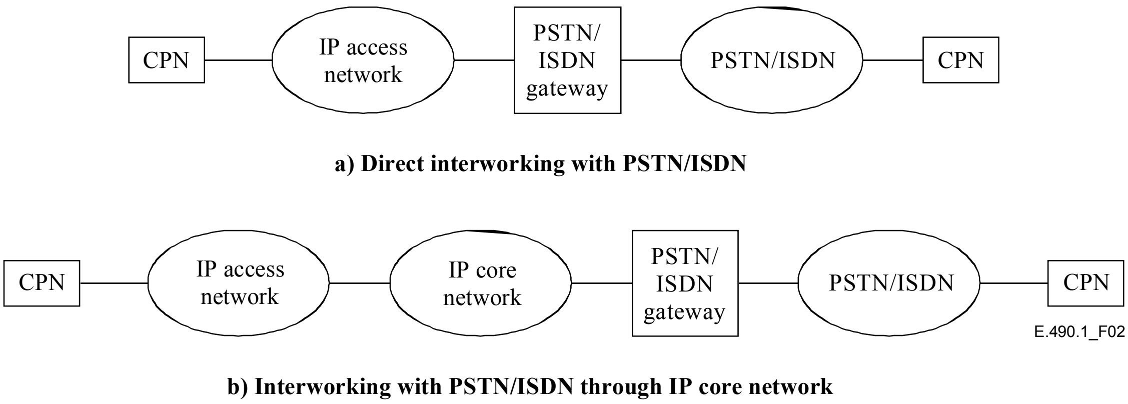

Figure 2/E.490.1 – IP-to-PSTN/ISDN or PSTN/ISDN-to-IP reference connection

We now apply the philosophy explained above for defining GoS objectives, starting with the elaboration of ITU-T Rec. E.720, devoted to N-ISDN. The Recommendations on GoS objectives for PSTN, which are generally older, follow a different philosophy and can now be considered an exception within the set of GoS Recommendations. Let us start this overview with the new Recommendations. They are listed in Table 5.

Table 5/E.490.1 – Recommendations on GOS objectives (except for PSTN)

Rec. No.	Last issue date	Title
E.720	11/88	ISDN grade of service concept
E.721	05/99	Network grade of service parameters and target values for circuit-switched services in the evolving ISDN
E.723	06/92	Grade-of-service parameters for Signalling System No.7 networks
E.724	02/96	GoS parameters and target GoS objectives for IN Services
E.726	03/00	Network grade of service parameters and target values for B-ISDN
E.728	03/98	Grade of service parameters for B-ISDN signalling
E.770	03/93	Land mobile and fixed network interconnection traffic grade of service concept
E.771	10/96	Network grade of service parameters and target values for circuit-switched public land mobile services
E.773	10/96	Maritime and aeronautical mobile grade of service concept
E.774	10/96	Network grade of service parameters and target values for maritime and aeronautical mobile services
E.775	02/96	UPT Grade of service concept
E.776	10/96	Network grade of service parameters for UPT
E.671	03/00	Post-selection delay in PSTN/ISDNs networks using Internet telephony for a portion of the connection

ITU-T Recs E.720 and E.721 are devoted to N-ISDN circuit-switched services. ITU-T Rec. E.720 provides general guidelines and ITU-T Rec. E.721 provides GoS parameters and target values. The recommended end-to-end GoS parameters are:

- pre-selection delay;
- post-selection delay;
- answer signal delay;
- call release delay;
- probability of end-to-end blocking.

After defining these parameters, ITU-T Rec. E.721 provides target values for *normal* and *high load* as defined in ITU-T Rec. E.500. For the delay parameters, target values are given for the mean delay and for the 95% quantile. For those parameters that are dependent on the length of the connection, different sets of target values are recommended for local, toll and international connections. The Recommendation provides reference connections, characterized by a typical range of the number of switching nodes, for the three types of connections.

Based on the delay related GoS parameters and target values given in ITU-T Rec. E.721, **ITU-T Rec. E.723** identifies GoS parameters and target values for the SS No.7 signalling networks. The identified parameters are the delays incurred by the initial address message (IAM) and by the answer message (ANM). Target values consistent with those of ITU-T Rec. E.721 are given for local, toll and international connections. The typical number of switching nodes of the reference connections provided in ITU-T Rec. E.721 is complemented in ITU-T Rec. E.723 with typical number of STPs (signal transfer points).

The target values provided in ITU-T Rec. E.721 refer to calls not invoking intelligent network (IN) services. **ITU-T Rec. E.724** specifies incremental delays that are allowed when they are invoked. Reference topologies are provided for the most relevant service classes, such as database query, call redirection, multiple set-up attempts, etc. Target values of the incremental delay for processing a single IN service are provided for some service classes, as well as of the total incremental post-selection delay for processing all IN services.

ITU-T Rec. E.726 is the equivalent of ITU-T Rec. E.721 for B-ISDN. As B-ISDN is a packet-switched network, call-level and packet-level (in this case cell-level) GoS parameters are distinguished. Call-level GoS parameters are analogous to those defined in ITU-T Rec. E.721. The end-to-end cell-level GoS parameters are:

- cell transfer delay;
- cell delay variation;
- severely errored cell block ratio;
- cell loss ratio;
- frame transmission delay;
- frame discard ratio.

While the call-level QoS requirements may be similar for all the services (perhaps with the exception of emergency services), the cell-level QoS requirements may be very different depending on the type of service: delay requirements for voice and video services are much more stringent than those for data services. Thus target values for the cell-level must be service dependent. These target values are left for further study in the current issue while target values are provided for the call-level GoS parameters for local, toll and international connections.

ITU-T Rec. E.728, for B-ISDN signalling, is based on the delay related call-level parameters of ITU-T Rec. E.726. ITU-T Rec. E.728, in its relation to ITU-T Rec. E.726, is analogous to the corresponding relationship between ITU-T Recs E.723 and E.721.

In the mobile network series, there are three pairs of Recommendations analogous to the E.720/E.721 pair: **ITU-T Recs E.770 and E.771** for land mobile networks, **ITU-T Recs E.773 and E.774** for maritime and aeronautical systems, and **ITU-T Recs E.775 and E.776** for UPT services. All these are for circuit-switched services. They analyse the features of the corresponding services that make it necessary to specify less stringent target values for the GoS parameters than those defined in ITU-T Rec. E.721, and define additional GoS parameters that are specific for these services. For example, in ITU-T Recs E.770 and E.771 on land mobile networks, the reasons for less stringent parameters are: the limitations of the radio interface, the need for the authentication of terminals and of paging of the called user, and the need for interrogating the home and (in case of roaming) visited network databases to obtain the routing number. An additional GoS parameter in land mobile networks is the probability of unsuccessful handover. Target values are given for fixed-to-mobile, mobile-to-fixed and mobile-to-mobile calls considering local, toll and international connections.

The elaboration of Recommendations on GoS parameters and target values for IP-based network has just started. **ITU-T Rec. E.671** only covers an aspect on which to give advice was urgent. It was to specify target values for the post-selection delay in PSTN/ISDN networks when a portion of the circuit-switched connection is replaced by IP telephony and the users are not aware of this fact. ITU-T Rec. E.671 states that the end-to-end delay must be in this case equal to that specified in ITU-T Rec. E.721.

Let us finish this overview on GoS Recommendations with those devoted to the PSTN. They are listed en Table 6.

Table 6/E.490.1 – Recommendations on GoS objectives in the PSTN

Rec. No.	Last issue date	Title
E.540	11/88	Overall grade of service of the international part of an international connection
E.541	11/88	Overall grade of service for international connections (subscriber-to-subscriber)
E.543	11/88	Grades-of-service in digital international telephone exchanges
E.550	03/93	Grade-of-service and new performance criteria under failure conditions in international telephone exchanges

ITU-T Recs E.540, E.541 and E.543 can be considered the counterpart for PSTN of ITU-T Rec. E.721 but organized in a different manner, as pointed out previously. They are focused on international connections, as was usual in the old Recommendations. **ITU-T Rec. E.540** specifies the blocking probability of the international part of an international connection, **ITU-T Rec. E.541** the end-to-end blocking probability of an international connection and **ITU-T Rec. E.543** the internal loss probability and delays of an international telephone exchange.

The target values specified in all of the GoS Recommendations assume that the network and its components are fully operational. On the other hand, the Recommendations on availability deal with the intensity of failures and duration of faults of network components, without considering the fraction of call attempts, which are blocked due to the failure. **ITU-T Rec. E.550** combines the concepts from the fields of both availability and traffic congestion, and defines new performance parameters and target values that take into account their joint effects in a telephone exchange.

8 Traffic control and dimensioning

Once the traffic demand has been characterised and the GoS objectives have been established, traffic engineering provides a cost efficient design and operation of the network while assuring that the traffic demand is carried and GoS objectives are satisfied.

The inputs of traffic engineering to the design and operation of networks are network dimensioning and traffic controls. Network dimensioning assures that the network has enough resources to support the traffic demand. It includes the dimensioning of the physical network elements and also of the logical network elements, such as the virtual paths of an ATM network. Traffic controls are also necessary to ensure that the GoS objectives are satisfied. Among the traffic controls we can distinguish:

- **Traffic routing**: Routing patterns describe the route set choices and route selection rules for each origin-destination pair. They may be hierarchical or non-hierarchical, fixed or dynamic. Dynamic methods include time-dependent routing methods, in which the routing pattern is altered at a fixed time on a pre-planned basis, and state-dependent or event-dependent routing, in which the network automatically alters the routing pattern based on present network conditions. ITU-T Recs E.170 to E.177, E.350 to E.353 and E.360.1 to E.360.7, all deal with routing, are out of the scope of this overview. Nevertheless, reference to routing is constantly made in the traffic engineering Recommendations here presented. On one hand, routing design is based on traffic engineering considerations: for example, alternative routing schemes are based on cost efficiency considerations, dynamic routing methods are based on considerations of robustness under focused overload or failure conditions or regarding traffic forecast errors. On the other hand, network dimensioning is done by taking into account routing methods and routing patterns.
- **Network traffic management controls**: These controls assure that network throughput is maintained under any overload or failure conditions. Traffic management controls may be protective or expansive. The protective controls such as code blocking or call gapping assure that the network does not waste resources in processing calls that will be unsuccessful or limit the flow of calls requiring many network resources (overflow calls). The expansive controls re-route the traffic towards those parts of the network that are not overloaded. Traffic management is usually carried out at traffic management centres where real-time monitoring of network performance is made through the collection and display of real-time traffic and performance data. Controls are usually triggered by an operator on a pre-planed basis (when a special event is foreseen) or in real-time. ITU-T Recs E.410 to E.417, dealing with this subject, are out of the scope of this overview. Nevertheless, reference to traffic management is made in the traffic engineering Recommendations here presented. For example, measurement requirements specified in the traffic and performance measurement Recommendations include the real-time measurements required for network traffic management.
- **Service protection methods**: They are call-level traffic controls that control the grade of service for certain streams of traffic by means of a discriminatory restriction of the access to circuit groups with little idle capacity. Service protection is used to provide stability in networks with non-hierarchical routing schemes by restricting overflow traffic to an alternative route that is shared with first-choice traffic. It is also used to balance GoS between traffic streams requesting different bandwidth or to give priority service to one type of traffic.
- **Packet-level traffic controls**: These controls assure that the packet-level GoS objectives of the accepted calls are satisfied under any network condition and that a cost-efficient grade of service differentiation is made between services with different packet-level QoS requirements.

- **Signalling and intelligent network (IN) controls**: Given that these networks are the nervous system of the whole network, a key objective in the design and operation of them is to maximize their robustness, that is, their ability to withstand both traffic overloads and failures of network elements. It is achieved both by means of redundancy of network elements and by means of a set of congestion and overload controls, as explained in ITU-T Rec. E.744 to be described below.

Let us classify the Recommendations on dimensioning and traffic controls into those devoted to circuit-switched networks, to packet-switched networks or to signalling and IN-structured networks.

8.1 Circuit-switched networks

Recommendations on traffic controls and dimensioning of circuit-switched networks are listed in Table 7. These Recommendations deal with dimensioning and service protection methods taking into account traffic routing methods.

Table 7/E.490.1 – Recommendations on traffic controls and dimensioning of circuit- switched networks

Rec. No.	Last issue date	Title
E.520	11/88	Number of circuits to be provided in automatic and/or semi-automatic operation, without overflow facilities
E.521	11/88	Calculation of the number of circuits in a group carrying overflow traffic
E.522	11/88	Number of circuits in a high-usage group
E.524	05/99	Overflow approximations for non-random inputs
E.525	06/92	Designing networks to control grade of service
E.526	03/93	Dimensioning a circuit group with multi-slot bearer services and no overflow inputs
E.527	03/00	Dimensioning at a circuit group with multi-slot bearer services and overflow traffic
E.528	02/96	Dimensioning of digital circuit multiplication equipment (DCME) systems
E.529	05/97	Network dimensioning using end-to-end GoS objectives
E.731	10/92	Methods for dimensioning resources operating in circuit-switched mode

ITU-T Recs E.520, E.521, E.522 and E.524 deal with the dimensioning of circuit groups or high-usage/final group arrangements carrying single-rate (or single-slot) connections. Service protection methods are not considered in these Recommendations:

- **ITU-T Rec. E.520** deals with the dimensioning of only-path circuit groups (see part a) of Figure 3).

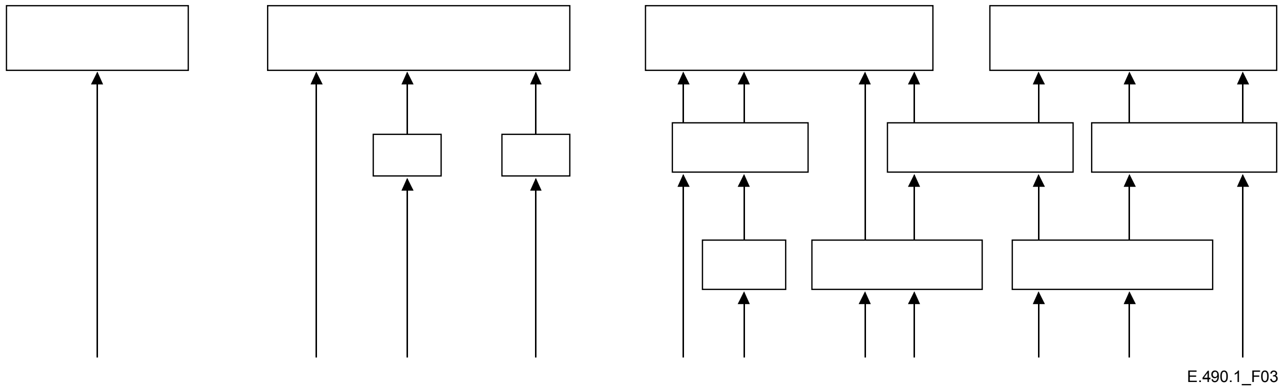

Figure 3/E.490.1 – Examples of circuit group arrangements

- **ITU-T Recs E.521 and E.522** provide methods for the dimensioning of simple alternative routing arrangements as the one shown in part b) of Figure 3, where there only exist first- and second-choice routes, and where the whole traffic overflowing from a circuit group is offered to the same circuit group. ITU-T Rec. E.521 provides methods for dimensioning the final group satisfying GoS requirements for given sizes of the high-usage circuit groups, and ITU-T Rec. E.522 advises on how to dimension high-usage groups to minimize the cost of the whole arrangement.
- **ITU-T Rec. E.524** provides overflows approximations for non-random inputs that allows for the dimensioning of more complex arrangements (i.e., without the previous mentioned limitations) as that shown in part c) of Figure 3. Several approaches are described and compared from the point of view of accuracy and complexity.

ITU-T Rec. E.525 introduces service protection methods for networks carrying single-rate connections. It describes the applications and the available methods: split circuit groups, circuit reservation (also called trunk reservation or, in packet-switched networks, bandwidth reservation) and virtual circuits. The Recommendation provides methods to evaluate the blocking probability of each traffic stream both for only-path circuit groups and for alternative routing arrangements, which allow for the dimensioning of the circuit groups and of the thresholds defining the protection methods. A comparison of the available service protection methods is made from the point of view of efficiency, overload protection, robustness and impact of peakedness.

ITU-T Recs E.526 and E.527 deal with the dimensioning of circuit groups carrying multi-slot (or multi-rate) connections. Service protection methods are considered in both of them. **ITU-T Rec. E.526** deals with only-path circuit groups while **ITU-T Rec. E.527** deals with alternative routing schemes.

Table 8 summarizes the items considered in each of the Recommendations mentioned above.

Table 8/E.490.1 – Items considered in the circuit group dimensioning, ITU-T Recs E.520 to E.527

Recommendation	E.520	E.521	E.522	E.524	E.525	E.526	E.527
Alternative routing	No	Yes*	Yes*	Yes	Yes	No	Yes
Service protection	No	No	No	No	Yes	Yes	Yes
Multi-slot connections	No	No	No	No	No	Yes	Yes
* Only simple arrangements.							

ITU-T Rec. E.528 deals with the dimensioning of a particular but very important type of circuit group, where Digital Circuit Multiplication Equipment (DCME) is used to achieve statistical multiplexing gain in communications via satellite. This is to save circuits by means of interpolating speech bursts of different channels by taking advantage of the silences existing in a conversation. Dimensioning methods for circuit groups providing integration of traffic containing voice, facsimile and voice band data are given.

ITU-T Rec. E.731 is also devoted to circuit group dimensioning and considers those special features of N-IDSN that may have an impact on traffic engineering. Apart from multi-slot connections and service protection methods, the Recommendation studies the impact of attribute negotiation (of attributes affecting either the choice of circuit group or the required number of circuits), of service reservation (reservation of dedicated resources or of resources shared with on demand services) and of point-to-multipoint connections.

ITU-T Rec. E.529 collects all the dimensioning methods on circuit group or alternative routing arrangement described in previous Recommendations, with a view to giving guidelines for the dimensioning of the whole network using end-to-end GoS objectives. Dimensioning methods for networks with fixed, time-dependent, state-dependent or event-dependent traffic routing are described. Principles for the decomposition of the networks into blocks that may be considered statistically independent are given, and the iterative procedure required for network optimization is described.

8.2 Packet-switched networks

Recommendations on traffic controls and dimensioning of packet-switched networks are listed in Table 9. They deal with B-ISDN networks using ATM technology, but most of the methods described apply to other packet-switched networks, as for example IP-based networks, in which the admission of connections is controlled.

Table 9/E.490.1 – Recommendations on traffic controls and dimensioning of packet-switched networks

Rec. No.	Last issue date	Title
E.735	05/97	Framework for traffic control and dimensioning in B-ISDN
E.736	03/00	Methods for cell level traffic control in B-ISDN
E.737	02/01	Dimensioning methods for B-ISDN

The connection admission control (CAC) establishes a division between the packet-level and the connection-level. When a user requests the establishment of a new connection, the CAC decides if the connection can be admitted while satisfying packet-level GoS of both new and existing connections. This decision is usually made by means of allocating resources (typically bandwidth) to each connection and refusing new request when there are insufficient resources. Thus:

- From a packet-level perspective: as the CAC assures that packet-level GoS objectives are satisfied regardless of the rate of connections offered to the network, it makes the packet-level independent from the connection-level offered traffic and from the network dimensioning.
- From a connection-level perspective: as the CAC, in deciding on the acceptance of a connection, takes into account all the packet-level controls implemented, it summarises all the packet-level controls in an amount of resources required by a connection. It makes the connection-level of a packet-switched networks similar to that of a circuit-switched network: the amount of resources required by a connection, called effective or equivalent

bandwidth (or, in ATM, equivalent cell rate) is equivalent to the number of slots required by a multi-slot connection in a circuit-switched network. Connection-level traffic controls and network dimensioning must assure that the connection-level GoS requirements, typically the specified connection blocking probabilities, are satisfied taking into account the effective bandwidth that has to be allocated to each connection.

In practice, this separation between packet-and connection-level is not so complete as described above: the effective bandwidth of a connection depends on the capacity of the physical or logical link in which it is carried (apart from the packet-level traffic characteristics of the connection) while, in its turn, the capacity of the links must be dimensioned by taking into account the effective bandwidth of the connections. Thus, an iterative process between connection- and packet-level for network dimensioning is necessary.

ITU-T Rec. E.735 is the framework for traffic control and dimensioning in B-ISDN. It introduces the concepts described above, defines what is a connection and what is a resource, and analyses strategies for logical network configuration.

ITU-T Rec. E.736 focuses on packet-level. It provides methods for packet-level performance evaluation, proposes possible multiplexing strategies (peak rate allocation, rate envelope multiplexing and statistical rate sharing) and analyses the implications and applications of each of them. Based on this analysis, the Recommendation provides methods for packet-level controls. Emphasis is placed on methods for Connection Admission Control and for the integration (or segregation) of services with different QoS requirements either by using dedicated resources or by sharing the same resources and implementing loss and/or delay priorities. It also addresses adaptive resource management techniques to control the flow of packets of services with non-stringent delay requirements.

ITU-T Rec. E.737 provides methods for circuit group and network dimensioning and addresses connection-level traffic controls, in particular service protection methods. Traffic routing methods are also taken into account. As the effective bandwidth of a connection is modelled as a number of slots of a multi-slot connection, this Recommendation is not very different from those on circuit-switched network dimensioning. Nevertheless the Recommendation deals with some features that are particular of packet-switched networks: the above-mentioned iteration between effective bandwidth and network dimensioning; the required bandwidth discretization into multiples of a bandwidth quantization unit, given that the multi-slot models only deal with integer number of slots; and the implications on the dimensioning of services with different packet-level QoS requirements.

8.3 Signalling and IN-structured networks

The Recommendations on traffic controls and dimensioning of signalling networks and intelligent networks (IN) are listed in Table 10. ITU-T Recs E.733 and E.734 deal with dimensioning and ITU-T Rec. E.744 with traffic controls.

Table 10/E.490.1 – Recommendations on traffic controls and dimensioning of signalling and IN-structured networks

Rec. No.	Last issue date	Title
E.733	11/98	Methods for dimensioning resources in Signalling System No. 7 networks
E.734	10/96	Methods for allocating and dimensioning Intelligent Network (IN) resources
E.744	10/96	Traffic and congestion control requirements for SS No. 7 and IN-structured networks

ITU-T Rec. E.733 provides a methodology for the planning and dimensioning of signalling system No.7 networks. The methodology takes into account the fact that the efficiency of the signalling links should not be the primary consideration, but the performance of the network under failure and traffic overload has greater importance. The Recommendation describes the reference traffic and reference period that, in agreement with ITU-T Recs E.492 and E.500, must be used to dimension the number of signalling links and to ensure that the capacity of network switching elements is not exceeded. It describes the factors for determining a maximum design link utilisation, ρ_{max}, which ensure that the end-to-end delay objectives described in ITU-T Rec. E.723 are met. Delays incurred when, due to failures, the link load is 2 ρ_{max} are also taken into account for determining ρ_{max}. Initial values for ρ_{max} being used are described and methods are given for determining the number of signalling links and the switching capacity required.

ITU-T Rec. E.734 deals with resource allocation and dimensioning methods for Intelligent Networks. It discusses the new traffic engineering factors to be considered: services with reference period out of the normal working hours, mass calling situations produced by some services, fast implementation of new services with uncertain forecast. The last factor makes it necessary to have the allocation and dimensioning procedures flexible enough to provide, as quickly as possible, the resources required as new services are implemented or the user demand changes. The Recommendation provides criteria for resource allocation, both for the location of the IN-specific elements and for the partitioning of the Intelligent Network functionality (such as service logic) among these elements. It also provides methods for the dimensioning of the IN nodes and of the supporting signalling subnetwork, and discusses the impact on the circuit-switched network dimensioning.

Traffic and congestion control procedures for SS No.7 and IN-structured networks are specified in the Q-and E.410-series Recommendations. These procedures generally leave key parameter values to be specified as part of the implementation. Given that robustness is a key requirement of signalling and IN-structured networks, a proper implementation of these controls is essential. **ITU-T Rec. E.744** provides guidelines for this implementation, indicating how the control parameters should be chosen in different types of networks. The Recommendation also advises on requirements to be placed on signalling nodes and IN nodes on the needs for node-level overload controls and on how such controls must interrelate with network-level controls. Finally the Recommendation states basic principles to keep different systems and controls harmonized in order to allow for various vendor products and network implementations to be interconnected with a high confidence that control procedures will work properly.

9 Performance monitoring

Once the network is operational, continuous monitoring of the GoS is required. Although the network is correctly dimensioned, there are overload and failure situations not considered in the dimensioning where short-term (minutes, hours) network traffic management actions have to be taken. In situations considered in the dimensioning, traffic forecast errors or approximations made in the dimensioning models might lead to a GoS different from the one expected. GoS monitoring is needed to detect these problems and to produce feedback for traffic characterization and network design. Depending on the problems detected, network reconfigurations, changes of the routing patterns or adjustment of traffic control parameters can be made in medium term (weeks, months). The urgency of a long term planning of network extensions may also be assessed.

ITU-T Recs E.490, E.491, E.502, E.503, E.504, E.505 and E.745, covering both traffic and performance measurements, have been described in 6.2. We consider in this section two other Recommendations, E.492 and E.493, listed in Table 11, which are only related to performance measurements.

Table 11/E.490.1 – Recommendations on performance measurements (for Recommendations covering both traffic and performance measurements, see Table 2/E.490.1)

Rec. No.	Last issue date	Title
E.492	02/96	Traffic reference period
E.493	02/96	Grade of service (GoS) monitoring

ITU-T Rec. E.492 provides the definition of traffic reference periods for the purposes of collecting measurements for monitoring Grade of service for networks and network components. This Recommendation is closely related to ITU-T Rec. E.500, which defines read-out periods for traffic intensity measurements required for network dimensioning. These read-out periods have to be consistent with those used for performance monitoring once the network is operative. ITU-T Rec. E.492 also defines the *normal* and *high load* periods that are representative of each month. The purpose of these definitions, also consistent with those or ITU-T Rec. E.500, is to identify which day and read-out period to use for comparing the monitored GoS to the GoS target values specified for *normal* and *high load*.

ITU-T Rec. E.493 addresses how to perform end-to-end GoS monitoring, taking into account practical limitations. Measurement of blocking or mishandling probabilities is straightforward. However, as direct measurements of end-to-end delays are not feasible in a continuous monitoring, the Recommendation proposes methods to approximate end-to-end delays (mean and 95 % quantile) by means of local measurements autonomously taken in each network element. The proposed methods do not require co-ordination between network elements to take the measurements. The Recommendation also explains how to apply the proposed methods to the monitoring of each of the connection-level GoS parameters defined in the Recommendations on GoS objectives.

10 Other Recommendations

There are a few other Recommendations for which their scope does not match any of the items considered in the classification made here. They are listed in Table 12.

Table 12/E.490.1 – Recommendations not matching under any of the items considered in the classification here

Rec. No.	Last issue date	Title
E.523	11/88	Standard traffic profiles for international traffic streams
E.600	03/93	Terms and definitions of traffic engineering
E.700	10/92	Framework of the E.700-series Recommendations
E.750	03/00	Introduction to the E.750 series of Recommendations on traffic engineering aspects of networks supporting personal communications services

ITU-T Rec. E.600 provides a list of traffic engineering terms and definitions used throughout the whole set of traffic engineering Recommendations.

ITU-T Recs E.700 and E.750 are introductory Recommendations to the E.700/E.749 series Recommendations on traffic engineering for N- and B-ISDN, and to the E.750/E.799 series Recommendations on traffic engineering for mobile networks, respectively.

ITU-T Rec E.523 provides standardized 24-hour traffic profiles for the traffic streams between countries in different relative time locations. This measurement-based information may be useful for those countries where no measurements are available. The profiles refer to telephone traffic and must not be used for data traffic for which the profiles may be very different.

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