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NETWORKS

Objective measuring apparatus

Analysis and interpretation of INMD voice-service measurements

ITU-T Recommendation P.562

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ITU-T Recommendation P.562

Analysis and interpretation of INMD voice-service measurements

Summary

This Recommendation provides advice on the analysis and interpretation of INMD voice-service measurements. It describes methods to analyse individual measurement parameters over single and multiple calls. The effects of the location of an INMD on measurements are discussed and the use of customer opinion models, and how these can be used with INMD measurements, described. This Recommendation also looks at how INMD measurements can be applied to network planning and maintenance.

Source

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FOREWORD

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ITU-T Recommendation P.562

Analysis and interpretation of INMD voice-service measurements

1 Scope

This Recommendation provides advice on the analysis and interpretation of voice-service measurements as produced by an in-service non-intrusive measurement device (INMD). It should be used in association with ITU-T Rec. P.561, *In-service, non-intrusive measurement device – Voice service measurements* [1].

INMDs are utilized primarily for the measurement of voice-grade parameters such as speech, noise and echo. INMDs may also be used to measure parameters associated with digital transmission systems, in both circuit switched and packet switched networks, that impact the performance of the voice-grade channels being transported. The INMD is used as a stand-alone device or can be used as part of a network element. They may be deployed at selected switch and facility nodes in telecommunication networks to measure the in-service performance parameters of voice grade services, and to locate and analyse network anomalies. For the circuit-switched network (i.e., using INMDs of classes A, B or C [1]), analysis of network anomalies is made easier when the connection information such as calling and called address digits, circuit assignments involved, etc., are known, together with the measured performance. This stands also for the packet-switched networks (i.e., using INMDs of class D [1]), with connection information as well as protocol information.

This Recommendation is divided into the following clauses. Clause 2 gives a list of references to related standards. Clause 3 provides abbreviations and definitions used within this Recommendation. Clause 4 describes how individual INMD measurements should be interpreted and describes limitations of this method. Clause 5 discusses the impact of Class C INMD location within the network on measurements. Clause 6 shows how INMD measurements can be used to predict average customer opinion, and how these customer opinion predictions should be interpreted. Clause 7 looks at how INMD measurements can be applied to network planning through the use of the E-model [2]. Clause 8 shows how INMD measurements can be used for network maintenance. Full details of the recommended model for predicting average customer opinion are given in Annex A and details of how to map INMD measurements into the E-model are given in Annex B.

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; users of this Recommendation are therefore encouraged to investigate the possibility of applying the most recent edition of the Recommendations and other references listed below. A list of the currently valid ITU-T Recommendations is regularly published. The reference to a document within this Recommendation does not give it, as a stand-alone document, the status of a Recommendation.

- [1] ITU-T Recommendation P.561 (2002), *In-service, non-intrusive measurement device – Voice service measurements*.
- [2] ITU-T Recommendation G.107 (2003), *The E-model, a computational model for use in transmission planning*.
- [3] ITU-T Recommendation G.100 (2001), *Definitions used in Recommendations on general characteristics of international telephone connections and circuits*.
- [4] ITU-T Recommendation G.131 (2003), *Talker echo and its control*.

- [5] ITU-T Recommendation G.169 (1999), *Automatic level control devices*.
- [6] ITU-T Recommendation P.800 (1996), *Methods for subjective determination of transmission quality*.
- [7] ITU-T Recommendation G.108 (1999), *Application of the E-mode: A planning guide*.
- [8] ITU-T Recommendation G.109 (1999), *Definition of categories of speech transmission quality*.
- [9] ITU-T Recommendation G.113 (2001), *Transmission impairments due to speech processing*.
- [10] ITU-T Recommendation G.114 (2003), *One-way transmission time*.
- [11] ITU-T Recommendation G.120 (1998), *Transmission characteristics of national networks*.
- [12] ITU-T Recommendation G.121 (1993), *Loudness ratings (LRs) of national systems*.
- [13] ITU-T Recommendation G.122 (1993), *Influence of national systems on stability and talker echo in international connections*.
- [14] ITU-T Recommendation P.79 (1999), *Calculation of loudness ratings for telephone sets*.
- [15] ITU-T Recommendation P.76 (1988), *Determination of loudness ratings; fundamental principles*.
- [16] ITU-T Recommendation G.223 (1988), *Assumptions for the calculation of noise on hypothetical reference circuits for telephony*.
- [17] ITU-T Recommendation G.212 (1988), *Hypothetical reference circuits for analogue systems*.

3 Abbreviations and definitions

3.1 Abbreviations

This Recommendation uses the following abbreviations:

ALC	Automatic Level Control
CCI	Call Clarity Index
CDR	Call Data Record
CME	Circuit Multiplication Equipment
CMS	Circuit Multiplication System
EC	Echo Canceller
EL	Echo Loss
EPL	Echo Path Loss
INMD	In-service Non-intrusive Measurement Device
ISC	International Switching Centre
LE	Local Exchange
MOS	Mean Opinion Score
OLR	Overall Loudness Rating
PCM	Pulse Code Modulation
RLR	Receiving Loudness Rating

SEPL	Speech Echo Path Loss
SLR	Sending Loudness Rating
TELR	Talker Echo Loudness Rating
TSG	Trunk SubGroup

3.2 Definitions

For definitions not listed here, please refer to ITU-T Recs P.561 [1] and G.100 [3].

3.2.1 customer opinion model: Customer opinion models aim to predict the average subjective opinion of customers using objective measures.

3.2.2 subjective opinion: A subjective opinion is a personal view and varies from person-to-person. A subjective opinion will not necessarily be the same when repeated under the same external conditions. Call quality is an example of a subjective measure.

3.2.3 objective measurement: An objective measurement is made using measurement equipment and is repeatable given the same external conditions. Active speech level is an example of an objective measure.

3.2.4 E1: A G.703 interface operating at 2048 kbit/s capable of carrying 32 channels of 64 kbit/s each.

3.2.5 T1: A G.703 interface operating at 1544 kbit/s capable of carrying 24 channels of 64 kbit/s each.

4 Interpreting INMD measurements

INMDs continuously monitor the network and have the potential to generate vast amounts of data. Interpreting this data is crucial to understanding the performance of the network being monitored. This clause provides guidelines on how individual voice-service measurements should be interpreted and how measurements from many calls can be collated. For each case the applications, benefits and limitations are described.

4.1 Single call measurements

Voice-service measurements made by an INMD are described in ITU-T Rec. P.561 [1], the minimum required measurements being: speech level, noise level, echo path delay and at least one type of echo loss measurement, plus IP delay variation and IP packet loss ratio for Class D INMDs.

Each of these parameters allows some aspect (or aspects) of network performance to be determined or predicted for that particular call. The parameters measured by an INMD characterize the network connection from each talker to the INMD equipment in that direction only. The network connection in the opposite direction, INMD to listener, is not measured. The only exception to this is the measurement of the echo-path which provides some information about the network connection from the INMD to source of reflected echo (usually the 4-wire to 2-wire hybrid) and back to the INMD. This means that the majority of impairments in the receive path, INMD to listener, cannot be detected by an INMD.

Some aspects of network performance that can be derived from single voice-service measurement parameters are shown in Table 1. Any assumptions made in deriving network performance are also listed.

**Table 1/P.562 – Aspects of network performance derived
from INMD measurement parameters**

Parameter	Aspect of network performance	Assumptions made
Active speech level	Network SLR	Speaker's vocal level
Psophometric noise level	Circuit noise level introduced by the network	Room noise level
Echo loss Echo path loss Speech echo path loss	Operation or presence of echo cancellers Hybrid performance	
Echo path delay	Transmission delay of the connection	Local delay
Speech activity factor	Accuracy of other parameters (e.g., 90% activity in both directions could mean noise is being classified as speech) Type of call (e.g., recorded message)	Normal conversational habits
Front end clipping	Performance of voice activity detectors (e.g., in CMEs)	
Saturation clipping	Amplitude clipping and distortion	
Double-talk	Rough indicator of delay of the connection	Normal conversational habits
One-way transmission	Short network outages	Two-way conversation
IP packet loss ratio	IP node congestion	Correct IP network dimensioning
IP delay variation	IP node congestion IP route flapping	

When interpreting INMD voice-service measurements, call results should ideally be viewed as a set. Investigating single parameters in isolation may give rise to misleading conclusions regarding the quality of the connection. In addition to this, data from a single call is prone to variations in customers' voices and customers' equipment which should be taken into account when considering the data. The examples below show how possible measurements can be misinterpreted.

Example 1

Measurements from a call show that the echo path loss is low and the echo-path delay is low. The low echo path loss indicates that there is significant echo present and the call is assumed to be of poor quality.

However, since the echo path delay is also low the user hears the echo only as sidetone, and perceives the call as good quality. This call would be correctly classified when using a customer opinion model (such as described in clause 6 – Using INMD measurements to predict average customer opinion).

For further information on echo and delay, and guidelines on the control of echo see ITU-T Rec. G.131 [4].

Example 2

Measurements from a call show no discernible noise present and average active speech levels. This initially appears to be a good quality call. Inspection of the speech activity factor reveals speech activity of over 90% in both directions.

The cause of this abnormal speech pattern may be due to high levels of noise being interpreted as speech or high levels of echo being interpreted as speech. In fact, this call may be severely degraded and could require investigation.

Example 3

Measurements from a call show no IP packets are apparently lost, whereas the measurements of IP delay variation from the same call show an important amount of jitter. If the jitter buffer of the IP end-point (VoIP gateway or customer equipment) is configured in such a way that it is not able to cope with this level of delay variation, then some packets will be discarded by the buffer, and will be seen as lost from the customer's point of view.

4.2 Multiple call measurements

Collating measurement data helps to reduce variations due to customers' voices and equipment. When collating measurement parameters, consideration should be given to the purpose for which the information is being gathered.

Measurement data to be used for reporting performance statistics should be selected according to a specific grouping. Recommended groupings to be used are listed in Table 2.

Table 2/P.562 – Recommended groupings for INMD parameter collation

Grouping	Description
Physical link	Single access medium; typically E1/T1 or 10/100 Mbit/s Ethernet
Route	Collection of physical links to the same destination
Province	Collection of routes to a single geographical area within a country
Carrier	Collection of routes delivered by a specific company to a country
Country	Collection of routes to a specific country

Once data on a single parameter has been gathered for a particular grouping, it should be processed using the following procedure:

Stage 1 Exclude all invalid measurements. An invalid measurement is defined as either a default code or a value outside the specified range of the measurement device. However, any default codes that can be reliably translated to a valid measurement should be translated and counted as valid. For example, a default code representing 'no echo detected' could be translated to an echo-path loss equal to the maximum limit of the specified range of the measurement device.

Stage 2 A sample size should be used that gives statistically valid results. For more information see 4.3 – Sample size.

Stage 3 Calculate the sample mean and sample standard deviation.

Stage 4 Calculate the percentage of valid measurements that exceed maximum and minimum pre-set threshold values. Table 3 lists recommended threshold values for the most common parameters. However, due to varying network performance goals, different Administrations may wish to set their own thresholds. The threshold values used should always be stated together with the results.

Stage 5 The following data should be reported:

- Grouping used.
- Date and time over which the measurements were collected.
- Threshold values used.
- Sample size.
- Sample mean, median and standard deviation.
- Percentage of samples above the maximum threshold value.
- Percentage of samples below the minimum threshold value.

Table 3/P.562 – Recommended threshold limits for multiple call measurements

Parameter	Recommended threshold values	
	minimum	maximum
Active speech level	–35 dBm0	–6 dBm0
Psophometric noise level	None	–50 dBmp
Echo path loss	15 dB (Note 1) or 35 dB (Note 2)	None
Echo path delay (round-trip) (Note 3)	None	40 ms (Note 1) or 800 ms (Note 2)
IP delay variation	0 ms	200 ms
IP packet loss ratio	0%	10%
NOTE 1 – For connections without echo cancellers.		
NOTE 2 – For connections with echo cancellers.		
NOTE 3 – This is the sum of the near and far end delay values.		

4.3 Sample size

When considering confidence intervals for a set of measurements, the following factors influence the minimum sample sizes required:

- Standard deviation of the population distribution.
- Significance level required for the confidence interval (e.g., 95%).
- Required accuracy of the confidence interval (e.g., ± 1 dB or $\pm 5\%$).

There are two different types of analysis: measurement averages and threshold percentages, each requiring different minimum sample sizes. Each of these are considered in the following subclauses.

4.3.1 Confidence intervals for measurement averages

Determining a confidence interval for a measurement average involves calculating the mean and standard deviation of a sample of measurements. The minimum number of samples required depends on the above factors. Examples of using these factors to calculate the minimum sample size required are given in Appendix II. Typical minimum sample sizes are also shown in Table 4.

Table 4/P.562 – Example minimum sample sizes for average calculations

Parameter	Standard deviation dB, % or ms	Confidence interval %	Required accuracy ($\pm$)	Minimum sample size
Speech level	7	95	1 dB	188
Noise level	6	95	1 dB	138
Echo path loss	8	95	1 dB	246
Echo path delay	4	95	1 ms	61
IP delay variation	TBD	95	1 ms	TBD
IP packet loss ratio	TBD	95	0.1%	TBD

4.3.2 Confidence intervals for thresholding

Thresholding involves calculating the percentage of measurements above or below a threshold for a sample of measurements. A suitable sample size depends on the accuracy required and the confidence factor that the specified accuracy is met. The number of samples can be calculated theoretically and these calculations are detailed in Appendix III. A graph of minimum sample sizes for confidence intervals, α , of 95% and 98% is shown in Figure 1.

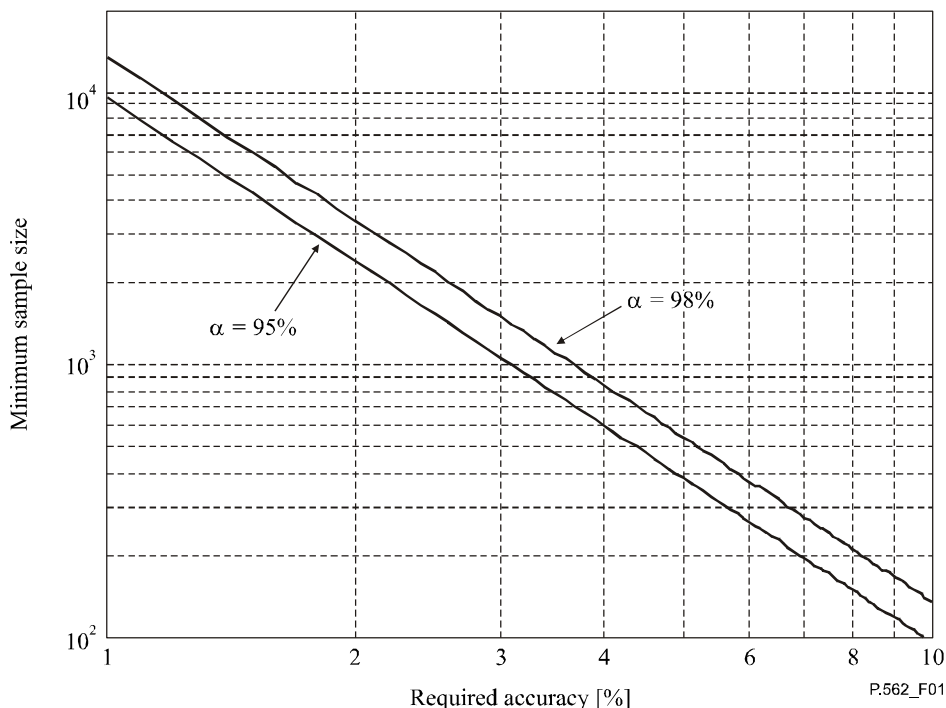


Figure 1/P.562 – Recommended minimum sample sizes for threshold calculations

5 Impact of Class C INMD location in the network

Although as stated in ITU-T Rec. P.561 [1] In-service Non-intrusive Measurement Devices (INMD) of Class C (i.e., for TDM links with echo path delays up to 1000 ms) can be connected at any four-wire DS1 interface on a link they are most commonly installed in international gateways.

In this clause, two different locations are considered for a Class C INMD in an international gateway: at the outgoing side and at the incoming side. For both scenarios the impact of transmission and/or processing devices inside and outside the international gateway on the non-intrusive measurement of parameters is described. Finally, suggested applications for each scenario are given along with the respective properties of interest to a network operator.

5.1 Context

In this discussion, we focus only on situations where the network of an operator, known as the "near end", is connected with the network of another operator, known as the "far end", through an international link. The hypothetical reference connection of such a link can be represented by the elements shown in Figure 2.

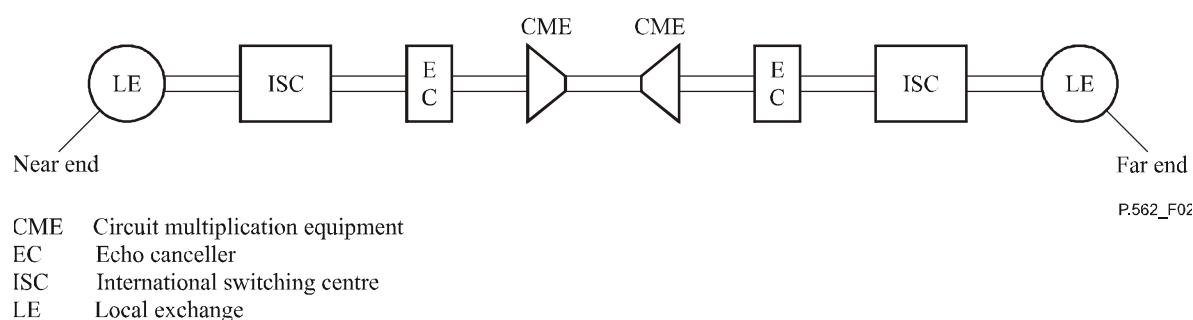


Figure 2/P.562 – Hypothetical reference international connection

In some cases no CMEs or echo cancellers (ECs) are present in the connection, but here we assume that they are present in connections where INMDs are used. The impact of ECs and ALCs in national networks is not considered in the following analysis.

5.2 INMD location at the outgoing side of the international gateway

A common use of INMDs is to connect to an international E1/T1, on the outgoing side of the international switching centre, beyond the echo canceller, as shown in Figure 3.

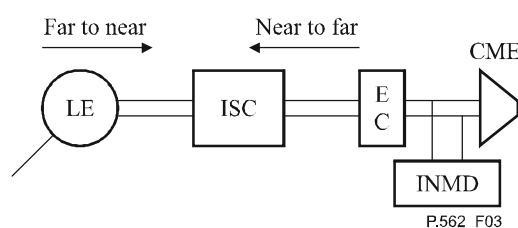


Figure 3/P.562 – Class C INMD implementation at the outgoing side of the international gateway

5.2.1 Advantages

- The measurements are made on both 'near-to-far' and 'far-to-near' directions of the E1/T1 so if a problem is detected, the defective E1/T1 (and the timeslot) is known.
- The measurement of echo is made, taking into account the effects of both the near and far end echo cancellers.

5.2.2 Disadvantages

- The measurements are dedicated to the E1/T1s connected. To monitor quality for all destinations, a high percentage of the E1/T1s must be connected. This requires a large monitoring system which generates huge volumes of data that need to be stored and managed.
- Most systems use signalling information which needs to be decoded. On the international network, several signalling systems still exist (R2, C5, different levels of C7: TUP, TUP+, ISUP) each requiring specific software to be decoded.

5.3 INMD location at the incoming side of the international gateway

An alternative implementation is to connect the INMD to a national E1/T1, on the incoming side of the international switching centre, as shown in Figure 4.

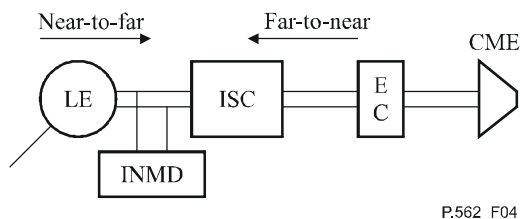


Figure 4/P.562 – Class C INMD implementation at the incoming side of the international gateway

5.3.1 Advantages

- Measurements can be made on calls to many destinations by monitoring a small number of E1/T1s. Choosing a few E1/T1s that are carrying a lot of international traffic, selected to cover a large proportion of the national network, provides the system with a significant volume of calls to many destinations.
- Systems that decode signalling information are less complex since, on most national networks, the number of signalling systems is generally limited to one or two rather than the wider range expected on international systems.

5.3.2 Disadvantages

- If a problem is detected, it is not immediately clear which outgoing E1/T1 is causing the problem. A solution to this problem could be to use Call Data Records (CDR).
- The effects of any near end echo canceller (which affects the person at the far end) are not taken into account. Thus more information regarding near end delay and hybrid performance is gained but no information is available on the performance of near end echo cancellers which can have significant influence on the perceived quality of the call. Measurements of echo and delay are more likely to be made, but do not represent the actual signals reaching the far end listener's ear.

5.4 Comparative impact of both scenarios on the measures recommended in ITU-T Rec. P.561

The implementations described in the previous two clauses can be distinguished not only by their respective advantages and drawbacks, but also by their effect on INMD measured parameters complying to ITU-T Rec. P.561. The effects of equipment, such as echo canceller (EC) [4] and automatic level control (ALC) [5], are shown in Table 5 and described below.

In Table 5, the terms "near to far" and "far to near" are used with the meaning they have in ITU-T Rec. P.561. Thus, the near to far echo path (and its delay and loss) corresponds to the loop followed by an incident speech signal originating from the near end, reflected at the far end and coming back to the near end.

Scenario 1 and 2 represent Class C INMD implementations at the outgoing and incoming sides of the international gateways respectively.

Table 5/P.562 – Comparison of scenarios

	Scenario 1 – Outgoing side		Scenario 2 – Incoming side	
	Near to far	Far to near	Near to far	Far to near
Active speech level Speech activity factor	Measure of levels transmitted by the near end network; includes effects of near end EC and ALC if present.	Measure of levels transmitted by the far end network; does not include effects of near end ALC if present.	Measure of levels from near end access network; does not include effects of near end EC or ALC if present.	Measure of levels transmitted to near end access network; includes effects of near ALC if present.
Noise level (Note 2)	Measure of noise transmitted by near end network; includes noise inserted by EC, ALC and C5 analogue signalling if present.	Measure of noise transmitted by the far end network; does not include effects of near end ALC if present.	Measure of noise from near end access network; does not include effects of near end EC, ALC or C5 analogue signalling if present.	Measure of noise transmitted to near end access network; includes effects of ALC if present.
Echo path delay (Notes 1 and 2)	Measure does not include switching and processing delays in near end gateway.	Measure includes switching and processing delays in near end gateway.	Measure includes switching and processing delays in near end gateway.	Measure does not include switching and processing delays in near end gateway. Echo measured before processed by EC.
Echo loss Echo path loss Speech echo path loss	Measure does not include effects of near end ALC if present. Defective ALC may amplify echo signal.	Measure includes effects of near end EC and ALC if present.	Measure includes effects of near end ALC if present. Defective ALC may amplify echo signal.	Measure does not include effects of near end EC. Echo measured before being processed by EC.
NOTE 1 – For both scenarios, the mean one-way delay value remains the same and is equal to the half of the sum of the two loop delays (if they can both be measured). NOTE 2 – CMEs are part of the international transmission path, and therefore have the same impact on the measurements in both scenarios (comfort noise, additional transmission delay). This is why they are not considered in the table above. The same remark can be made for analogue transmission, which can cause noise and asymmetric loss.				

5.5 Discussion

The difference between the two implementations, presented above, in terms of impact on the measurements results is significant. Depending on a network operator's aim in using an INMD, one of the two solutions will be more suitable. To see this more clearly, consider the following types of international link:

Link 1: with echo cancellers and CME at both sides;

Link 2: with echo cancellers and without CME at both sides;

Link 3: without echo cancellers and without CME at both sides.

For each parameter with each scenario and each kind of link and considering the insertion of ALCs in the international switching centre, it is possible to estimate how the perception of quality is evaluated for the following points of view:

- near end customer;
- far end customer;
- interconnection.

The figures in normal type in Table 6 show how many of the four parameters whose measurement is helped using that scenario. More detailed information for each of the parameters can be found in Appendix I.

Table 6/P.562 – Percentage of measurements which help evaluate the perception of quality

		Scenario 1 – Outgoing				Scenario 2 – Incoming			
		Link 1	Link 2	Link 3	TOTAL	Link 1	Link 2	Link 3	TOTAL
With ALC	Near end customer	1	1	2	33%	4	4	4	100%
	Far end customer	0	1	2	25%	0	1	2	25%
	Interconnection	3	4	4	92%	0	1	2	25%
	TOTAL	33%	50%	67%	50%	33%	50%	67%	50%
Without ALC	Near end customer	4	4	4	100%	4	4	4	100%
	Far end customer	2	4	4	83%	1	1	4	50%
	Interconnection	3	4	4	92%	1	2	4	58%
	TOTAL	75%	100%	100%	92%	50%	58%	100%	69%

NOTE – Numbers in normal type represent the number of parameters that the scenario helps to measure from a total of four parameters (speech and noise level, echo loss and delay).

Percentages in bold type represent the total percentage of parameters that the scenario helps to measure based on a maximum of four parameters per condition.

If we compare the overall performance of both scenarios, scenarios 1 and 2 are equivalent when ALC is present and scenario 1 provides more useful information than scenario 2 without ALC. Comparing performances for each type of application reveals significant differences between scenarios.

If the aim of transmission quality monitoring is mainly for the supervision of interconnections with other networks, the implementation of INMDs on the outgoing side (scenario 1) is the best solution.

However, the implementation on the incoming side (scenario 2) provides an operator with the most useful information on the voice quality as perceived by near end customers when ALCs are present.

When ALCs are not used, then scenario 2 provides no benefits over scenario 1 in terms of measurements.

The consistent difference between the two implementations is cost. It is cheaper to implement an INMD on the national side (scenario 2) so if two interconnected carriers both implemented systems on the national side and shared the results, this would provide a more accurate indication of the quality perceived by the users at each end of the network. However, locating any faults on the outgoing side would be harder when using in INMD on the national side.

5.6 Conclusion

The analysis on Class C INMD location within an international connection shows that there is no unique use of such a measurement device, and that, according to the ultimate aim of a network operator, each scenario has advantages and disadvantages.

To summarize the advantages of each scenario:

- the implementation at the outgoing side provides the most accurate indication of quality provided by the near end network to the far end network and provides useful information about the operation or presence of echo cancellers;
- the implementation at the incoming side provides the most accurate indication of quality provided to the near end network user in the specific case where ALC is enabled on the near end. This implementation can also be a cheaper solution.

A more complete evaluation of the end-to-end speech transmission quality can be achieved if two interconnected carriers share their measurement results and the knowledge of the characteristics of their respective near end access network.

6 Using INMD measurements to predict average customer opinion

Individual measurement parameters, by themselves, do not provide a complete picture of the connection. A customer opinion model can be used to encapsulate all available information from many measurement parameters into a single figure quality prediction.

The recommended model for predicting average customer opinion from measurements made by an INMD of classes A, B or C is described in this clause. The model, known as the Call Clarity Index (CCI), has been specifically designed for use with non-intrusive measurements and has been shown to be more robust than using planning models for this purpose.

As far as INMDs of Class D are concerned, there is currently no customer opinion model integrating all mandatory measurements of P.561. Nevertheless:

- the model described in this clause is also applicable to class D, provided that the impact of IP impairments is negligible;
- if the impact of IP impairments only (mandatory and optional measurements) is addressed, the parametric model currently studied by ITU-T SG 12, Question 16 group, and soon available as ITU-T draft Recommendation P.VTQ, gives the possibility of predicting customer opinion.

6.1 Using a model to predict customer opinion

Customer opinion models attempt to map objective measures of network performance to subjective opinions. A customer opinion model for INMDs should, therefore, be able to relate the network performance (as represented by the objective measurements such as speech level, echo loss, etc.) to customer perceived performance (represented by an opinion score).

Benefits of using a model to interpret INMD measurements include:

- 1) The identification of combination effects that are incorrectly classified when using individual measures.
- 2) Reduction in data volume (a single figure now represents the measured quality compared to many individual measurements).
- 3) The model encapsulates expert knowledge about the effects of impairments on customer perception.

Benefit 1 is illustrated in Figures 5 and 6 below. Here, as an example, just two parameters are considered, echo loss and echo path delay, whereas, in reality, the problem is multidimensional. Use of independent thresholds for each parameter would identify the measurement combinations marked with crosses in Figure 5 as failures, and the ticks as passes. The true perceptual threshold, however, would look more like the curved line and result in the passes and failures shown in Figure 6. It can be seen that several false positives and false negatives can be avoided by the use of a model, helping to enable more efficient application of investment in network repairs or upgrade.