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

International telephone connections and circuits – Transmission plan aspects of special circuits and connections using the international telephone connection network

Transmission planning for private/public network interconnection of voice traffic

ITU-T Recommendation G.175

(Formerly CCITT Recommendation)

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ITU-T Recommendation G.175

Transmission planning for private/public network interconnection of voice traffic

Summary

This ITU-T Recommendation deals with the digital interconnection of public ISDN/PSTN and private networks. The primary application is to the overall quality of speech transmission for 3.1 kHz voiceband telephony using handsets, independent of all other types of services (e.g. facsimile and voiceband data) provided by those networks. The intention is to give guidance for transmission planning purposes, not only for a given network operator, but also for negotiations between the involved network operators.

Source

ITU-T Recommendation G.175 was revised by ITU-T Study Group 12 (1997-2000) and approved under the WTSC Resolution 1 procedure on 18 May 2000.

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 Conference (WTSC), 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 WTSC 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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ITU-T Recommendation G.175

Transmission planning for private/public network interconnection of voice traffic

1 Scope

Most of the ITU-T Recommendations in the G-series are presently based on configurations where the national part of an international connection is usually terminated by a single analogue telephone set or by a digital terminal. Consequently, these ITU-T Recommendations do not take into account PABXs (Private Automatic Branch Exchange) or private networks. However, modern private networks, mainly those of large size and/or using new technologies, will contribute in a specific, possibly significant amount to the overall transmission quality.

This ITU-T Recommendation deals with the digital interconnection of public ISDN/PSTN and private networks. The primary application is to the overall quality of speech transmission for 3.1 kHz voiceband telephony using handsets, independent of all other types of services (e.g. facsimile and voiceband data) provided by those networks. The intention is to give guidance for transmission planning purposes, not only for a given network operator, but also for negotiations between the involved network operators.

For the purpose of this ITU-T Recommendation, only call paths between the private network and other networks (private or public) including telephone sets or other speech terminals are considered. Consequently, the provision of through-connections between two interfaces to other networks, or a call path between two terminals inside the same network are not covered by this ITU-T Recommendation.

NOTE – Although in principle the planning of internal- and through-connections of the Private Network is not covered here, the methods and rules described in this ITU-T Recommendation may be used for those applications as well.

2 Normative 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.

[1] ITU-T Recommendation G.100 (1993), *Definitions used in Recommendations on general characteristics of international telephone connections and circuits.*

[2] ITU-T Recommendation G.101 (1996), *The transmission plan*.

[3] ITU-T Recommendation G.107 (2000), *The E-Model, a computational model for use in transmission planning.*

[4] ITU-T Recommendation G.108 (1999), *Application of the E-model: A planning guide.*

[5] ITU-T Recommendation G.109 (1999), *Definition of categories of speech transmission quality.*

[6] ITU-T Recommendation G.113 (1996), *Transmission impairments*.

[7] ITU-T Recommendation G.122 (1993), *Influence of national systems on stability and talker echo in international connections*.

[8] ITU-T Recommendation G.165 (1993), *Echo cancellers.*

[9] ITU-T Recommendation G.168 (2000), *Digital network echo cancellers.*

[10] ITU-T Recommendation G.703 (1998), *Physical/electrical characteristics of hierarchical digital interfaces.*

[11] CCITT Recommendation G.711 (1988), *Pulse code modulation (PCM) of voice frequencies.*

3 Abbreviations

This ITU-T Recommendation uses the following abbreviations:

ATM Asynchronous Transfer Mode

DCME Digital Circuit Multiplication Equipment

ETSI European Telecommunication Standards Institute

%GoB Percentage Good or Better

ICP International Connection Point

ISDN Integrated Services Digital Network

LSTR Listener SideTone Rating

MOS Mean Opinion Score

OLR Overall Loudness Rating

PABX Private Automatic Branch eXchange

PCM Pulse Code Modulation

%PoW Percentage Poor or Worse

PSTN Public Switched Telephone Network

qdu Quantizing Distortion Unit

RLR Receiving Loudness Rating

SLR Sending Loudness Rating

STMR SideTone Masking Rating

TELR Talker Echo Loudness Rating

VPN Virtual Private Network

WEPL Weighted Echo Path Loss

4 Definitions

This ITU-T Recommendation defines the following terms:

4.1 private network: The term "private" is normally used in conjunction with several PABXs forming a network, mainly in an application for a restricted user group. In complement, the term "public" is usually used to describe main national or regional telecommunication networks providing services to general public.

The following list, specifying in more detail the definition of a private network, is also based on the assumption that the call path within the private network is contributing a possibly significant amount of transmission impairments to the overall transmission quality, such as loss, transmission time, number of qdus, etc.

The term "private network" is defined as follows:

1) It consists normally of more than one switching equipment (PABX), connected via private or leased lines, forming a network, independent of its structure and hierarchy. Switching equipment and leased lines can be either digital or analogue.

2) It provides switching functions and all other features only to a single customer or a group of customers, but is not accessible to everyone.

3) There is no limitation by its geographical size, it is not restricted to the national area and it is not limited on the number of extensions and access points to other networks.

A private network consists of private local exchanges providing interfaces for all types of terminal elements and for transmission elements to other private local or private transit exchanges and private transit exchanges with interfaces for transmission elements to other private transit or private local exchanges.

4.2 public network: The term "public network" is used in this ITU-T Recommendation for all networks providing their switching functions and features not only to a specific user group, but also to the general public. The word "public" is not related to the legal status of the network operator. Public networks can be restricted to only a limited size of specific features and switching functions.

Furthermore, public networks may provide access points only in a specific geographical area. From the point of view of a connection, public networks are mainly "transit networks". However, they may also be considered as a combination of "transit and terminating networks" in cases where the public network operator is also providing terminal equipment such as telephone sets, PABXs, or PABX-Features.

4.3 network elements: All the components forming a connection can be divided into three main groups. The interconnection between private and public network is shown in the reference configurations of Figures 1 through 4. The private network is comprised of terminal elements, switching elements and transmission elements.

4.4 types of traffic: In the case of some private networks, the "main types of traffic" via other networks (mainly public networks) may be taken into account for a possible higher amount of permitted impairments within the private network. The inclusion of the type of external traffic into planning enables the planner, wherever this is possible, to extend the limits for specific parameters (e.g. transmission time) within the private network, resulting in a more economical design of the network.

As a basic distinction for the traffic via public networks, three different types can be identified for planning purposes and with respect to the amount of transmission impairments. Referred to the switching element (local exchange) of the public network providing the access to the private network, *Local Traffic* means all connections in the local public network or in a restricted geographical area of the public network.

A second type of traffic is the *National Long Distance Call Traffic*, which designates all calls in the entire area of a country. Usually this area is identical to the area of coverage of the major public network(s) in this country.

Finally, *International Calls* must be considered to contribute in most cases with a higher amount of transmission impairments than national calls.

The distinction into these types of traffic may support negotiations between public and private network operators, not only for the partitioning of transmission impairments, but also in conjunction with other technical aspects, such as the correct insertion of echo cancellers, the use of ATM with nodes in different networks, etc.

4.5 access to the public network: Among others, the type of access to a public network may also influence the transmission planning of the private network and may be helpful for negotiations between the network operators. "Access" in this context means not only the physical characteristics of the interfaces between public and private networks, but also the point of access with respect to the hierarchy of the public network and to additional features for private networks, provided by the public network. For large private networks, the point of access does not need to be identical to the access for single subscribers. According to the scope of this ITU-T Recommendation, only digital interfaces for the access to public networks are considered.

4.5.1 digital access at the local exchange: In most cases the access to the public network will be provided by a local exchange, or by a comparable switching element in the same hierarchy of the public network, serving the area of the respective switching element within the private network. The physical characteristics of these digital interfaces will follow standardized and commonly used frame structures and bit rates, as described in ITU-T Recommendation G.703 [10].

4.5.2 digital access at higher hierarchies (e.g. transit exchange): For large and complex private networks with a high number of access channels to the public network, it could be advantageous for both public and private network operators to access the public network in a higher hierarchy (e.g. a transit exchange), bypassing the local exchange. This can be done either for the entirety of all access channels, or only for those channels carrying exclusively long distance or international traffic. In both applications, physical interfaces with higher bit rates and fibre optics as the transmission media may be used.

4.5.3 virtual private networks (VPN): The meaning of the term Virtual Private Network (VPN) in this context is related to a feature where connections between two switching elements of the private network are established via switching and transmission elements of a public network on a "call-by-call" basis instead of a fixed leased line. For planning purposes, such a routing should be considered as part of the private network, taking into account that the impairments of a VPN may vary for every connection contrary to a fixed leased line.

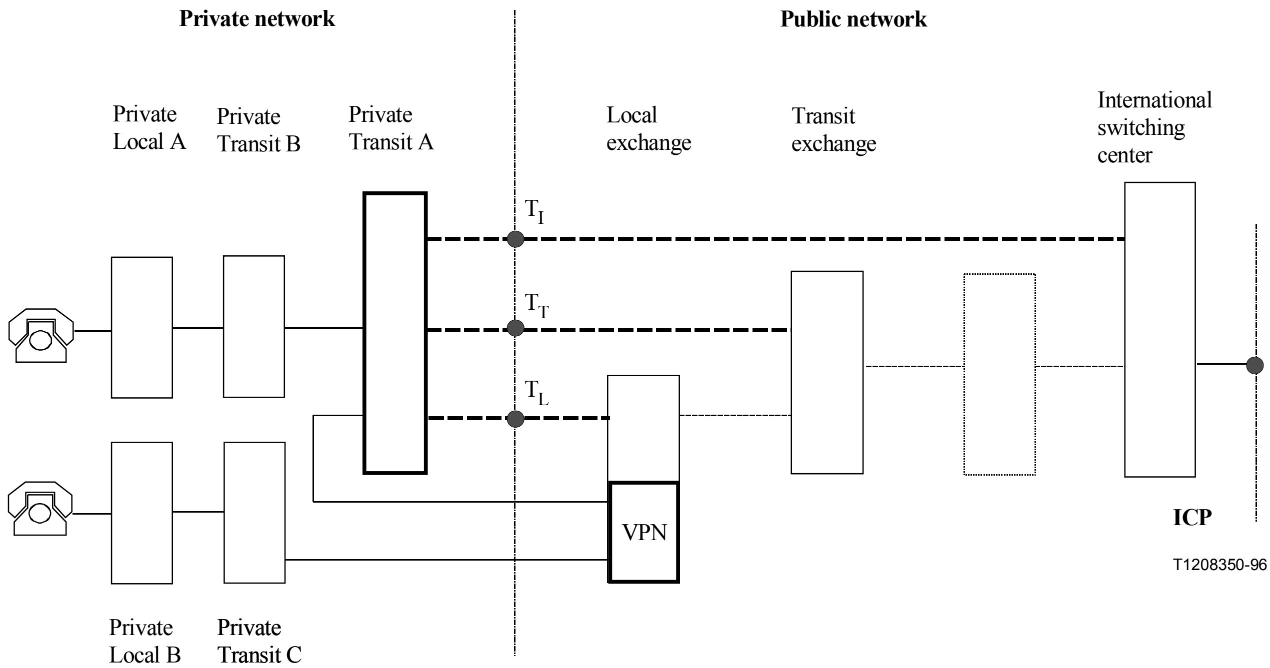
4.6 access to other private networks: Considering the access to another private network, it is necessary to clearly identify if there is in fact a distinction between these two networks with respect to the private network definition in 4.1, or if these two networks may be considered as one network for transmission planning. The planning guidelines in this ITU-T Recommendation may be also advantageous mainly in those cases, where the interconnection is only used for calls between these two networks without any routing via a public network.

While standardized interfaces and access-points will be commonly used for the access to public networks, a wider variety of physical characteristics with respect to the used frame structures, bit rates and transmission media must be considered for the interconnection between different private networks. For transmission planning, it seems important to identify if the interconnection is performed directly, or via an additional transmission element (such as a leased line, radio, or satellite link etc.), which contributes with further impairments.

5 Reference configurations

Due to the variety of hierarchies, structures, routing, and number and types of network elements in a private network, each connection investigated will result in a different reference configuration. Therefore, it is not possible to create only one basic figure for the whole task of private network planning. Figures 1 to 4 are to be considered only as examples, used mainly for definitions in this ITU-T Recommendation.

The basic reference configuration for the interconnection between a public and a private network is shown in Figure 1. The private network contains transit and local exchanges with its terminals. The public network is only shown up to the international connection point of an international switching centre.



ICP International Connection Point

T_L Access point to local exchange of public network

T_T Access point to transit exchange of public network

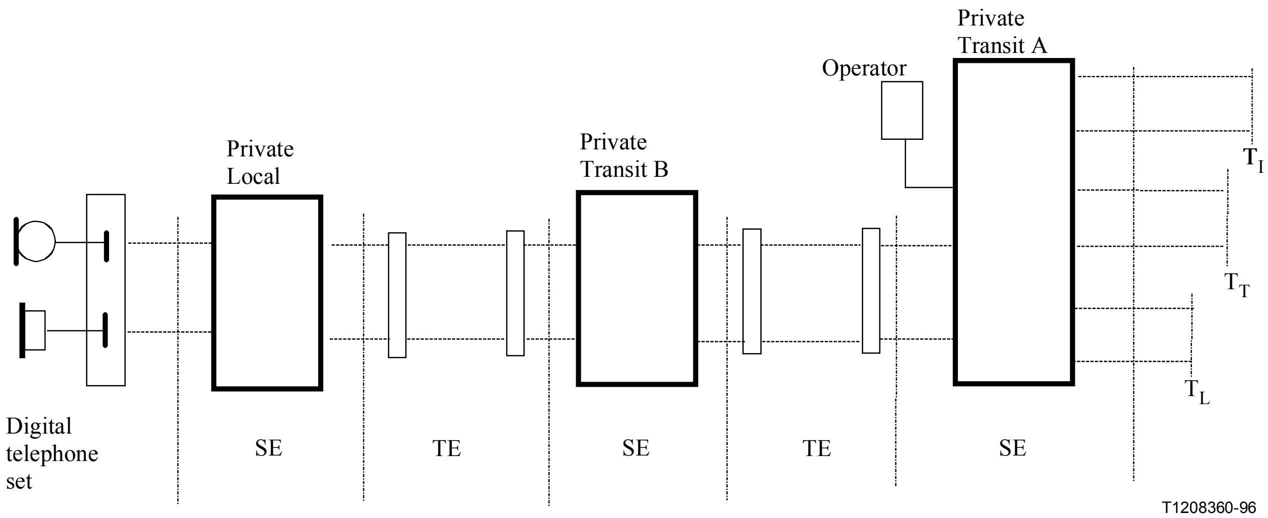
T_I Access point to international switching center

VPN Virtual Private Network

Figure 1/G.175 – Basic reference configuration for the interconnection between private and public network

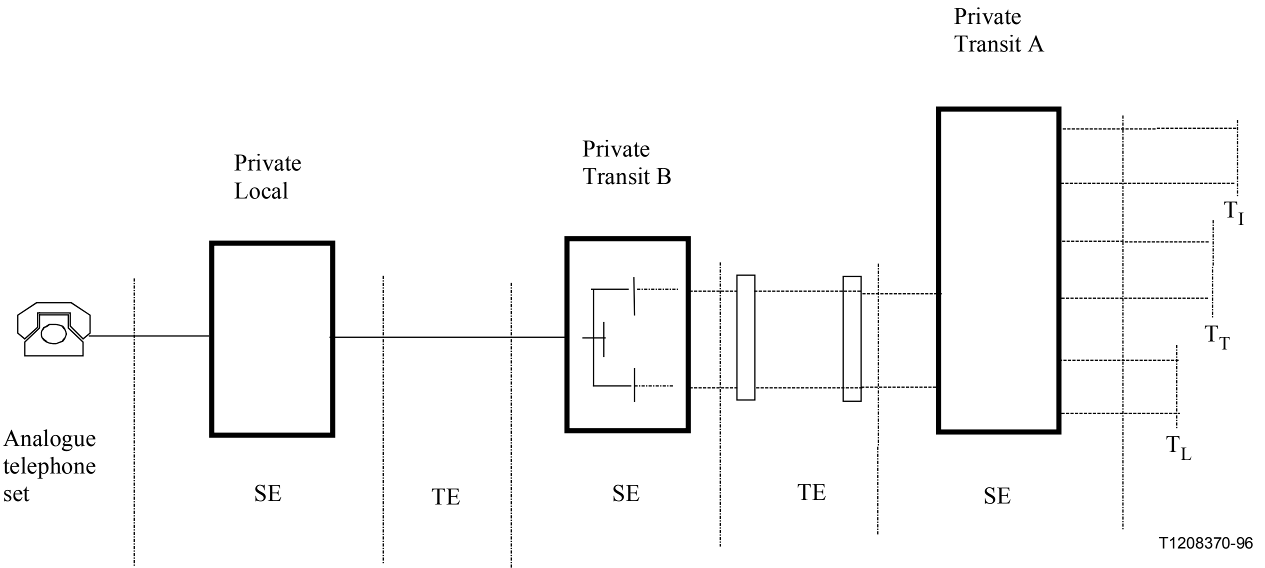
It is assumed that the permitted impairments between the access points for calls within the national network are partitioned symmetrically with reference to the International Connection Point (ICP), which will be considered as a virtual centre of the public network. Since calls can be terminated on both sides of private networks in the same configuration, it seems sufficient to draw Figure 1 in this simple way. From the planning point of view, the private network is also divided into local exchanges and into higher level transit exchanges, similar to the public network. The interconnection between the private and the public network is assumed in three different configurations. The access T_L represents the standard interconnection to the local exchange of the public network. Further types of access called T_T and T_I are bypassing the local exchange and entering the public network in a higher hierarchy, either in a transit exchange or directly enter the international switching centre.

Figures 2 through 4 present in more detail some examples of possible configurations within the private network, in conjunction with different types of access to the public network.



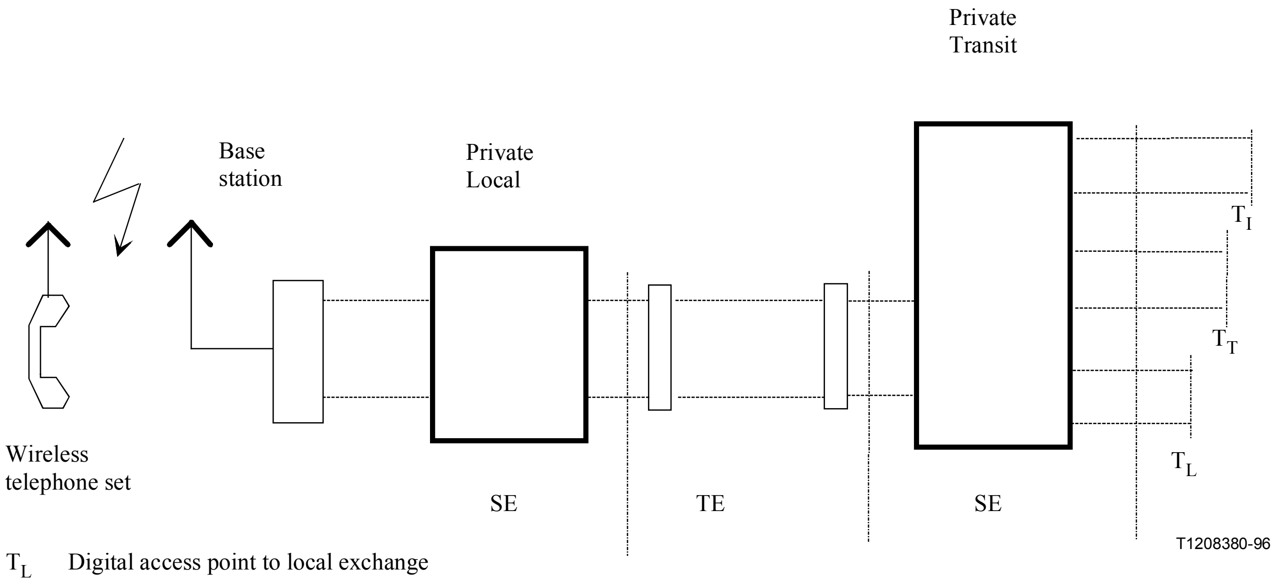
T_L Digital access point to local exchange
T_T Digital access point to transit exchange
T_I Digital access point to international switching center
SE Switching Element
TE Transmission Element

Figure 2/G.175 – Private network with fully digital routing



T_L Digital access point to local exchange
T_T Digital access point to transit exchange
T_I Digital access point to international switching center
SE Switching Element
TE Transmission Element

Figure 3/G.175 – Private network with analogue/digital routing



T_L Digital access point to local exchange
T_T Digital access point to transit exchange
T_I Digital access point to international switching center
SE Switching Element
TE Transmission Element

Figure 4/G.175 – Private network in conjunction with a digitally-connected wireless telephone

6 Basic planning principle – the impairment factor method in conjunction with the E-Model

In general, the quality of speech transmission via telephone channels is based on a subjective judgement by the users at both ends. Therefore, transmission planning as given in ITU-T Recommendation G.101 [2] is, in principle, derived from an end-to-end consideration in conjunction with a partitioning of all relevant parameters between different networks, or parts of a network, where applicable. For private networks, this method was in common use in the field of regulation for all calls via the public network, providing limits for the private network between the acoustical interface of the telephone set and an electrical interface to the public network. These limits were defined to guarantee a sufficient quality for all calls (national and international).

In conjunction with increasing liberalization in many countries, the responsibility for a sufficient voice transmission quality is now shifted to the private network operator. However, planning of private networks with respect to voice transmission quality needs knowledge and experience in the field of transmission parameters and their influence to quality. Therefore, it seems necessary to provide a planning method, easy to handle and accompanied by tutorial information and planning tools. This is the main task of this ITU-T Recommendation.

The basic planning principle as used in this ITU-T Recommendation deviates from previous planning methods for private/public network interconnection scenarios. These interconnection scenarios are not covered by other ITU-T Recommendations of the G.100-series, which still provide good guidance for end-to-end transmission planning. For all configurations subject to this ITU-T Recommendation, the planning of speech transmission quality should be based on an end-to-end consideration rather than on a specification of individual objective parameter limits. End-to-end speech transmission quality is expressed in terms of the E-Model Rating *R*, as a result of calculations with the E-Model (described in ITU-T Recommendation G.107 [3]). The E-Model is a planning tool which is based on the equipment impairment factor method, as described in ITU-T Recommendation G.113 [6]. The E-Model Rating *R* can be transformed into other quality measures, which have been used in transmission planning before, such as Mean Opinion Score (MOS), Percentage Good or Better (%GoB) or Percentage Poor or Worse (%PoW), according to Annex B/G.107.

It should be noted that the preferable purpose of network planning is to control the summation of transmission impairments, caused by the different network elements in all possible configurations. It is not the task of network planning to limit the transmission impairment of a specific network element. Unless indicated otherwise, it is assumed that transmission, switching and terminal elements in general are designed to meet all relevant requirements as given in ITU-T Recommendations and in international or national standards applicable for this type of element.

The introduction of a quality issue for planning purposes also enables the private network operator to make the design of the network on a cost versus quality relation, taking into account the specific requirements for the private network.

Transmission planning based on the E-Model as recommended in this clause provides a prediction of the expected quality, as perceived by the user, for an investigated connection. Based on subjective testing users perception is expressed in terms of MOS, %GoB or %PoW. During transmission planning, however, it is not practical to perform subjective tests. Therefore, a method must be provided which enables the planner to combine by calculation all existing transmission impairments in the given connection to a total value of impairment. This calculation must be performed by using an algorithm based on subjective testing. In telephone connections consisting of a variety of network elements, different transmission parameters may also simultaneously contribute to the total impairment. Therefore, the planning method used must also incorporate combination effects.

A planning method with the approach to meet the requirements given above is available with the impairment factor method [6] in conjunction with the E-Model [3].

Based on an end-to-end assessment for each transmission parameter (including the type and number of low bit-rate codecs) impairment values are derived. This method accounts for low bit-rate coding devices as well as for impairments introduced by standard PCM coders and for impairments not directly related to digital processing.

The impairment factor method is based on the assumption that transmission impairments can be transformed into psychological factors and that these psychological factors are additive on the "Psychological Scale". An appropriate mathematical algorithm is provided by the E-Model, with which the different transmission parameters can be transformed into different "Impairment Factors". This method and the algorithm of the E-Model also include the combination effects of those impairments in the considered connection which occur simultaneously as well as some masking effects. With the E-Model, a very useful tool is available, which provides a simplified and easy-to-handle method for practical planning purposes.

The final result of any calculation with the E-Model is the E-Model Rating R. The relation between the different impairment values and R is given by the equation:

$$R = Ro - Is - Id - Ie + A \text{ (see Note)}$$

High values of the E-Model Rating R in a range of $90 \leq R < 100$ should be interpreted as excellent quality, while a lower value of R indicates a lower quality.

NOTE – For the calculations shown in this ITU-T Recommendation the algorithm of the E-Model has been taken from G.107 at the time of publication. In case a later revision of G.107 does show a refined version of the algorithm, the value of $R = 94.1$ for all input values default may slightly change. Nevertheless, this ITU-T Recommendation will still provide valid guidance for tutorial purposes. For actual transmission planning tasks it should, in any case, be referred to the latest version of G.107.

The term Ro expresses the basic signal-to-noise ratio.

The term Is represents all impairments which occur more or less simultaneously with the voice signal, such as: too loud speech level (non-optimum OLR), non-optimum sidetone (STMR), quantization noise (qdu), etc.

The "delay impairment" factor *Id* sums all impairments due to delay and echo effects, and the "equipment impairment factor", *Ie*, represents impairments which are caused by low bit-rate codecs used in special equipment.

The "Advantage Factor " *A* represents an "Advantage of Access" which certain systems may provide in comparison to conventional systems. While all other impairment factors are subtracted from the basic signal-to-noise ratio *Ro*, this value is added and thus compensates other impairments to a certain amount. It can be used to take into account the fact that the user will tolerate some decrease in transmission quality in exchange for the "Advantage of Access". Examples of such advantages are cordless and mobile systems or connections into hard-to-reach regions via multi satellite hops. The use and the amount of the Advantage Factor *A* fall into the responsibility of the individual transmission planner and are for further study.

It should be noted, that, in some cases, not only the final result for *R* is of interest, but also the specific impairment values *Is*, *Id* and *Ie*. Their individual contribution to the total value of impairments can be used for the determination of the major impairments in the given configuration and for possible solutions for the reduction of these impairments' severity: e.g. reducing *Id* by the insertion of echo cancellers.

A more detailed description of the different impairment factors can be found together with the algorithm of E-Model in ITU-T Recommendation G.107.

7 Planning method and limits

The introduction of the basic principles and of new planning methods were already shortly described in clause 6. Planning of private networks is performed in many cases by the operator of the private network, but it is in most applications strongly influenced by the transmission planning of the public network. Previous or still existing planning rules for interconnections with public ISDN/PSTN are applied only to the private network domain, i.e. between the acoustic interfaces and the interface to the public network. The planning values are based on a partitioning of permitted impairments, or on limits for each specific transmission parameter.

Such a partitioning, usually not taking into account the specific size, structure and complexity of a private network, will result in a very rigid handling in conjunction with stringent limits for the different transmission parameters. To provide more flexibility in this field, the planning and design of private networks should therefore be based more on individual negotiations between public and private network operators than on partitioning. Although in most cases the borders between public and private networks can be clearly identified at specific interfaces, the priority of negotiations should be more in the determination of the actual impairments in the public and private network domain. This can be supported by considering the individual configurations and requirements of a private network, such as type and point of access to the public network and the majority of connection types (international, national long distance, or local calls).

To meet these goals, a planning method is recommended and described as follows for the interconnection between public and private network. This method may also be generally applicable to multi-operator networks.

7.1 Planning method

The planning method for the interconnection of private networks and the public ISDN/PSTN can be considered as a sequence of steps. The following detailed description of these different steps may be used as a guidance.

– *Configuration and requirements of the individual private network*

  In a first step, the configuration of the private network, its features with all resulting possible routings, and the type and point of access to the public network, should be considered.

Furthermore, the majority of traffic via public networks should be taken into account, whenever this seems applicable, and depending on the business affairs of the private network operator.

– *Determination of reference configurations*

As usual in network planning, it is advisable to develop a reference configuration mainly for the path within the private network. This makes it easier to clearly identify all network elements and their relevant transmission impairments. It is assumed that the most critical path with respect to transmission impairments is selected as the reference configuration. However, depending on the network operator's decision, some specific configurations or routings, achieved only in exceptional cases within the network, may be accepted with lower quality, but not taken as the reference configuration.

– *Ascertainment of actual transmission impairments*

For each of the network elements within the private network and for all main parameters, subject to planning as listed in 7.2, the actual values must be determined. It should be noticed that some elements may contribute with more than one parameter to the total impairment. For most of the main transmission parameters, the actual values of impairments for each element can be determined separately, followed by a simple addition of all element-related values. For some parameters such as echo and stability, however, the investigation must be performed for the relevant entire part of a connection.

During this step it is also advisable to investigate some possible sources for further transmission impairments, such as impedance mismatching at analogue interfaces, relation between signal level and load capacity of codecs, and excessive room noise at specific locations.

The determination of actual transmission impairments caused by public networks is subject to agreements between public and private network operators. Whenever possible, this ascertainment should include not only information about the contributing parameters and their actual values with respect to the different routing for local, national long distance and international calls, but also information about the use of echo cancellers and their performance. It must be taken into account that these values may vary in a wide range, only representing an estimate of the transmission performance of paths through the public network. Nevertheless, it is recommended that the preference should be more for a statistical than for a worst-case consideration.

The same is valid for the opposite termination, which must be defined for the purpose of an end-to-end inspection. Most of the opposite terminations will be formed by a single analogue or digital telephone set, but PABXs or private networks must also be considered. The definition of these terminations and their transmission parameters, mainly SLR, RLR, distortions, delay and provided echo loss, should also be derived by a statistical consideration. If possible, the necessary information can be obtained from the public network operator with respect to the network configuration in the subscriber area.

The actual values with respect to all relevant transmission parameters should also be determined for all types of digital or analogue leased lines. Although these leased lines will usually be provided by public network operators, they must be considered as part of the private network from the point of view of transmission planning.

– *Planning calculation*

All actual values of the main parameters from the different elements within the private network, the public network(s) and the opposite termination, are transformed to be used in the E-Model. A detailed description on the use of this model is given in 7.4. The results can be obtained as the E-Model Rating *R* to be judged according to Table 1. More details about the planning calculations using the E-Model is given in 7.4.2.

– *Judgement of results*

The results of planning investigation expressed in terms of E-Model Rating R should be judged according to the categories given in 7.3. It is worth noticing that this planning method may also be used to compare different technical solutions for a specific network element by means of their influence to the expected quality, e.g. influence of different codec algorithms, use of DCME in transmission elements, deployment of ATM, etc. For the benefit of an economical design for the private network, the final decision can be based on a ratio between costs and perceived quality.

7.2 Main parameters

Based on the assumption that in modern private networks the majority of exchanges and interconnecting (leased) lines uses digital technology and that interconnections to the public ISDN and to the PSTN are only digital, a rating of the different transmission parameters should be performed with respect to their influence on speech quality. In a digital environment, some parameters (e.g. frequency distortion, steady circuit noise, loss variation with time, etc.) have become less important. The following parameters are recommended to be included in the transmission planning.

– *Overall Loudness Rating (OLR)*

In some configurations for private networks, mainly in the lower hierarchy, small PABXs connected via 2-wire analogue sections will be in use contributing with loss. Furthermore, analogue telephone sets designed in their SLR and RLR for previous fully-analogue connections may introduce impairments caused by a non-optimum overall loudness rating.

– *Absolute delay in echo-free connections*

This parameter is mainly important in case of international calls.

– *Echo*

The investigation of impairments due to echo effects tends to be one of the most important planning aspects in a digital environment. Two different parameters, the Talker Echo Loudness Rating (TELR) and the mean one-way-delay *T* of the echo path must be considered. The investigation of echo should also include decisions about the use of echo cancellers.

– *Stability*

According to the assumption that private networks are interconnected digitally with the public ISDN/PSTN, any 4-wire to 2-wire conversion within the private network may terminate the international chain, eventually affecting the stability. Calculations of the stability are not covered by the E-Model, although the provision of a sufficient stability loss is strongly recommended. Values and guidance can be found in ITU-T Recommendation G.122 [7].

– *Quantization distortion*

In modern private and public networks which are using more and more fully digital routing, the impairment due to quantization distortion expressed in a number of qdu is decreasing. The E-Model includes this parameter, however, it should only be used for a PCM coding process according to ITU-T Recommendation G.711 [11]. For all other coding algorithms, the equipment impairment factor *Ie*, as shown in Appendix I/G.113 [6] should be used.

– *Equipment impairment factor Ie*

The equipment impairment factor *Ie* which expresses the impairments caused by low bit-rate coding algorithms and other processing devices is one of the most important impairments in modern networks. Available values to be used with the E-Model are given in Appendix I/G.113.

7.3 Quality expectation and absolute upper planning limits

As described in ITU-T Recommendation G.107 [3] and in 7.4, the results of planning calculations using the E-Model are primarily obtained in terms of an E-Model Rating *R* for the considered configuration. The E-Model Rating *R* can lie in the range from 0 to 100, where $R = 100$ is representing a very high transmission quality and $R = 0$ means extremely bad or unacceptable. The *R*-value can be transformed into a number of different quality measures such as MOS, %GoB and %PoW using the Gaussian Error function as described in Annex B/G.107.

Basically, the judgement of the resulting E-Model Rating *R* is up to the planner's decision. However, it is strongly recommended to establish a specific limit which never should be exceeded, even in exceptional cases.

In some cases, planners may not be familiar with the use of E-Model Rating *R* as a result from planning calculations. Guidance in terms of a verbal description of the expected user satisfaction for the different *R*-values is given in Table 1, taken from ITU-T Recommendation G.109 [5].

Table 1/G.175 – Definition of categories of speech transmission quality

***R*-value range**	**Speech transmission quality category**	**User satisfaction**
$90 \le R < 100$	Best	Very satisfied
$80 \le R < 90$	High	Satisfied
$70 \le R < 80$	Medium	Some users dissatisfied
$60 \le R < 70$	Low	Many users dissatisfied
$50 \le R < 60$	Poor	Nearly all users dissatisfied
NOTE – Connections with *R*-values below 50 are not recommended.		

7.4 Use of the E-Model

The basic principles and the algorithm of the E-Model are contained in ITU-T Recommendation G.107 [3] including a reference configuration of the model. When using the E-Model for planning calculations, care should be taken for a correct input of all transmission parameters. The following list of all parameters will provide the necessary guidance, whereas in ITU-T Recommendation G.108 [4] tutorial information for different applications can be found. The model distinguishes between the send side and the receive side. Both sides and most of the parameters are referred to a virtual 0 dBr point. There are 18 input transmission parameters in total, but not all of them are varied for the purpose of transmission planning. It is important to note that the E-Model estimates the speech communication quality for both talking and listening as perceived by the user at the receive side. For transmission parameters not varied during planning calculations, default values should be set, as recommended in 7.4.3.

7.4.1 Input parameters

The following input parameters are used in the E-Model.

– *Send Loudness Rating (SLR) and Receive Loudness Rating (RLR)*

The values of SLR and RLR are not directly related to the values of the telephone sets which are used. SLR represents the loudness rating between the human mouth at the send side and the virtual 0 dBr point and RLR represents the loudness rating from the 0 dBr point to the human ear at the receive side. If network elements contributing with loss are inserted between the telephone set and the 0 dBr point and vice versa, the calculation of the total SLR and RLR must be performed separately, since the model does not allow for an input of Circuit Loudness Rating. The Overall Loudness Rating (OLR) is in any case the sum of SLR and RLR. Should a specific range of OLR be investigated, it is recommended to vary SLR and RLR simultaneously to avoid errors. If different values for SLR and RLR are existing for the telephone sets used on each end of the connection, the *R* values for both transmission directions must be calculated separately. In this application, only the SLR at the send side and the RLR at the receive side may be used as an input to the model. The remaining parameters (SLR at receive side and RLR at send side) are not used. Their influence to the speech transmission quality due to room noise and to talker echo is included via the parameters TELR, STMR and LSTR.

– *Sidetone Masking Rating (STMR) and Listener Sidetone Rating (LSTR)*

These parameters, which are directly related to the telephone sets used, are in most cases not subject to planning and should be set to the default values. They must only be taken into account if incorrect impedance matching of analogue telephone sets, or low values for STMR and LSTR should be expected.

– *D-Factors (Ds and Dr)*

The D-Factors *Ds* for the send side and *Dr* for the receive side are fixed values depending on the shape of the handsets of the telephone sets used. As a fixed value, they are usually not subject to planning. For the *D*-Factors and for the values for STMR and LSTR of a telephone set, a fixed relation is assumed:

$$LSTR = STMR + D$$

– *Talker Echo Loudness Rating (TELR)*

The TELR, expressing the loudness rating of the echo path, is defined as the sum of SLR and RLR of the talker's telephone and the echo loss of the echo path. This value has to be calculated separately using the SLR/RLR values at the receive side with respect to the E-Model. The echo path must be identified and calculated carefully within the reference configuration to avoid wrong inputs for the TELR.

– *Weighted Echo Path Loss (WEPL)*

In conjunction with the round-trip delay in a closed 4-wire loop, this parameter may cause impairments due to listener echo. Closed 4-wire loops may happen in a configuration if the connection includes 4-wire to 2-wire conversions. These conversions may be located in different networks and in different countries. The WEPL is defined as the sum of all losses and gains within the loop, also called the "Round-Trip Loss". In most cases, listener echo can be neglected, if sufficient echo control is provided in a telephone connection.

– *Delay values (T, Ta and Tr)*

The E-Model distinguishes three different values for delay, which must be determined and used separately in the model. The mean one-way delay time *T* in ms is used to calculate the impairments due to talker echo in conjunction with TELR. It should be noted that although this is an impairment to the talker, the estimate of the impairment is referred to the receive side of the model. The mean one-way delay *T* has to be determined and calculated only for the sections in the reference configuration forming the echo path, i.e. from talker's telephone up to the identified point where signal reflections may occur, e.g. a 4-wire to 2-wire conversion. Complementarily, the absolute one-way delay *Ta* in ms is in any case the total delay via the whole connection between the two subscribers. *Ta* represents impairments due to too-long delay and must be included mainly in planning for international calls, even if perfect echo cancellation is provided. The round-trip delay *Tr* in ms will cause listener echo in conjunction with WEPL. *Tr* is defined as the total delay within the closed 4-wire loop.

– *Equipment impairment factor (Ie)*

The values for the equipment impairment factor *Ie* as an input to the E-Model are representing impairments due to low bit-rate codecs in specific network elements. Values based on subjective tests are given in Appendix I/G.113.

– *Advantage factor (A)*

The algorithm of the E-Model also includes the Factor *A* for the calculation of the E-Model Rating *R*; however, the inclusion and its value are subject to the planners' decision. For more information, see clause 6.

– *Room Noise (Ps and Pr)*

Impairments perceived at the receive side may also be caused by the room noise at the send side and at the receive side, contributing to the basic signal-to-noise ratio. Values for the room noise *Ps* in dB(A) at send side and *Pr* in dB(A) at receive side are usually set to default values, but may be varied for planning purposes in case of excessive noise at a specific location. The algorithm in the E-Model transforms these values into an equivalent circuit noise referred to the 0 dBr point.

– *Circuit Noise (Nc)*

If necessary, the circuit noise *Nc* in dBm0p can be obtained by a power addition of all electric noise sources in the connection, all referred to the 0 dBr point. In most cases, sources for steady noise in a digital environment may be neglected and the input parameter may be set to its default value.

– *Noise Floor (Nfor)*

The input parameter noise floor in dBmp represents a basic noise in the equipment at the receive side. Its nominal value is set to –64 dBmp and should not be modified.

– *Number of Quantizing Distortion Units (qdus)*

Impairments due to quantization distortion are entered into the model as a number of qdu. It should be noted that qdus may only be used for a codec pair using PCM coding according to ITU-T Recommendation G.711 and for distortions arising from digital loss or gain pads (0.7 qdu). For all other coding algorithms, the relevant equipment impairment factors *Ie* must be used.

7.4.2 Performing the calculation

If all input parameters are available, the calculation process can be described as follows:

a) Compute separately SLR and RLR and perform the calculation of the basic signal-to-noise ratio *Ro*.

b) Compute the simultaneous impairment factor *Is*.

c) Calculate separately the mean one-way delay and TELR of the echo path, the absolute one-way delay *Ta* and the round-trip delay *Tr*, and compute the delayed impairment factor *Id*.

d) Add the equipment impairment factors *Ie* for the different equipments.

e) Compute the rating factor *R* and add the *A* factor if applicable.

f) Check whether the recommended limit of *R* = 50 is violated.

In practice, computer programs will be used for the calculations providing a total run via all steps a) through f).

7.4.3 Default values

For all input parameters used in the algorithm of the E-Model, the default values are listed in ITU-T Recommendation G.107. It is strongly recommended to use these default values for all parameters which are not varied during planning calculation. If all parameters are set to the default values, the calculation results in a very high quality with a rating factor of *R* = 94.1 (see Note in clause 6).

8 Implementation of echo cancellers

The increasing use of speech processing devices and digital radio sections also in modern private networks will increase the delay values within the private network by an amount, which requires the implementation of echo control devices not only for national long distance calls, but also for local or internal calls. Since less experience with the insertion of such devices in the private network domain can be expected, some guidance should be given to the planner.

Primarily it is recommended to use echo cancellers, the use of echo suppressors (as per previous ITU-T Recommendation G.164) is no longer recommended. Echo cancellers should meet or exceed the requirements of ITU-T Recommendation G.168 [9], echo cancellers according to the older ITU-T Recommendation G.165 [8] may be used if no problems occur. Mainly in case of international calls, where echo cancellers are inserted by the public network operator, a tandeming of cancellers may occur. Practical experiences have shown that echo cancellers (recently designed according to ITU-T Recommendation G.165 [8]) will cause no major problems in a tandem configuration, but tandeming may impact the perceived speech quality in certain cases, such possible impact depends on various factors, which are not subject to transmission planning (e.g. double talk, highly interactive conversation, ECs from different manufacturers). It is advisable to inquire the application of cancellers and their performance of the public network operator. Depending on the permitted echo path delay of this equipment, on the point of access and on the routing within the public network, additional cancellers in the private network could possibly be avoided in some cases.

The investigation and the final decision about the insertion of echo cancellers within the private network must not only cover the echo control for the talker in the private network but also for the talker at the opposite termination in case of local or national long-distance calls via the public network.

Some terminal and transmission elements, such as cordless and mobile telephones, or speech companding devices, may provide integrated echo cancellers which must be taken into account. Those devices must be carefully investigated with respect to the relevant performance parameters, such as permitted echo path delay, residual echo loss, required echo path loss, etc.

As a basic rule, echo cancellers should be located close to the echo source within the private network for the benefit of the opposite termination. For echo cancellers according to ITU-T Recommendation G.165 [8] a linear echo path with a minimum echo path loss of 6 dB must be provided. For the control of the talker echo experienced by the subscriber in the private network (echo path via the public network and the opposite termination), information about this echo path regarding delay, echo path loss and linearity should be obtained by negotiations between public and private network operator, to allow a careful selection of the necessary devices. In most cases, these echo cancellers will be located close to the interface to the public network.

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