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TRANSMISSION SYSTEMS AND MEDIA

GENERAL RECOMMENDATIONS ON THE TRANSMISSION QUALITY FOR AN ENTIRE INTERNATIONAL TELEPHONE CONNECTION

ONE-WAY TRANSMISSION TIME

ITU-T Recommendation G.114

(Previously "CCITT Recommendation")

FOREWORD

The ITU Telecommunication Standardization Sector (ITU-T) is a permanent organ of the International Telecommunication Union. The 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, established the topics for study by the ITU-T Study Groups which, in their turn, produce Recommendations on these topics.

ITU-T Recommendation G.114 was revised by the ITU-T Study Group XII (1988-1993) and was approved by the WTSC (Helsinki, March 1-12, 1993).

NOTES

1 As a consequence of a reform process within the International Telecommunication Union (ITU), the CCITT ceased to exist as of 28 February 1993. In its place, the ITU Telecommunication Standardization Sector (ITU-T) was created as of 1 March 1993. Similarly, in this reform process, the CCIR and the IFRB have been replaced by the Radiocommunication Sector.

In order not to delay publication of this Recommendation, no change has been made in the text to references containing the acronyms "CCITT, CCIR or IFRB" or their associated entities such as Plenary Assembly, Secretariat, etc. Future editions of this Recommendation will contain the proper terminology related to the new ITU structure.

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

CONTENTS

Recommendation G.114

ONE-WAY TRANSMISSION TIME

*(Geneva, 1964; amended Mar del Plata, 1968; Geneva, 1980;
Malaga-Torremolinos, 1984; Melbourne, 1988 and Helsinki, 1993)*

Transmission time for connections with digital segments includes delay due to equipment processing as well as propagation delay, such that both types of delay can be significant contributors to overall transmission time. Guidance is especially needed for designers of telecommunications equipment that uses signal processing, causing increase in delay.

Historically a value of 400 ms was considered a meaningful limit for network planning purposes, where voice telephony was the focus. This value was not originally intended as guidance for equipment designers who, on an increasingly frequent basis, can substantially affect the transmission time by the amount of signal processing in their designs.

Transmission time is a very important parameter for any application whose overall performance is dependent on user or terminal interactivity. Applications such as voice, voice-band data, digital data, and videotelephony may involve user tasks or terminal equipment characteristics that vary substantially in their sensitivity to transmission delay. Because network and service providers cannot alter the transmission time characteristics nor transmission media between two Administrations, in response to all possible user tasks and applications, some highly interactive tasks may experience degradation even at delays on the order of 100 ms. Accordingly, it is critical that the delay (transmission time) be seen as a vital resource that is to be consumed with caution, and only when clear service benefits derive from it. This especially applies to delay associated with signal processing.

This Recommendation is intended to assist equipment designers and network planners in realizing acceptable services to users performing a wide variety of tasks with multiple applications. It is recognized that not all possible user applications and network configurations can be predicted, and that some user applications and network arrangements may combine processing delays and propagation times such that the total transmission time exceeds 400 ms.

A clear purpose of this Recommendation is thus to emphasize the need to consider the delay impact on evolving service applications, and indicate the desirability of avoiding delay increases, especially processing delays, whenever possible.

In consideration of the above points, the CCITT *recommends* the following limits for one-way transmission time for connections with echo adequately controlled (see Note 1) according to Recommendation G.131:

0 to 150 ms	Acceptable for most user applications (see Note 2).
150 to 400 ms	Acceptable provided that Administrations are aware of the transmission time impact on the transmission quality of user applications (see Note 3).
above 400 ms	Unacceptable for general network planning purposes; however, it is recognized that in some exceptional cases (see Note 4) this limit will be exceeded.

NOTES

1 The use of echo control equipment that introduces other impairments, such as speech clipping and noise contrast, may have to be controlled in order to achieve acceptable transmission quality.

2 Some highly interactive voice and data applications may experience degradation for values below 150 ms. Therefore, increases in processing delay on connections with transmission times even well below 150 ms should be discouraged unless there are clear service and application benefits.

3 For example, international connections with satellite hops that have transmission times below 400 ms are considered acceptable.

4 Examples of such exceptions are unavoidable double satellite hops, satellites used to restore terrestrial routes, fixed satellite and digital cellular interconnections, videotelephony over satellite circuits, and very long international connections with two digital cellular systems connected by long terrestrial facilities.

The recommended limits given here can be better interpreted if the information provided in Annex B is considered. For example, the voice quality data indicate that, even in the complete absence of echo, 10% or more of the speakers may experience difficulty due to a delay of 400 ms. Increases in delay beyond this value will cause a further increase in unacceptable connections, especially for highly interactive conversations. To provision services with route diversity and restoration capabilities, Administrations may nonetheless choose to exceed 400 ms, on an exceptional basis. The data in Annex A provides guidance as to the service quality impact of such a decision.

Annex A

Delay estimation for circuits

(This annex forms an integral part of this Recommendation)

In the establishment of the general interconnection plan within the limits in Recommendation G.114, the one-way transmission time of both the national extension circuits and the international circuits must be taken into account. The transmission time of circuits and connections is the aggregate of several components: e.g. group delay in cables and equipment processing times (e.g. digital switches), etc.

The conventional planning values given in A.1 may be used to estimate the total transmission time of specified assemblies which may form circuits or connections.

A.1 Conventional planning values of transmission time

Provisionally, the conventional planning values of transmission time in Table A.1 may be used.

A.2 National extension circuits

The main arteries of the national network should consist of high-velocity propagation lines. In these conditions, the transmission time between the international centre and the subscriber farthest away from it in the national network can be estimated as follows:

a) in purely analogue networks, the transmission time will probably not exceed:

$$12 + (0.004 \times \text{distance in kilometres})\ \text{ms}$$

Here the factor 0.004 is based on the assumption that national trunk circuits will be routed over high-velocity plant (250 km/ms). The 12 ms constant term makes allowance for terminal equipment and for the probable presence in the national network of a certain quantity of loaded cables (e.g. three pairs of channel translating equipments plus about 160 km of H 88/36 loaded cables). For an average size country (see Figure 2/G.103) the one-way propagation time will be less than 18 ms;

b) in mixed analogue/digital networks, the transmission time can generally be estimated by the equation given for purely analogue networks. However, under certain unfavourable conditions increased delay may occur compared with the purely analogue case. This occurs in particular when digital exchanges are connected with analogue transmission systems through PCM/FDM equipments in tandem, or transmultiplexers. With the growing degree of digitization the transmission time will gradually approach the condition of purely digital networks;

c) in purely digital networks between local exchanges (e.g. an IDN), the transmission time as defined above will probably not exceed:

$$3 + (0.004 \times \text{distance in kilometres})\ \text{ms}$$

The 3 ms constant term makes allowance for one PCM coder or decoder and five digitally switched exchanges.

NOTE – The value 0.004 is a mean value for coaxial cable systems and radio-relay systems; for optical fibre systems 0.005 is to be used;

d) in purely digital networks between subscribers (e.g. an ISDN), the delay of c) above has to be increased by up to 3.6 ms if burst-mode (time compression multiplexing) transmission is used on 2-W local subscriber lines.

These values do not cover the additional delays introduced by PABXs and Private Branch Networks (PBNs).

A.3 International circuits

International circuits[1] will use high-velocity transmission systems, e.g. terrestrial cable or radio-relay systems, submarine systems or satellite systems. The planning values of A.1 may be used.

The magnitude of the mean one-way transmission time for circuits on high altitude communication satellite systems makes it desirable to impose some routing restrictions on their use. Details of these restrictions are given in Recommendation Q.13 [12].

TABLE A.1/G.114

Transmission medium	Contribution to one-way transmission time	Remarks
Terrestrial coaxial cable or radio-relay system; FDM and digital transmission	4 µs/km	Allows for delay in repeaters and regenerators
Optical fibre cable system; digital transmission	5 µs/km [g]	
Submarine coaxial cable system	6 µs/km	
Satellite system – 14,000 km altitude – 36,000 km altitude	 110 ms 260 ms	Between earth stations only
FDM channel modulator or demodulator	0.75 ms [a]	Half the sum of propagation times in both directions of transmission
FDM compandored channel modulator or demodulator	0.5 ms [b]	
PCM coder or decoder	0.3 ms [a]	
PCM/ADPCM/PCM transcoding	0.5 ms	
G.728 coder and decoder	2.0 ms	
8 kbit/s	32 ms [c]	
PLMS (Public Land Mobile System) (objective 40 ms, Rec. G.173)	80-110 ms	
H.261 video coder and decoder	FS	
G.763 coder and decoder	FS	
G.765 coder and decoder	FS	
Transmultiplexer	1.5 ms [d]	
Digital transit exchange, digital-digital	0.45 ms [e]	

[1] For short nearby links, telecommunications cables operated at voice frequencies may also be used in the conditions set out in the introduction to subclause 5.4 of Fascicle III.2.

TABLE A.1/G.114 (*cont.*)

Transmission medium	Contribution to one-way transmission time	Remarks
Digital local exchange analogue-analogue	1.5 ms [e)]	Half the sum of propagation times in both directions of transmission
Digital local exchange, analogue subscriber line-digital junction	0.975 ms [e)]	
Digital local exchange, digital subscriber line-digital junction	0.825 ms [e)]	
Echo cancellers	1 ms [f)]	

a) These values allow for group-delay distortion around frequencies of peak speech energy and for delay of intermediate higher order multiplex and through-connecting equipment.

b) This value refers to FDM equipments designed to be used with a compandor and special filters.

c) This is a performance requirements value. Hardware is currently not available.

d) For satellite digital communications where the transmultiplexer is located at the earth station, this value may be increased to 3.3 ms.

e) These are mean values: depending on traffic loading, higher values can be encountered, e.g. 0.75 ms (1.950 ms, 1.350 ms or 1.250 ms) with 0.95 probability of not exceeding. (For details, see Recommendation Q.551.)

f) Echo cancellers, when placed in service, will add a one-way propagation time of up to 1 ms in the send path of each echo canceller. This delay excludes the delay through any codec in the echo canceller. No significant delay should be incurred in the receive path of the echo canceller.

g) This value is provisional and is under study.

Annex B

Long delay considerations for telephone, videotelephone and videoconference circuits

(This annex forms an integral part of this Recommendation)

B.1 Introduction

International connections (see Figure 1/G.103) comprising submarine cables, may involve a maximum one-way transmission delay of about 170 ms.

A one hop satellite connection even with an ISL (Inter-Satellite Link) of moderate length introduces one-way transmission delay within the recommended limit of 400 ms. However, a careful analysis of the additional probable delay contributions by digital signal processing (e.g. TDMA, DSI, DCME, 16 kbit/s, 32 kbit/s and lower bit rate encoding, bit-regeneration, packet-switching, etc.), among other sources, shows that in some cases the recommended limit of 400 ms mean one-way transmission time might be exceeded.

In light of recent technical improvements in echo-control techniques and considering that fixed processing delays may reach hundreds of milliseconds in some currently designed systems (e.g. low bit rate digital mobile systems), it is important to understand also the effects of delay, in the absence of echo, on communications. This annex addresses this issue.

The 4-wire circuits provide a close approximation to echo-free connections, assuming adequate acoustic coupling less across the handset. In the long run, with expansion of the ISDN implementation, use of 4-wire circuits is expected to grow. However, 2-wire circuits and their accompanying hybrid connection, as well as other components causing echo, are still likely to be present in varying degrees during the foreseeable future. Thus, the use of modern echo cancellers in satellite circuits is currently regarded as the most effective method for overcoming the echo problem, provided that the characteristics of the echo path to be modelled by the echo canceller are linear and time invariant, or varying only slowly compared with the convergence speed of the echo canceller.

A brief discussion of delay effect, in the absence of echo, on communication quality is provided below.

B.2 Effect of long transmission delays on the subscriber

B.2.1 Effects of echo cancellers

In 1987, Communications Satellite Corporation (COMSAT) of the United States performed a series of tests to determine the effectiveness of echo cancellers in terrestrial and satellite circuits, using echo cancellers conforming to Recommendation G.165 [2] and a callback interview procedure as per Annex A/P.82. Details of the procedure were presented in [3] and a summary of the results is shown in Figure B.1, giving a plot of the per cent difficulty as a function of one-way transmission time. A one-way delay value of 45 ms over terrestrial circuits was taken as a reference, and the effect of increasing the delay value to 300 ms and 500 ms over terrestrial and satellite links was evaluated.

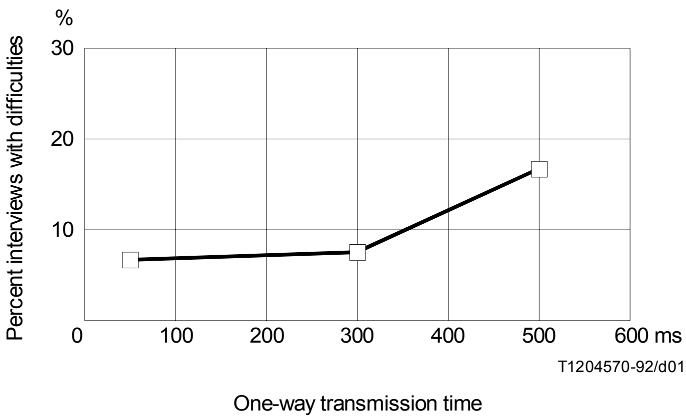

FIGURE B.1/G.114

Effect of long one-way transmission times on the difficulty of conversation with echo cancellers in the circuit

The COMSAT results show that no significant difference between 45 ms and 300 ms delays resulted for the "per cent difficulty" score. At a 500 ms delay, the per cent difficulty score approximately doubled (from 7.3% to 15.8%), but this value is still considerably smaller than earlier results of over 60% obtained with echo suppressors.

The above results support the view that connections with delays somewhat greater than 400 ms may be accepted provided that echo cancellers conforming to the specifications of Recommendation G.165 or other echo control devices with equivalent performance are used.

B.2.2 Effects of delay on dynamics of conversation

The most recent evidence presented by some Administrations suggests that the performance degradation due to conversation dynamics impairments is noticeable even below 400 ms one-way delay limit. This effect can be observed when structured interactive tasks and selected sensitive measures are employed in subjective experimentation.

In 1989 BNR (Canada) performed a series of subjective experiments [4] to determine the impact of the delay on the conversational characteristics deemed to be important in a business-type environment. A structured conversational task coupled with objective and subjective measures of the temporal dynamics of the conversation were developed and used in the experiment. Subjective measures included ratings on the ease of interruption, the necessity of repeating utterances, the attentiveness, responsiveness and helpfulness of the partner. Standard overall quality MOS rating was also used. The results are shown in Figure B.2.

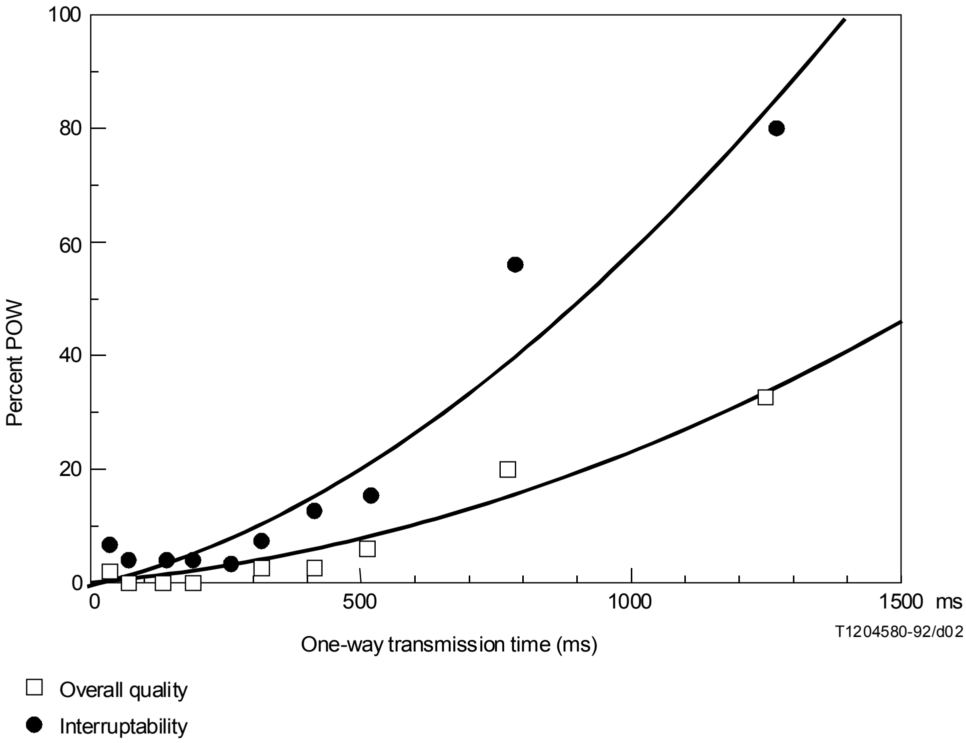

FIGURE B.2/G.114

Comparison of POW for overall quality and interruptability

A Bellcore subjective test intended to evaluate the effects of pure delay on speech quality was completed in 1990 [5]. The test was designed to obtain subjective reactions, in the context of interruptability and quality, to echo-free telephone circuits in which various amounts of delay were introduced. The results indicated that long delays did not greatly reduce mean opinion scores over the range of delay tested, viz. 0 to 1000 ms of one-way delay. In addition, the measure of interruptability did not show the divergence from overall quality to be as significant as indicated in Figure B.2. However, observations during the test and subject interviews after the test showed the subjects experienced some real difficulties in communicating at the longer delays, although subjects did not always associate the difficulty with the delay.

A second Bellcore subjective test intended to evaluate the effects of pure delay on telephone connections used by volunteer Telco customers was completed in 1991 [6]. The calls from these customers were routed through the Bellcore New Technology Laboratory where varying amounts of delay, viz. 0 to 750 ms of one-way delay was added. The test results showed that calls with (one-way delay): 0 ms of inserted delay were rated “good”; 250 ms of inserted delay were rated “fair”; and 500 ms of inserted delay were rated “poor”. These results are presented in Figure B.3.

Similar experiments were conducted by: CSELT [7], NTT [8] and PTT Netherlands [9]. The following is a highlight of the NTT results.

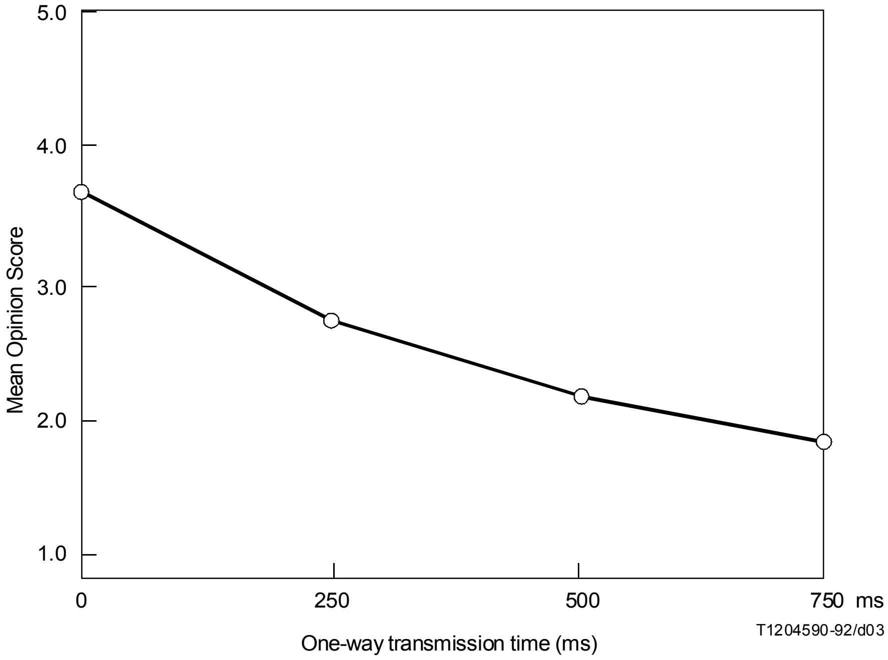

FIGURE B.3/G.114

Mean Opinion Scores (MOS) for the four delay conditions

The effect of delay was measured using a combination of objective physical parameters related to efficiency of a conversation. It was studied using the following six different conversational modes (tasks):

- Task 1 – Read out random numbers as quickly as possible in turn.
- Task 2 – Verify random numbers as quickly as possible in turn.
- Task 3 – Complete words with lost letters as quickly as possible by exchanging information.
- Task 4 – Verify city names as quickly as possible in turn.
- Task 5 – Determine the shape of a figure by receiving oral information.
- Task 6 – Free conversation.

Subjective opinion tests were performed and delay detectability thresholds. Mean Opinion Scores (MOS) and conversation efficiency were obtained. Figure B.4 shows detectability thresholds for various conversational tasks. The results show that the subjective quality as a function of delay varies depending on a conversational mode and subject group (trained, untrained).

In Figure B.4, the detectability threshold for round-trip delay was defined as the delay detected by 50% of a task's subjects and provides some guidance to network planners in providing acceptable service to the user.

B.2.3 Interaction between delay and user applications

NTT conducted tests to assess the interaction between delay and user applications. In these tests a comparison of telephone conversations with videophone were made and it was shown that there is little difference between both types of connection. Figure B.5 shows the degradations of MOS, using a condition without delay as ANCHOR [10].

A methodology for objective assessment of the effects of delay on speech communication in real networks was derived using the results of the above subjective experiments. This is described in the follow-up contribution [9].

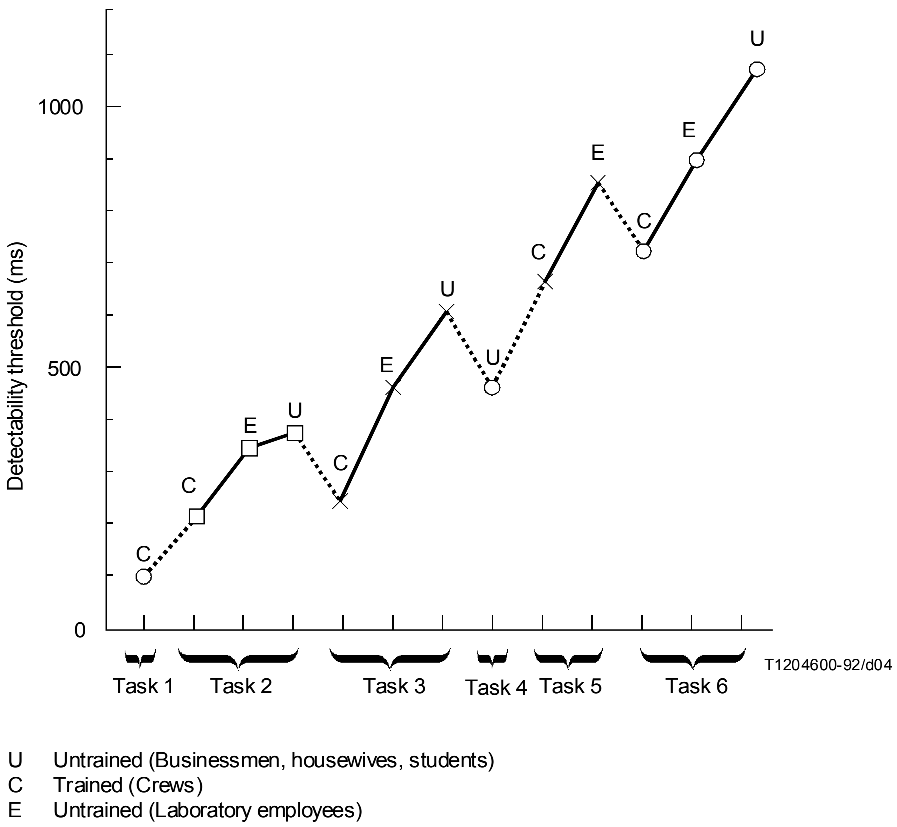

FIGURE B.4/G.114

Detectability thresholds for various conversational models

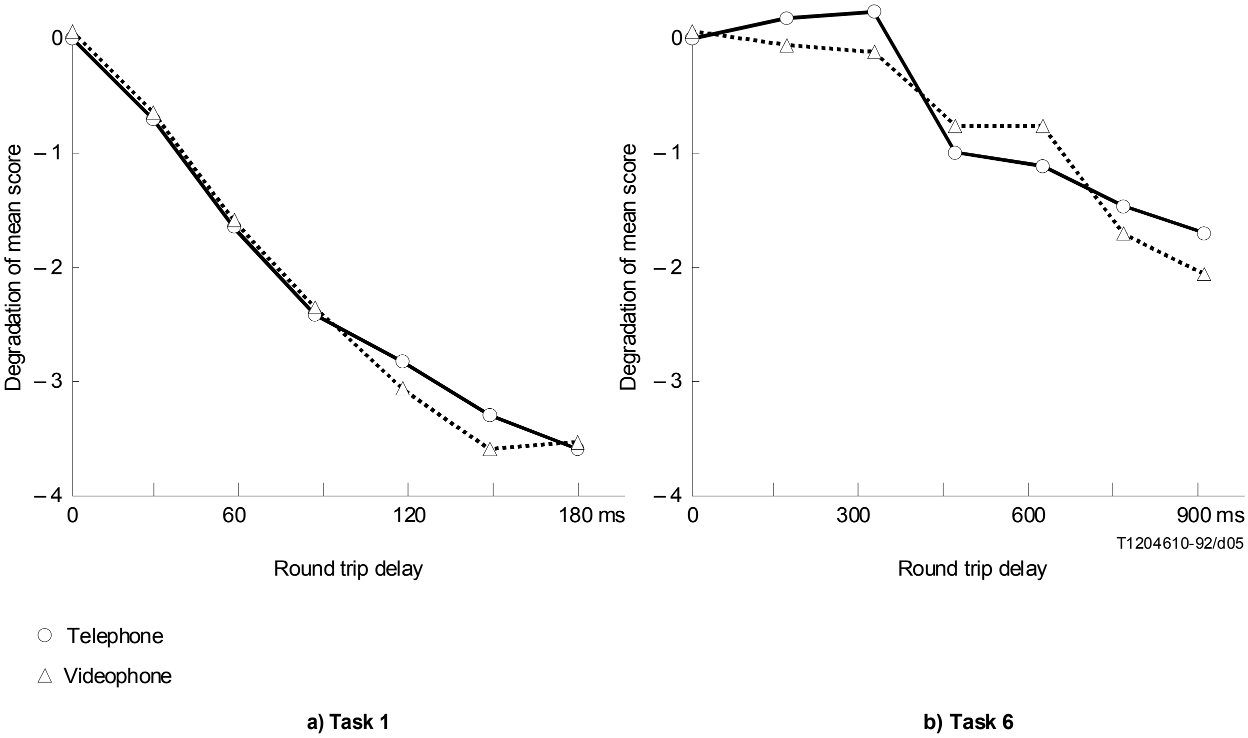

FIGURE B.5/G.114

Effects of delay on communications quality for telephone and videophone

The information on temporal characteristics and their correlation to subjective opinions was extracted from the subjective data. This data was then used to formulate equations predicting detectability threshold and MOS as a function of delay. The effects of the delay on performance in commercial networks can be estimated by measuring the basic temporal parameters from the real life traffic and then using this data to calculate the objective measures applying the experimentally derived equations.

Table B.1 presents an example of the results obtained using this methodology for a commercial circuit.

TABLE B.1/G.114

Effect of delay on speech quality in a real network

Conversation mode	Quality	Cumulative distribution (%)	Detectability threshold (Round trip delay ms)
Type of commercial call	Task 1	0,1	90
	Task 2	1	210
	Task 3	9	290
	Task 4	21	480
	Task 5	86	680
	Task 6	80	740
NOTE – More information to this table is given in [8].			

In 1992 the Communications Satellite Corporation (COMSAT) of the United States performed a study to assess the subjective impact of end-to-end transmission delay in audiovisual communications [11]. The experimental conditions included three point-to-point videophone connections with 200, 450 and 700 ms of one-way transmission delays. Subjects engaged in a series of five-minute long conversations and were interrogated at the end of each condition, as well as after the whole session. The results are summarized in Table B.2. Similar results were obtained from a videotelephony test conducted by CSELT [12].

TABLE B.2/G.114

Variation of subjective performance for three end-to-end videophone connections

	One-way transmission delays		
	200 ms	450 ms	700 ms
MOS connection quality	3,74 ± 0,52	3,69 ± 0,51	3,48 ± 0,48
MOS ease of interruption	4,00 ± 0,55	3,79 ± 0,53	3,56 ± 0,49
Communication difficulty	28 ± 4%	35 ± 5%	46 ± 6%
Connection acceptability	80 ± 11%	78 ± 11%	73 ± 10%
NOTE – MOS values were derived on the basis of a five point (1 to 5) scale. All errors are defined at a 95% level of confidence.			

B.3 Summary and conclusions

The transmission impairments associated with long delay circuits are best analysed by separating the echo-induced degradation and the subjective difficulty due to pure delay. Appropriate use of echo cancellers has been shown to indeed provide international or national satellite connections yielding quality and performance practically equivalent to the terrestrial connections for telephony. These results only refer to electric echo and additional studies are necessary to determine the effect of acoustic echo.

Thus, under these conditions, the dominant impairments are associated with the pure delay component.

Recently presented information suggests that

- The effects of pure delay (no echo) on conversation dynamics can be detected well below 400 ms one-way delay if subjective experiments employ highly interactive tasks and subjective measures related to specific conversational difficulties, such as ability to interrupt, are used.
- The effects of pure delay (no echo) on speech quality appear to moderately increase as the delay is increased.

However, as a standard set of tests has not been agreed to, obtained experimental results depend upon the type of activity selected to evaluate the impact of delay and experimental results vary significantly from laboratory to laboratory. Thus, designers must determine the type of services, and hence the communication interactivity needs, that will be carried if the performance of the system is to be appropriately evaluated.

References

[1] CCITT Recommendation *The International Routing Plan*, Vol. VI, Rec. Q.13.

[2] CCITT Recommendation *Echo cancellers*, Vol. III, Rec. G.165.

[3] CCITT – Contribution COM XII-177, June 1987.

[4] CCITT – Delayed Contribution D.21, December 1989].

[5] CCITT – Contribution COM XII-62, August 1990.

[6] CCITT – Delayed Contribution D.131, February 1992.

[7] CCITT – Contribution COM XII-94, September 1991.

[8] CCITT – Contribution COM XII-85, July 1991.

[9] CCITT – Delayed Contribution D.80, September 1991.

[10] CCITT – Contribution COM XII-84, July 1991.

[11] CCITT – Delayed Contribution D.126, February 1992.

[12] CCITT – Delayed Contribution D.128, February 1992.

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