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

Digital transmission systems – Digital networks – General aspects

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Architecture of transport networks based on the synchronous digital hierarchy (SDH)

ITU-T Recommendation G.803

Superseded by a more recent version

(Previously CCITT Recommendation)

Superseded by a more recent version

ITU-T G-SERIES RECOMMENDATIONS

TRANSMISSION SYSTEMS AND MEDIA, DIGITAL SYSTEMS AND NETWORKS

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ITU-T RECOMMENDATION G.803

ARCHITECTURE OF TRANSPORT NETWORKS BASED ON THE SYNCHRONOUS DIGITAL HIERARCHY (SDH)

Summary

This Recommendation describes the functional architecture of transport networks including network synchronization principles for networks that are based on the SDH. This Recommendation uses the architectural description defined in Recommendation G.805, the generic functional architecture of transport networks. The application of various mappings is also included.

Source

ITU-T Recommendation G.803 was revised by ITU-T Study Group 13 (1997-2000) and was approved under the WTSC Resolution No. 1 procedure on the 20th of June 1997.

FOREWORD

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NOTE

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

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As of the date of approval of this Recommendation, the ITU had/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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ARCHITECTURE OF TRANSPORT NETWORKS BASED ON THE SYNCHRONOUS DIGITAL HIERARCHY (SDH)

(revised in 1997)

1 Scope

This Recommendation describes the functional architecture of transport networks including network synchronization principles for networks that are based on the SDH. This Recommendation uses the architectural description defined in Recommendation G.805, the generic functional architecture of transport networks. The application of various mappings is also included.

2 References

The following ITU-T Recommendations and other references contain provisions which, through reference in this text, constitute provisions of this Recommendation. At the time of publication, the editions indicated were valid. All Recommendations and other references are subject to revision; all users of this Recommendation are therefore encouraged to investigate the possibility of applying the most recent edition of the Recommendations and other references listed below. A list of the currently valid ITU-T Recommendations is regularly published.

– CCITT Recommendation G.702 (1988), *Digital hierarchy bit rates*.

– CCITT Recommendation G.703 (1991), *Physical/electrical characteristics of hierarchical digital interfaces*.

– ITU-T Recommendation G.704 (1995), *Synchronous frame structures used at 1544, 6312, 2048, 8488 and 44 736 kbit/s hierarchical levels*.

– ITU-T Recommendation G.707 (1996), *Network node interface for the Synchronous Digital Hierarchy (SDH)*.

– CCITT Recommendation G.774 (1992), *Synchronous Digital Hierarchy (SDH) management information model for the network element view*.

– ITU-T Recommendation G.783 (1997), *Characteristics of Synchronous Digital Hierarchy (SDH) equipment functional blocks*.

– ITU-T Recommendation G.805 (1995), *Generic functional architecture of transport networks*.

– ITU-T Recommendation G.810 (1996), *Definitions and terminology for synchronization networks*.

– CCITT Recommendation G.811 (1988), *Timing requirements at the outputs of primary reference clocks suitable for plesiochronous operation of international digital links*.

– CCITT Recommendation G.812 (1988), *Timing requirements at the outputs of slave clocks suitable for plesiochronous operation of international digital links*.

– ITU-T Recommendation G.813 (1996), *Timing characteristics of SDH equipment slave clocks (SEC)*.

- CCITT Recommendation G.822 (1988), *Controlled slip rate objectives on an international digital connection*.
- ITU-T Recommendation G.823 (1993), *The control of jitter and wander within digital networks which are based on the 2048 kbit/s hierarchy*.
- ITU-T Recommendation G.824 (1993), *The control of jitter and wander within digital networks which are based on the 1544 kbit/s hierarchy*.
- ITU-T Recommendation G.832 (1995), *Transport of SDH elements on PDH networks – Frame and multiplexing structures*.
- ITU-T Recommendation G.841 (1995), *Types and characteristics of SDH network protection architectures*.
- ITU-T Recommendation G.964 (1994), *V-Interfaces at the digital Local Exchange (LE) – V5.1 Interface (based on 2048 kbit/s) for the support of Access Network (AN)*.
- ITU-T Recommendation G.965 (1995), *V-Interfaces at the digital Local Exchange (LE) – V5.2 Interface (based on 2048 kbit/s) for the support of Access Network (AN)*.
- ITU-T Recommendation I.326 (1995), *Functional architecture of transport networks based on ATM*.

3 Terms and definitions

This Recommendation uses the terminology defined in Recommendations G.783, G.805 and G.841; the following terms are specific to this Recommendation. The layer networks defined below terminate and generate the overheads defined in Recommendation G.707.

3.1 SDH higher-order path layer networks: Those layer networks with characteristic information of VC-3[1] , VC-4 or VC-4-Xc.

3.2 SDH lower-order path layer networks: Those layer networks with characteristic information of VC-11, VC-12, VC-2, VC-2-Xc or VC-3[1].

3.3 SDH path layer: A transport assembly composed of the SDH higher-order path layer network and lower-order path layer network together with the associated adaptation functions.

3.4 SDH section layer: A transport assembly composed of the SDH multiplex section layer network and regenerator section layer network together with the associated adaptation functions.

3.5 SDH multiplex section layer: A layer network with characteristic information of STM-N, i.e. with a bit rate of STM-N and the multiplex section overhead as defined in Recommendation G.707.

3.6 SDH regenerator section layer: A layer network with characteristic information of STM-N, i.e. with a bit rate of STM-N and the regenerator section overhead as defined in Recommendation G.707.

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[1] The VC-3 is considered to be a higher-order path if it is supported directly by an AU-3 in a multiplex section layer network; it is considered a lower-order path if it is supported by a TU-3 in a VC-4 layer network.

4 Abbreviations

This Recommendation uses the following abbreviations:

ADM	Add/Drop Multiplex
AIS	Alarm Indication Signal
APS	Automatic Protection Switching
ATM	Asynchronous Transfer Mode
AUG	Administrative Unit Group
AU-n	Administrative Unit (level) n
DXC	Digital Cross-Connect
HOP	Higher-Order Path
HOPT	Higher-Order Path Termination
HOTCA	Higher-Order Tandem Connection Adaptation
HOTCT	Higher-Order Tandem Connection Termination
HOPM	Higher-Order Path Matrix
LOP	Lower-Order Path
MS	Multiplex Section
PDH	Plesiochronous Digital Hierarchy
PRC	Primary Reference Clock
PSTN	Public Switched Telephony Network
RS	Regenerator Section
SDH	Synchronous Digital Hierarchy
STM-N	Synchronous Transport Module (level) N
TU-n	Tributary Unit (level) n
TUG-n	Tributary Unit Group (level) n
VC-n	Virtual Container (level) n
VC-n-Xc	Concatenation of X virtual containers (of level n)
VP	ATM virtual path

5 Application of the G.805 layering concept

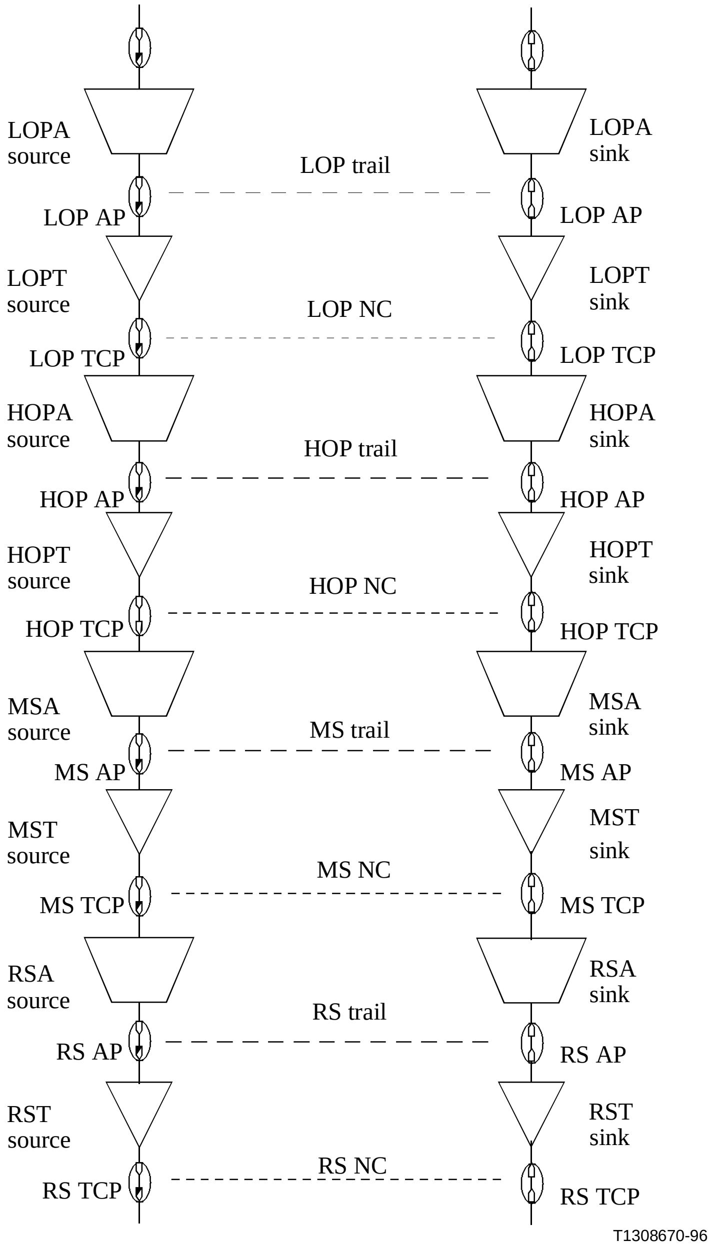
The functional architecture of SDH transport networks is described using the generic rules defined in Recommendation G.805. The specific aspects regarding the characteristic information, client/server associations, the topology, the connection supervision and protection switching of SDH transport networks are provided in this Recommendation. This Recommendation uses the terminology and functional architecture and diagrammatic conventions defined in Recommendation G.805.

A transport network based on the SDH can be decomposed into a number of independent transport layer networks with a client/server association between adjacent layer networks. Each layer network can be separately partitioned in a way which reflects the internal structure of that layer network or the way that it will be managed. The structure of the SDH layer networks and the adaptation functions is show in Figure 5-1. For the purposes of description of the SDH, the interlayer adaptation function is named in relation to the server layer network. In this Recommendation, the G.805 transport assembly is called a "layer" to maintain continuity of the terminology used in the 1992 version of Recommendation G.803. The current set of client server associations is listed in Appendix I together with the Figure I.1 that identifies the corresponding SDH layers (or transport assemblies).

A detailed description of each of these functions is provided in Recommendation G.783.

When supporting multiple clients, the adaptation function is grouped with the server layer network. Figure 5-2 illustrates the case of a VC-4 Higher-Order Path (HOP) server layer supporting VC-12, VC-2 and VC-3 Lower-Order Path (LOP) client layer networks. Figure 5-2 provides further details of the internal structure of the HOP interlayer adaptation function to show the grouping of three TU-12s into a TUG-2 and seven TUG-2s into a TUG-3 to reflect the SDH multiplex structure defined in Recommendation G.707. Note that the TUG only describes grouping and does not change the format of the signal. The case of a STM-4 supporting VC-3 and VC-4 clients is illustrated in Figure 5-3; again, the figure provides more details of the internal structure of the Multiplex Section (MS) interlayer adaptation function to show the grouping of 3 AU-3s into an AUG to reflect the G.707 multiplex structure. This grouping within the multiplex structure is reflected in Recommendation G.774 using the indirect adaptor object class.

For the purpose of describing transport networks based on ATM, Recommendation I.326 shows the ATM transport assembly that groups the VP to VC-4 adaptation function with the client layer network. This difference in grouping of the adaptation function for the description of ATM and SDH-based transport networks has no impact on the actual functions performed by these networks. The interface between the ATM transport assembly and the VC-4 layer network is the access point. Note that when the client is an ATM VP layer network, the VC-4 server layer network can only support a single client layer network.



AP	Access Point
HOPA	Higher-Order Path Adaptation
HOPT	Higher-Order Path Termination
LOPA	Lower-Order Path Adaptation
LOPT	Lower-Order Path Termination
MSA	Multiplex Section Adaptation
MST	Mutiplex Section Termination
NC	Network Connection
RSA	Regenerator Section Adaptation
RST	Regenerator Section Termination
TCP	Termination Connection Point

Figure 5-1/G.803 – SDH layer networks and adaptation functions

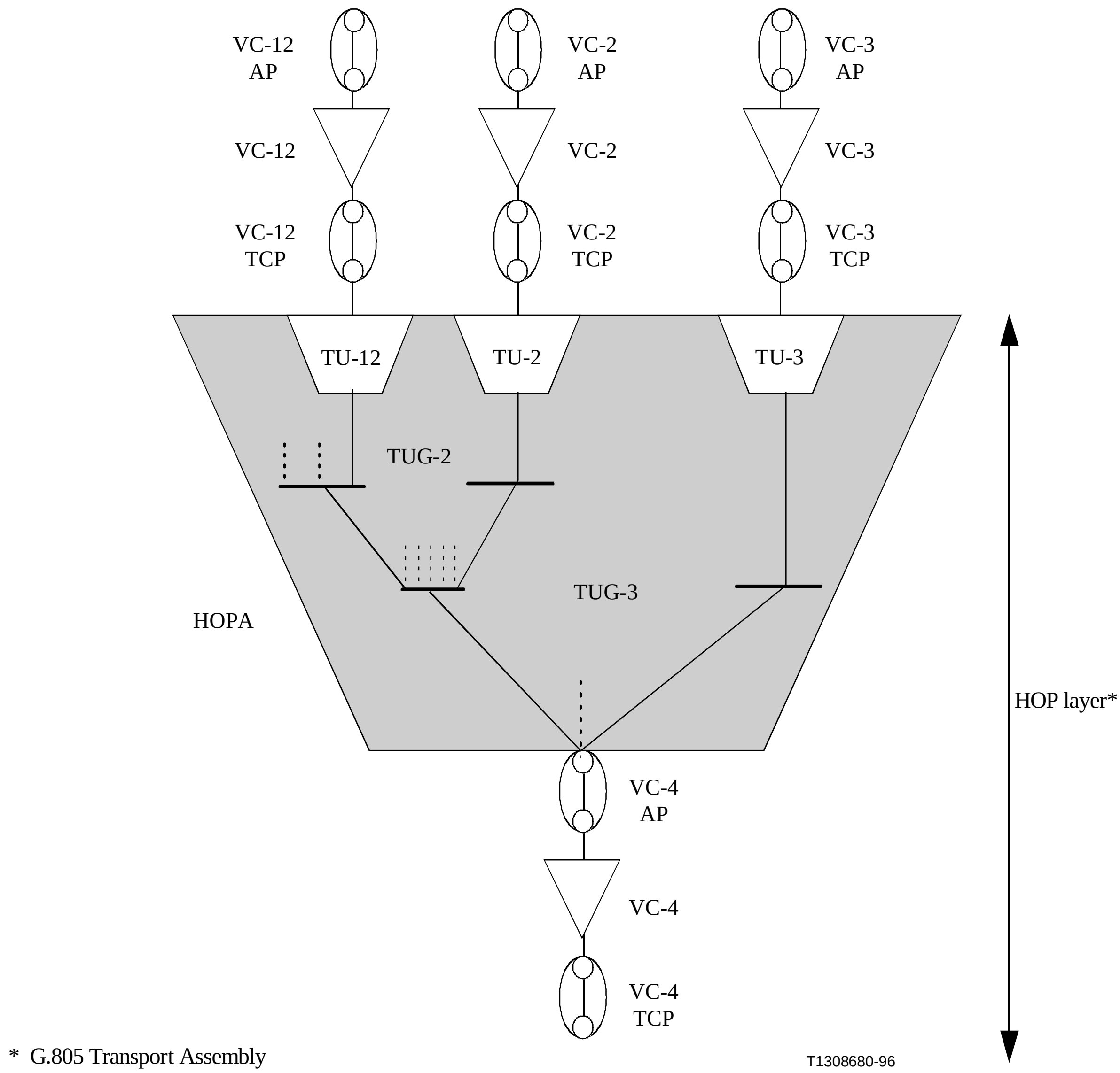


Figure 5-2/G.803 – VC-4 supporting multiple client layer networks

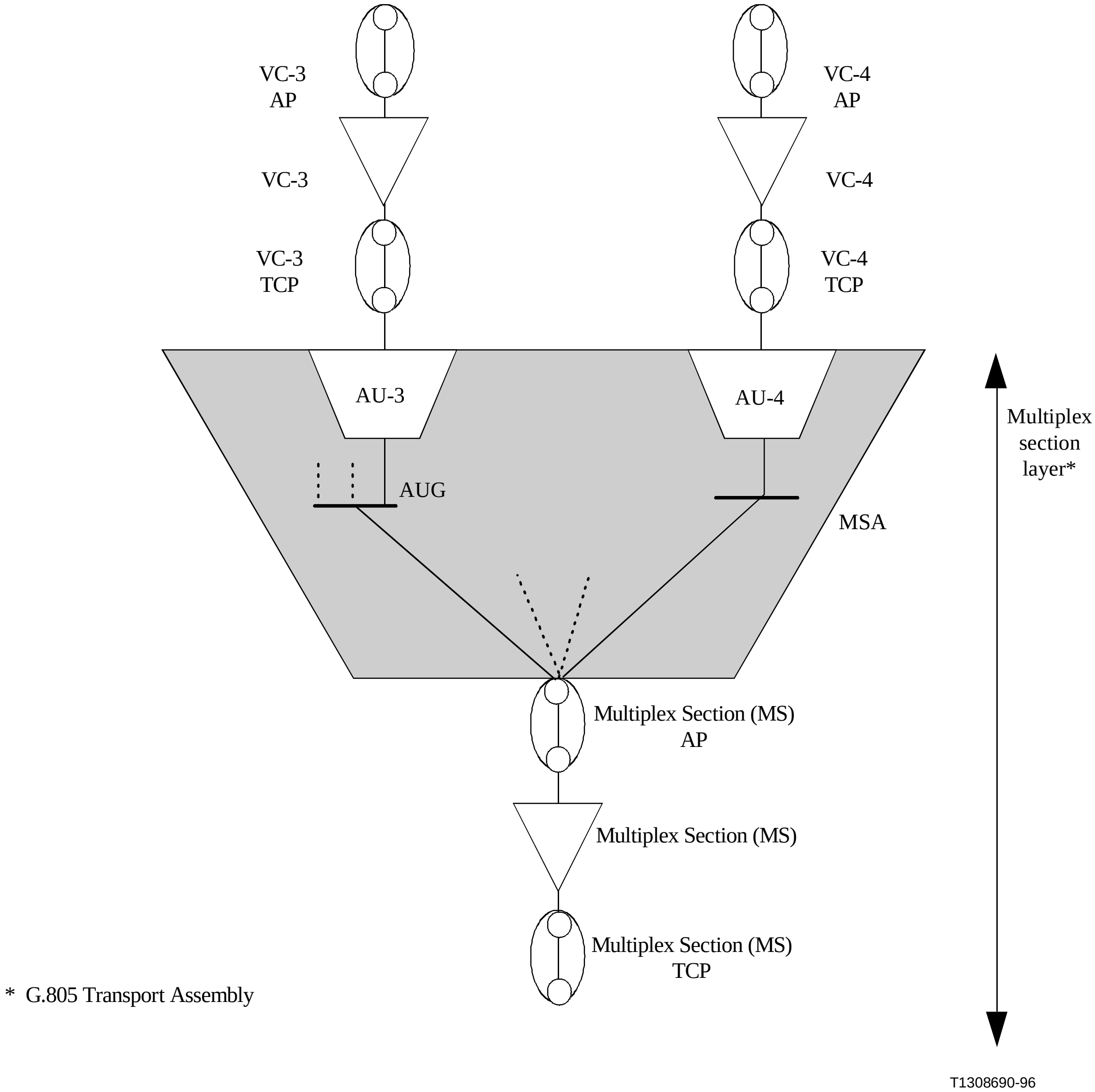


Figure 5-3/G.803 – Multiplex Section (MS) supporting VC-3 and VC-4

6 Connection supervision

6.1 Inherent monitoring

Path layer connections may be indirectly monitored by using the inherently available data from the multiplex section or higher-order path server layers and computing the approximate state of the client path connection from the available data. For example for a higher-order path, impairments detected at the multiplex section adaptation such as AU AIS and AU LOP (Loss of Pointer) are an indication of impairments in underlying server layer networks that affect the client layer connection that is being monitored.

6.2 Non-intrusive monitoring

Connections may be directly monitored by the relevant overhead information in regenerator section, multiplex section, higher-order path or lower-order path and then computing the approximate state of the connection from the difference between the monitored states at each end of the connection.

6.3 Sublayer monitoring

Connections may be directly monitored at one end of a connection by overwriting some portion of the original trail's overhead capacity at the beginning of the connection. For SDH, overhead has been defined for this purpose at the higher-order and lower-order path layers. When applied to a SDH tandem connection, this monitoring method is referred to as tandem connection monitoring.

A general example of a tandem connection that is monitored by means of a sublayer trail as given in Recommendation G.805 is shown in Figure 6-1.

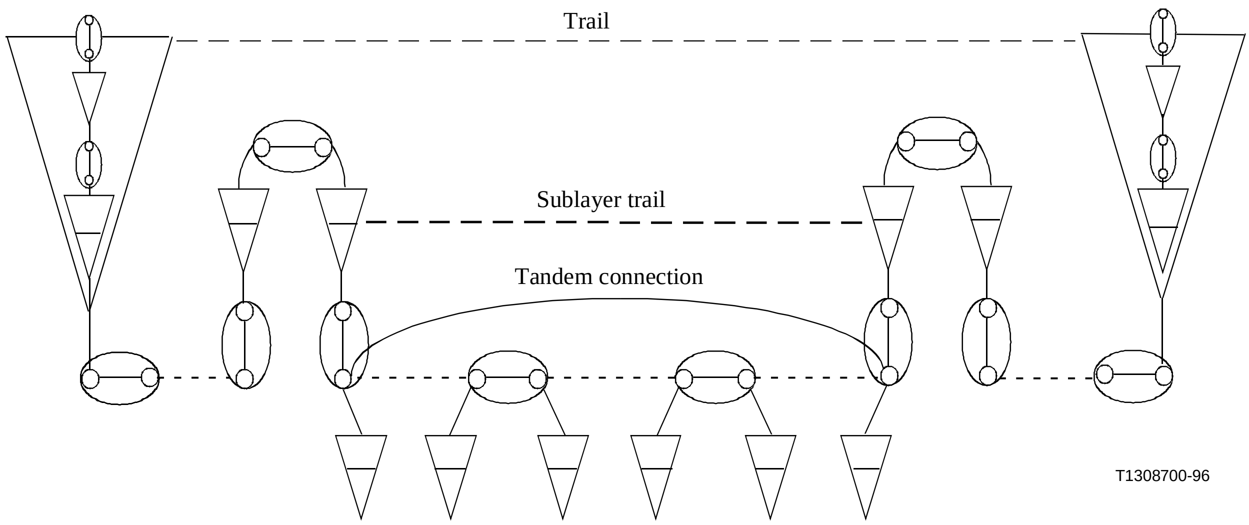


Figure 6-1/G.803 – Tandem connection monitoring by means of a sublayer trail

Figure 6-2 illustrates a SDH network application of tandem connection monitoring. Typically a tandem connection will be contained within the administrative domain of a network operator. It is assumed that tandem connections are not required between two operator domains. This latter segment of the VC-*n* path may be monitored via the VC-*n* path's server layer[2] capabilities.

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[2] For a VC-4, the server layer is the multiplex section layer; for a VC-12, the server layer is the VC-4 layer.

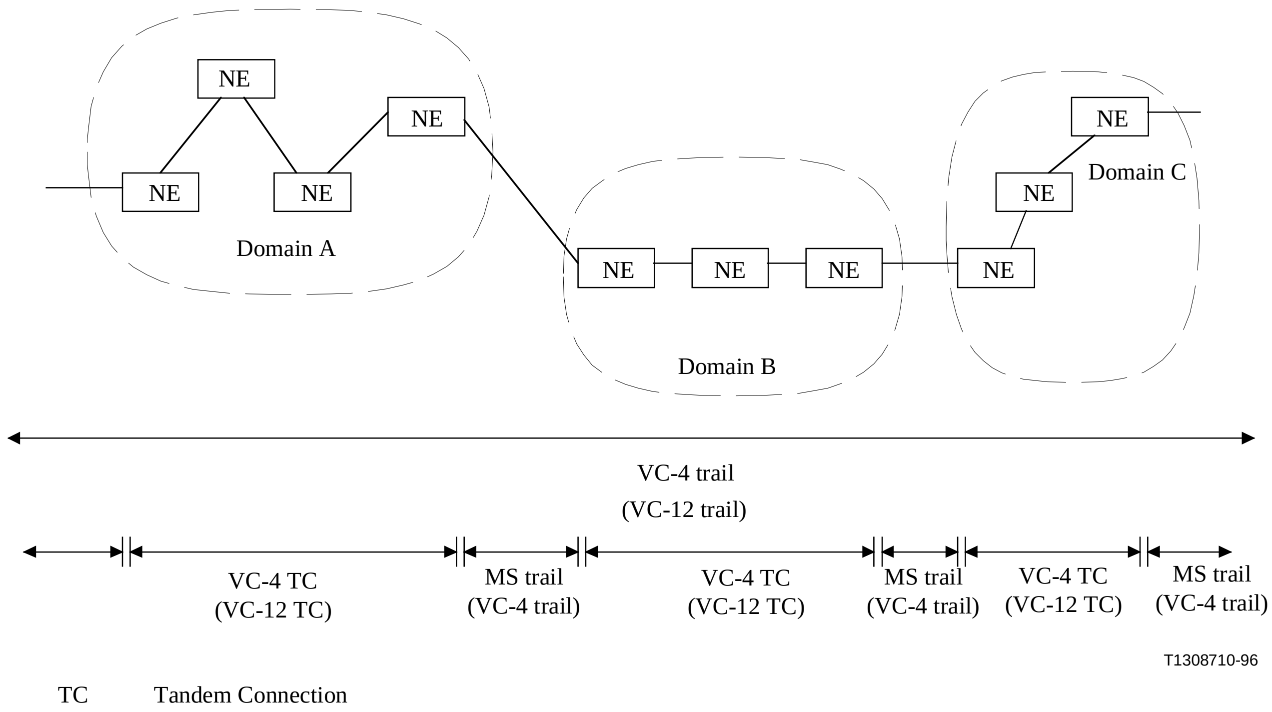


Figure 6-2/G.803 – Multi-operator domain VC-*n* trail, monitored via tandem connections

Figures 6-3 and 6-4 are examples of tandem connection arrangements, based on a VC-4 trail. The VC-4 trail consists of the two VC-4 trail terminations (HOPT), and the VC-4 network connection.

The Tandem Connection (TC) may include or exclude the matrix (connection function) within an equipment. Where practicable it is preferred to include the connection functions at the ingress and egress equipment within a tandem connection, which is why this possibility is shown in both examples.

In Figure 6-3, the VC-4 network connection is partitioned into two subnetwork connections, one in Telecom Operator (TO) domain A and the other in TO domain B. Both subnetworks are interconnected by a link connection supported by a multiplex section.

The two TO subnetworks are implemented as TC sublayers (monitored subnetworks). This adds the VC-4 TC Adaptation (HOTCA) and Trail Termination (HOTCT) functions to the TO subnetworks.

The TO subnetworks are further partitioned into a series of subnetworks, represented by the VC-4 Matrices (HOPM), and intermediate link connections.

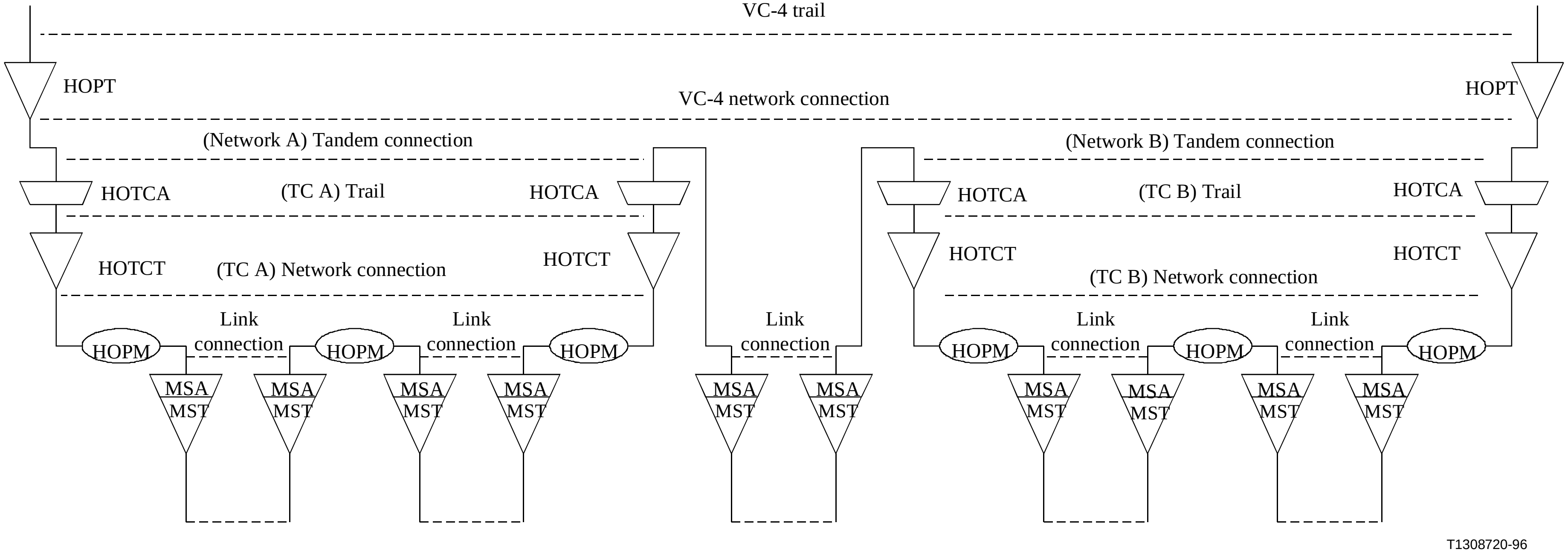
In Figure 6-4, the VC-4 network connection is partitioned into three subnetwork connections, interconnected by link connections supported by multiplex sections.

One of the three subnetworks is implemented as a TC sublayer (monitored subnetworks). This adds the VC-4 TC Adaptation (HOTCA) and Trail Termination (HOTCT) functions to the TO subnetwork.

The TO subnetwork is further partitioned into a series of subnetworks, represented by the VC-4 matrices (HOPM), and intermediate link connections.

In the network element in which the tandem connection starts, the tandem connection overhead is inserted in the signal before the signal is applied at the layer's connection function (if present).

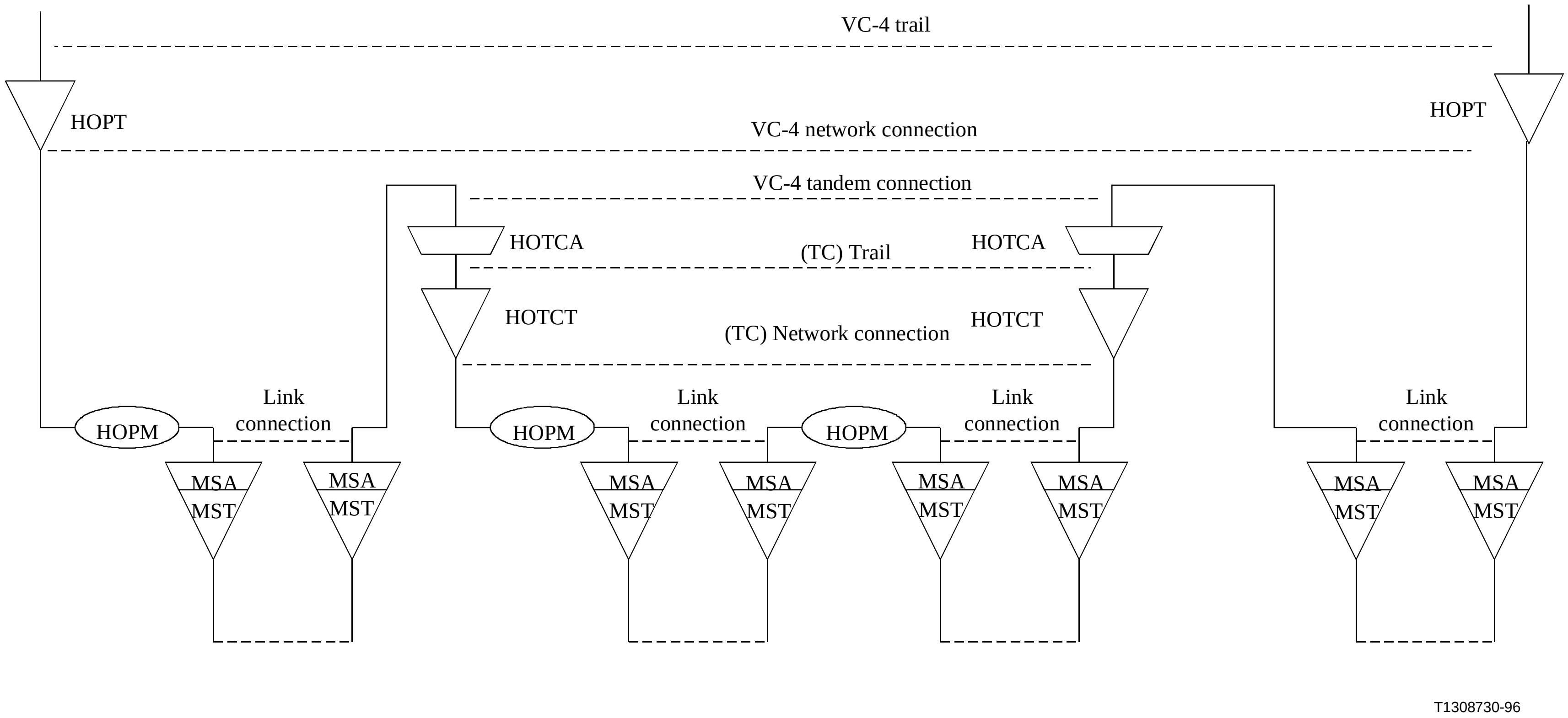
Similarly, the tandem connection overhead is removed from the signal after it is passed through the layer's connection function (if present) within the network element in which the tandem connection ends.



HOPT Higher-Order Path Termination
HOTCA Higher-Order Tandem Connection Adaptation
HOTCT Higher-Order Tandem Connection Termination
HOPM Higher-Order Path Matrix

MSA Multiplex Section Adaptation
MST Multiplex Section Termination

Figure 6-3/G.803 – Example of a VC-4 trail passing two operator domains



HOPT Higher-Order Path Termination
HOTCA Higher-Order Tandem Connection Adaptation
HOTCT Higher-Order Tandem Connection Termination
HOPM Higher-Order Path Matrix
MSA Multiplex Section Adaptation
MST Multiplex Section Termination

Figure 6-4/G.803 – Example of a VC-trail with a tandem connection in an intermediate operator domain

7 SDH transport network availability enhancement techniques

A description of the generic protection types is provided in Recommendation G.805. This Recommendation indicates how these generic types are applied in the case of the SDH. A detailed description of the implementation of some of these schemes is provided in Recommendations G.783 and G.841.

7.1 SDH multiplex section protection

SDH multiplex section protection is a type of trail protection as described in Recommendation G.805. Failure events are detected by the Multiplex Section Termination (MST) function and the reconfiguration uses the protection switching functions that are in the multiplex section protection sublayer. The resultant reconfiguration may involve protection switching in multiple SDH network elements. The coordination of such switching in multiple SDH network elements is by means of an Automatic Protection Switching (APS) protocol.

7.1.1 SDH multiplex section 1+1 protection

In a 1+1 SDH multiplex section protection system, two multiplex sections are provided; one carries the traffic, the other acts as a standby. A description of multiplex section 1+1 protection is given in Recommendation G.783.

7.1.2 SDH multiplex section 1:N protection

A 1:N SDH multiplex section protection system consists of N traffic carrying multiplex sections that are to be protected, together with an additional multiplex section to provide protection. When not required for protection, this additional multiplex section capacity can be used to support lower priority "extra traffic". This extra traffic is not itself protected. A description of multiplex section 1:N protection together with the APS protocol is given in Recommendation G.783.

7.1.3 SDH multiplex section shared protection rings

Multiplex section shared protection rings are characterized by dividing the total payload per multiplex section equally into working and protection capacity, e.g. for a two fibre STM-N ring, there are N/2 administrative unit groups (AUGs) available for working and N/2 AUGs for protection whilst in a four fibre STM-N ring, there are N AUGs available for working and N AUGs available for protection. The ring protection capacity can be accessed by any multiplex section of a multinode ring under a section or node failure condition. Thus, the protection capacity is shared between multiple multiplex sections. This sharing of protection capacity may allow a multiplex section shared protection ring to carry more traffic under normal conditions than other ring types. Under non-failure conditions, the protection capacity can be used to support lower priority "extra traffic". This extra traffic is not itself protected. A description of multiplex section shared protection rings including the definition of the APS protocol is provided in Recommendation G.841.

7.1.4 SDH multiplex section dedicated rings

A multiplex section dedicated protection ring is a 1:N protection scheme where N = 1. A system consists of two counter rotating rings (each transmitting in opposite directions relative to each other). Under failure conditions, the entire working channel is looped to the protection channel. The APS protocol required for this scheme is not provided in Recommendation G.841, since the maximum capacity of this type of ring is the sum of the capacity on each span and therefore, the applications for this type of protection scheme are limited.

7.2 SDH subnetwork connection protection examples

Subnetwork connection protection is described in Recommendation G.805. It may be applied to either a SDH higher-order path or lower-order path. To support subnetwork protection, two dedicated subnetwork connections are provided; one carries the traffic, the other acts as a standby. This protection mechanism can be used on any physical transport structure (e.g. meshed, rings or mixed). It can be used to protect a complete end-to-end network connection or a portion of a network connection. Further details of the application of this scheme in the SDH are provided in Recommendation G.841.

8 Architecture of synchronization networks

8.1 Introduction

This subclause describes architectural aspects of the distribution of timing information within a SDH network. It focuses on the need for SDH clocks to be traceable to a Primary Reference Clock (PRC) and have good short-term stability performance in order to comply with the generic slip rate objectives in Recommendation G.822.

It is further explained that, provided the SDH clock meets the short-term stability mask, there are no practical limitations to the number of pointer processing elements that can be cascaded in a SDH network to comply with the payload output jitter requirements at a SDH/PDH boundary.

Evolutionary scenarios are presented to identify how SDH network synchronization can be integrated with the existing synchronization network.

8.2 Synchronization network aspects

8.2.1 Synchronization methods

There are two fundamental methods of synchronizing nodal clocks. These are identified in Recommendation G.810:

– master-slave synchronization;

– mutual synchronization.

Master-slave synchronization is appropriate for synchronizing SDH networks and the following material offers guidance on using this method. The feasibility of employing mutual synchronization is left for further study.

Master-slave synchronization uses a hierarchy of clocks in which each level of the hierarchy is synchronized with reference to a higher level, the highest level being the PRC. Clock reference signals are distributed between levels of the hierarchy via a distribution network which may use the facilities of the transport network. The hierarchical levels are shown below:

–	PRC	G.811
–	Slave clock (transit node)	G.812
–	Slave clock (local node)	G.812
–	SDH network element clock	G.813

The distribution of timing between hierarchical node clocks must be done by a method which avoids intermediate pointer processing. Two possible methods are as follows:

1) Recover timing from a received STM-N signal. This avoids the unpredictable effect of a pointer adjustment on the downstream slave clock. The exact technique to adopt is for further study.

2) Derive timing from a synchronization trail that is not supported by a SDH network.

The master-slave method uses a single-ended synchronization technique with the slave clock determining the synchronization trail to be used as its reference and changing to an alternative if the original trail fails. This is a unilateral control scheme.

8.2.2 Synchronization network architecture

The architecture employed in SDH requires the timing of all network element clocks to be traceable to a PRC which is compliant with Recommendation G.811. The discussion below details the target architecture for SDH network synchronization. Evolutionary aspects are discussed in 8.2.6.

The distribution of synchronization can be categorized into intra-station within stations containing a G.812 level clock and inter-station as follows:

a) Intra-station distribution within stations containing a G.812 level clock conforms to a logical star topology. All lower level network element clocks within a station boundary derive timing from the highest hierarchical level in the station. Only the clock of the highest hierarchical level in the station will recover timing from synchronization links from other stations. Timing is distributed from network elements within the boundary to network elements beyond the boundary via the SDH transmission medium. The relationship between clocks within a station is shown in Figure 8-1.

b) Inter-station distribution conforms to a tree-like topology and enables all the stations in the SDH network to be synchronized. The hierarchical relationship between clocks is shown in Figure 8-2. With this architecture, it is important for the correct operation of the synchronization network that clocks of lower hierarchical level only accept timing from clocks of the same or higher hierarchical level and that timing loops are avoided. To ensure that this relationship is preserved, the distribution network must be designed so that, even under fault conditions, only valid higher level references are presented to hierarchical clocks.

Clocks of a lower hierarchical level must have a capture range sufficiently wide to ensure they can automatically acquire and lock to the timing signal generated by the same or higher level clock that they are using as a reference.

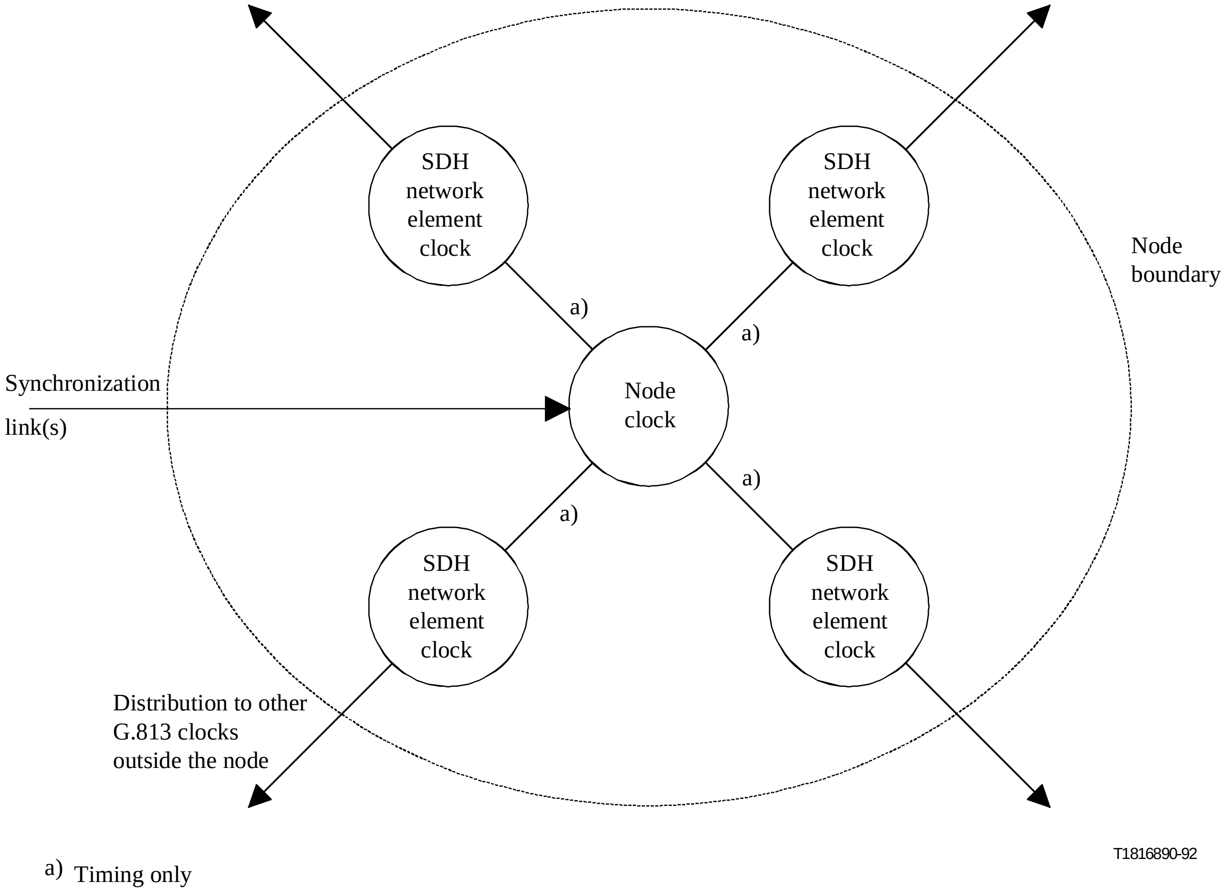


Figure 8-1/G.803 – Synchronization network architecture intra-node distribution

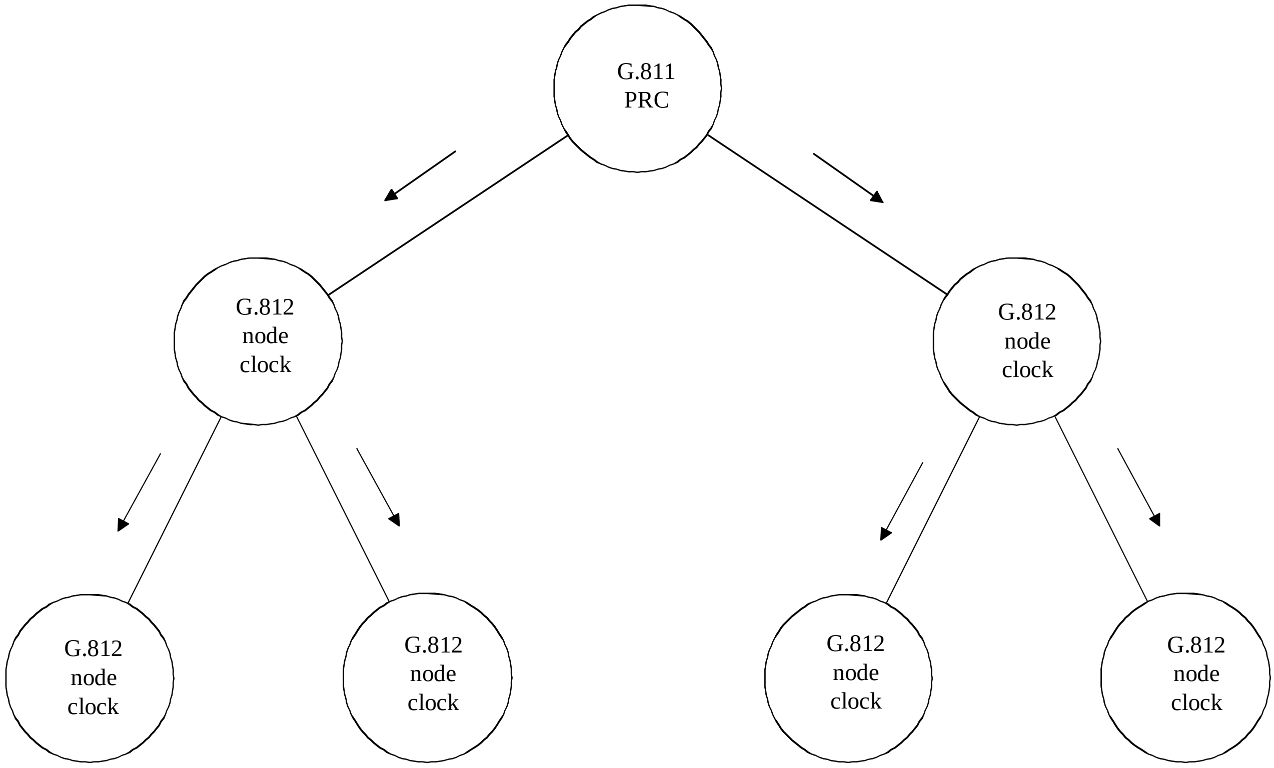


Figure 8-2/G.803 – Synchronization network architecture inter-node distribution

The functional architecture of synchronization networks deals with the modelling of the transfer of timing information between hierarchical synchronization clocks. An example is provided in Figure 8-3. The three clocks defined in Recommendations G.811, G.812 and G.813 are represented as adaptation functions which modify the quality of the timing information according to their quality level.

All synchronization clocks are located in a single layer: the Synchronization Distribution (SD) layer. The SD layer network provides the trails for the transfer of timing information from one clock to another. The SD layer network is concerned with unidirectional transfer of information; therefore, all access points of the SD layer network are unidirectional.

The SD layer may be supported by any multiplex section or path layer provided that these server layers are transparent for timing information. SDH VC-*n* layers and PDH path layers that are supported by SDH path layers do not qualify as such, because pointer processing impacts the timing information.

Figure 8-3 also shows the client of the SD layer as the Network Synchronization (NS) layer. The NS layer is solely responsible for providing the point-to-multipoint through connections from the PRC to all other clocks in the network. At every connection point in the NS layer there is an estimate of Universal Time Coordinated (UTC) available. The quality of the estimate of UTC depends on the configuration of the NS layer network and the timing quality of the SD trails provided by the SD layer network.

Note that line system regenerator clocks are not shown in the SD layer. They are contained in the section layer that supports the SD layer. The difference between these regenerator clocks and the clocks in the SD layer is that the former are "transparent". The regenerator clocks transfer timing or squelch the timing information. Conversely, the SD clocks provide timing even in case of a failure of the SD trail that transfers the timing from the previous clock in the NS connection.

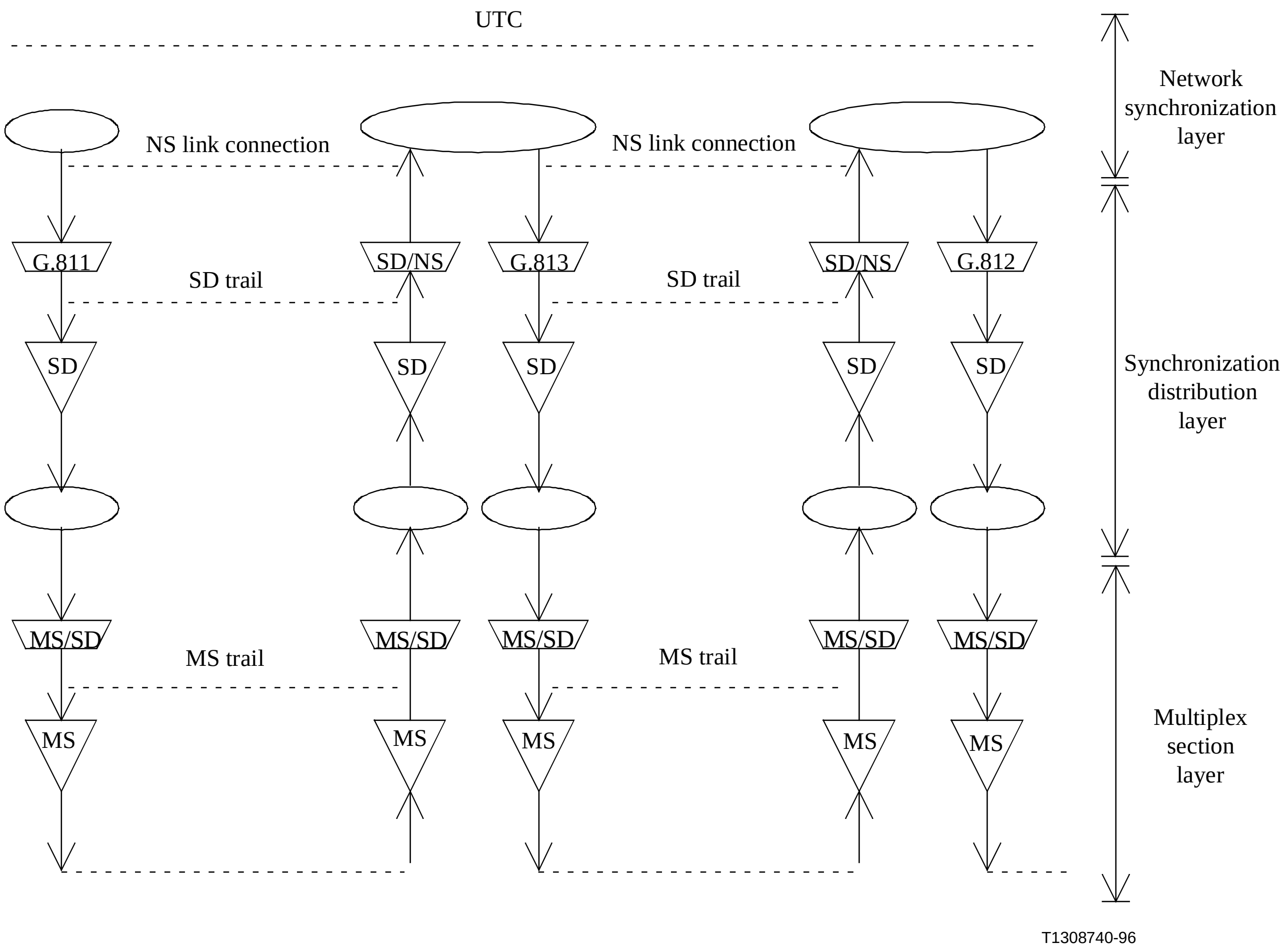
The connection matrices shown in the NS layer provide for the configuration of the synchronization network. The link connections between the matrices are supported by trails in the SD layer. Autonomous reconfiguration of the synchronization network, including protection switching, is also performed via these matrices.

The connection matrices in the SD layer are for the provisioning of the SD trails. They are used to select the multiplex sections or paths that support the SD trails.

Synchronization status messaging may be used to convey timing quality information (see 8.2.7). This information is inserted at the SD trail termination source and extracted at the SD trail termination sink. Furthermore, it is the SD trail termination that reports the failure of an SD trail.

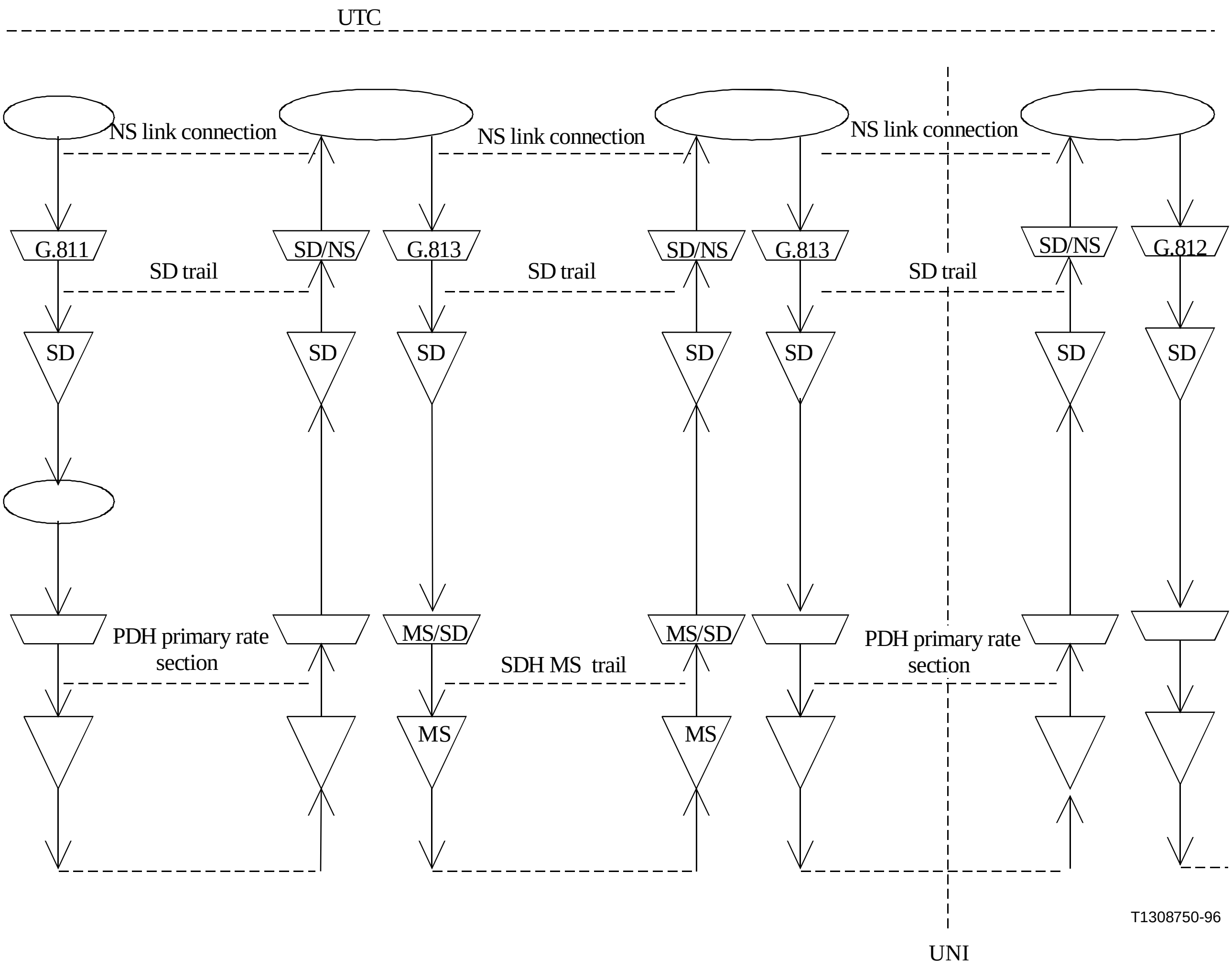
Figure 8-4 shows a specific example of synchronization distribution from the public network across a PDH primary rate user network interface to a G.812 clock in a private network. In this example the primary rate signal is retimed from the SDH network element clock.

Alternative methods of passing synchronization across the user network interface are for further study.



UTC	Universal Time Coordinated	MST	Multiplex Section Termination
SD	Synchronization Distribution	SD/NS	SD to NS adaptation
NS	Network Synchronization	MS/SD	MS to SD adaptation

Figure 8-3/G.803 – Example of synchronization distribution showing the synchronization layers



UTC	Universal Time Coordinated	MST	Mulitplex Section Termination
SD	Synchronization Distribution	SD/NS	SD to NS adaptation
NS	Network Synchronization	MS/SD	MS to SD adaptation

Figure 8-4/G.803 – Example of synchronization distribution across a PDH UNI

8.2.3 Synchronization modes

Four synchronization modes can be identified. These are:

– synchronous;

– pseudo-synchronous;

– plesiochronous;

– asynchronous.

In synchronous mode, all clocks in the network will be traceable to the network PRC. Pointer adjustments will only occur randomly. This is the normal mode of operation within a single operator's domain.

In pseudo-synchronous mode, not all clocks in the network will be traceable to the same PRC. However, each PRC will comply with Recommendation G.811 and therefore pointer adjustments will occur at the synchronization boundary network element. This is the normal mode of operation for the international and inter-operator network.

In plesiochronous mode, the synchronization trail and the fallback alternatives to one or more clocks in the network will have been disabled. The clock will enter holdover or free-run mode. If synchronization is lost to a SDH network element performing asynchronous mapping, the frequency offset and drift of the clock will cause pointer adjustments persisting through the whole SDH network connection. If synchronization is lost to the last network element in the SDH network connection (or the penultimate network element in the case where the last one is slaved, e.g. consists of a loop-timed multiplexer), there will also be pointer adjustments to cater for at the SDH network output. However, if the synchronization failure occurs at an intermediate network element, this will not result in a net pointer adjustment at the final output network element provided the input network element remains synchronized with the PRC. Pointer movement at the intermediate network element will be corrected by the next network element in the connection which is still synchronized.

Asynchronous mode corresponds to the situation where large frequency offsets occur. The SDH network is not required to maintain traffic with a clock accuracy less than that specified in Recommendation G.813. A clock accuracy of ±20 ppm is required to send AIS (applicable for regenerators and any other SDH equipment where loss of all synchronization inputs implies loss of all traffic).

8.2.4 Synchronization network reference chain

The synchronization network reference chain is shown in Figure 8-5. The node clocks are interconnected via *N* network elements each having clocks compliant with Recommendation G.813.

The longest chain should not exceed *K* slave clocks compliant with Recommendation G.812. Only one type of G.812 slave clock is shown because the difference in holdover performance of the transit and local clock is not relevant for SDH network synchronization. This contrasts with the situation in the PSTN environment which is sensitive to long-term instability.

The quality of timing will deteriorate as the number of synchronization links increases.

The value of *N* will be limited by the quality of timing required by the last network element in the chain. This ensures the short-term stability requirements, defined in the appendix of Recommendation G.813, will be met.

To determine synchronization clock specifications, the values for the worst-case synchronization reference chain are: $K = 10$, $N = 20$ with the total number of SDH network element clocks limited to 60. These values are only applicable to "option 1" clocks as defined in Recommendation G.813; the values for "option 2" clocks are for further study. The "option 1" values have been derived from theoretical calculations; practical measurements are required for their verification. It should be noted, however, that in practical synchronization network design, the number of network elements in tandem should be minimized for reliability reasons.

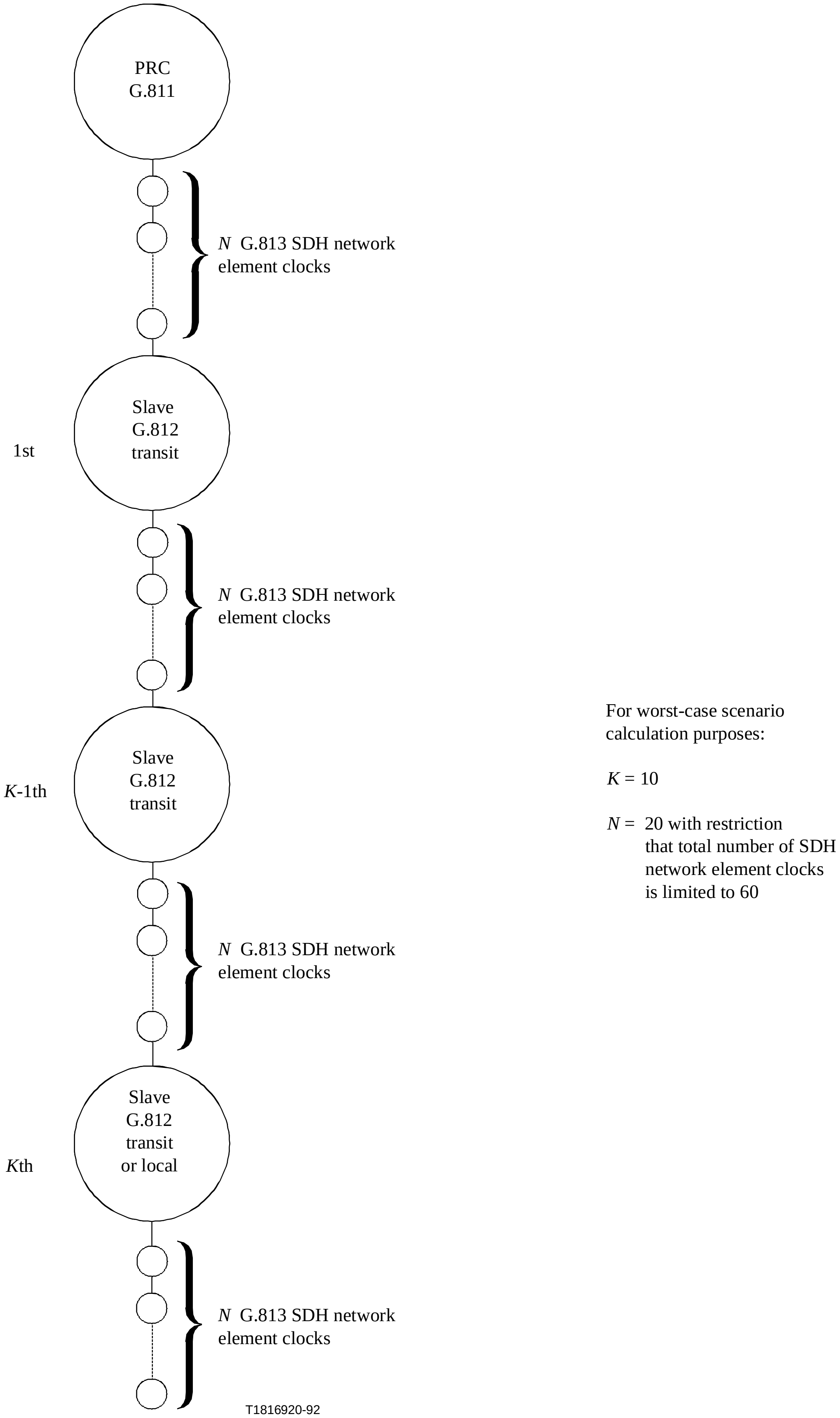


Figure 8-5/G.803 – Synchronization network reference chain

8.2.5 Synchronization strategy

The synchronization strategy is to integrate SDH network synchronization with the existing PSTN network synchronization architecture with the minimum of disruption and reconfiguration. Present node clocks are either separate units or integrated in the exchanges. With the introduction of SDH there is also the possibility to integrate the node clock in certain types of SDH equipment, typically in large SDH cross-connects. In that case, the G.813 network element clock is replaced by a G.811 or G.812 quality clock.

8.2.6 Synchronization network evolution

The SDH is designed to operate in pseudo-synchronous mode. The network elements can be integrated into existing synchronization hierarchies.

When SDH equipment is initially introduced, the network element must be timed from either the PRC or one of the slave clocks. Timing is distributed throughout the SDH network using the master-slave approach. This may require a new interface on the slave clock to time the SDH network element.

If the SDH network introduction results in PDH islands, steps must be taken so that synchronization links supported by primary rate PDH trails do not transit the SDH network. This requires a reconfiguration of the synchronization architecture since all synchronization links transiting the SDH network must be supported on SDH multiplex section trails. This may require new interfaces on the slave clocks and on the PRC.

Where a network is fully SDH-based, then the synchronization distribution will be determined solely by the synchronization network reference chain.

During the evolution of the network to SDH, the network synchronization plan will have to be altered to accommodate the SDH network elements. This requires careful planning to ensure that network synchronization is not jeopardized.

Evolutionary scenarios with multiple SDH islands supporting the transport of a PDH payload need further study.

8.2.7 Synchronization network robustness

It is preferable if all node clocks and network element clocks are able to recover timing from at least two synchronization distribution trails. The slave clock must reconfigure to recover timing from an alternative trail if the original trail fails. Where possible, synchronization trails should be provided over diversely routed paths.

In the event of a failure of synchronization distribution, all network elements will seek to recover timing from the highest hierarchical level clock source available. To effect this, both G.812 and G.813 clocks may have to reconfigure and recover timing from one of their alternate synchronization distribution trails. This will ensure that a SDH network element clock-timed network element rarely enters holdover or free-run mode. However, it may have to recover timing from a G.812 clock which is itself in holdover if this is the highest hierarchical level source available to it.

Within SDH subnetworks, timing is distributed between network nodes via a number of network elements with clocks of lower hierarchical level. A timing quality marking scheme is provided to allow selection and confirmation of the highest quality synchronization distribution trail (including under synchronization failure conditions).

The quality marking scheme provides an indication of the quality of the timing using a status messaging approach. The status message is conveyed in the multiplex section overhead as described in Recommendation G.707. When an output is used to support a synchronization trail with synchronization status messaging, then the synchronization status message shall indicate the quality and or traceability of the clock that originally generated the synchronization signal. Note that it does not reflect any degradation caused by the accumulation of jitter or wander as a result of transmission through a transport network.

Within SDH subnetworks, the status message is conveyed in the multiplex section overhead as described in Recommendation G.707. In PDH distribution trails, it is possible to convey the status message as described in Recommendation G.704. For PDH distribution trails carrying ATM, the status message is described in Recommendation G.832.

Synchronization status messages contain clock quality information that allows clocks to select the most suitable synchronization reference from the set of available references. The purpose of these messages is to allow clocks to reconfigure their synchronization references autonomously while avoiding the creation of timing loops. The use of synchronization status messages can minimize the length of time a clock is in holdover. However, it is critical to realize that the use of synchronization status messages alone will not avoid the creation of timing loops. Synchronization planning and engineering is still required.

To provide an example of a reconfiguration, if the first network element from the PRC loses its synchronization trail from the PRC, it must reconfigure and accept timing from the G.812 slave clock. This is shown in Figure 8-6.

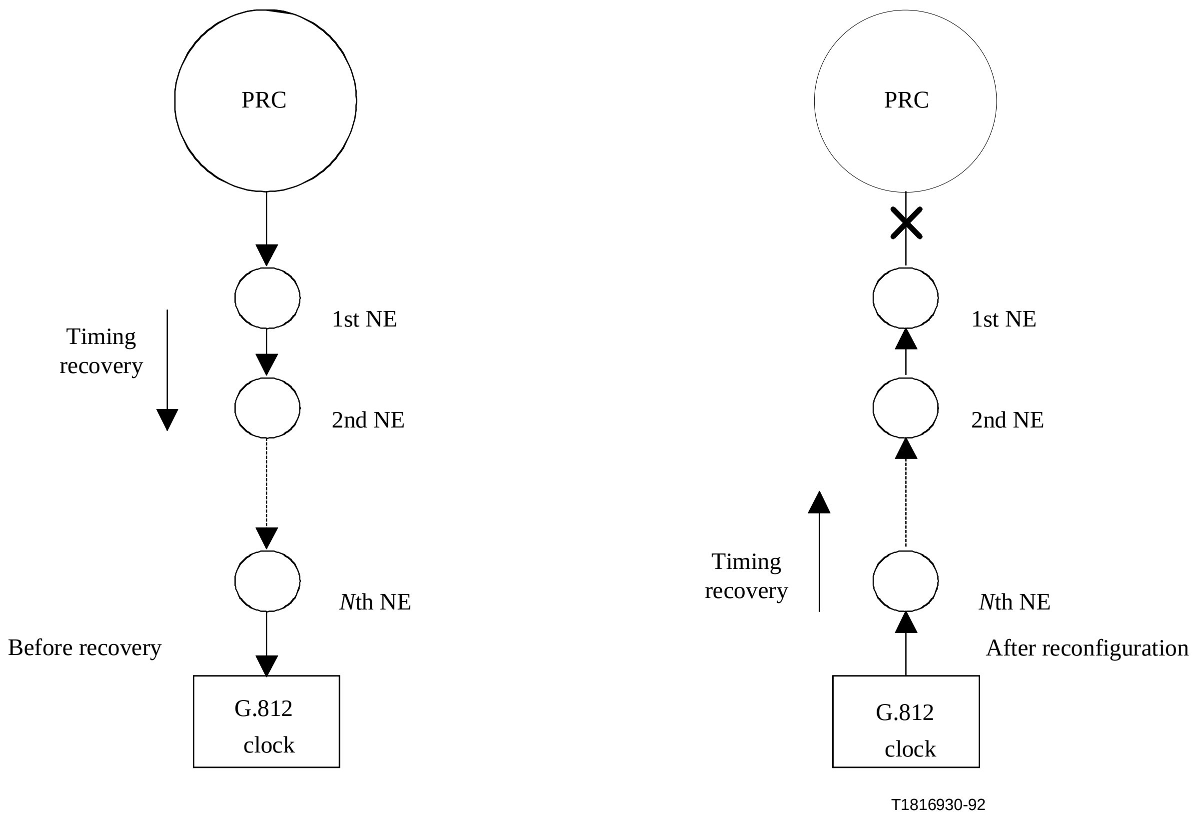


Figure 8-6/G.803 – Reconfiguration example

8.3 Payload jitter and wander

In SDH, the quality of the timing information of a payload signal is influenced by several sources:

– the synchronization network;

– the pointer processing mechanism;

– the payload mapping mechanisms.

Subclause 8.2 defines a synchronization reference chain which is used to calculate the accumulation of jitter and wander in the synchronization network. The resulting short-term stability requirements, which are specified in Appendix I/G.813, represent a network limit for the clock stability of the timing source internal to a network element. This clock stability determines the statistics of the pointer adjustments resulting from the pointer processing mechanism.

The purpose of this subclause is to define the network topologies that have to be supported by a SDH network taking into account the network limits for payload jitter and wander given in Recommendations G.823 and G.824. In addition, reference configurations are specified that may occur when SDH is introduced in the existing PDH environment.

8.3.1 SDH network model for pointer activity simulation

For the transport of PDH signals through a SDH network, the model shown in Figure 8-7 is used to simulate the accumulation of jitter and wander through a reference connection due to pointer activity. The clock acting upon each pointer processing node is assumed to have the stability specified in Recommendation G.813. Since this specification reflects the network limit, this represents a worst-case scenario.

Simulations have shown that the pointer statistics are bounded when the number of processing nodes increases. With the pointer processor buffer threshold spacings specified in Recommendation G.783, pointer adjustments at the TU-1 level are an extremely rare event, even when intermediate pointer processing at the administrative unit level is taken into account. This means that the pointer mechanism does not impose a practical upper bound on the number of tributary unit processing nodes that can be put in tandem. At the administrative unit level, pointer adjustments, including some double pointer adjustments, do occur with statistical saturation starting to show at about 10 nodes. This implies that there is also no practical constraint on the number of administrative unit pointer processing nodes that can be cascaded, provided the short-term stability mask is met at each node clock.

8.3.2 Jitter at a SDH/PDH boundary

Jitter appearing at a SDH/PDH boundary consists of pointer adjustment jitter and payload mapping jitter. Since pointer adjustments occur in 8 unit interval steps (24 unit intervals at the AU-4 level), stringent requirements are placed on the desynchronizer at the SDH/PDH boundary. This also applies at the TU-1 level since, although pointer adjustment events are unlikely under normal operational conditions (i.e. all nodes synchronized), they will occur under degraded conditions (i.e. pseudo-synchronous or plesiochronous modes) when the originating or terminating node looses synchronization. This requires desynchronizers with relatively narrow equivalent bandwidth. It should be noted that, even with narrowband desynchronizers, the effect of pointer justifications on signals that are used to convey third party timing may be larger than assumed in the design of customer premises equipment synchronization utilities. Therefore, they may not be able to adequately track the phase variations. The desynchronizer will also filter the line jitter that may accumulate along a chain of regenerators if not already filtered by the characteristics of the SDH network element clock equipment clock. Mapping jitter is generated at the originating node at the SDH/PDH boundary but does not accumulate across a SDH network. Its relative contribution to the output jitter at a SDH/PDH boundary will depend upon desynchronizer design. Its maximum value is specified in Recommendation G.783.

As a result, the output jitter limit at a SDH/PDH boundary is dominated by pointer adjustment jitter which in turn is governed by the short-term stability of the clocks at each node.

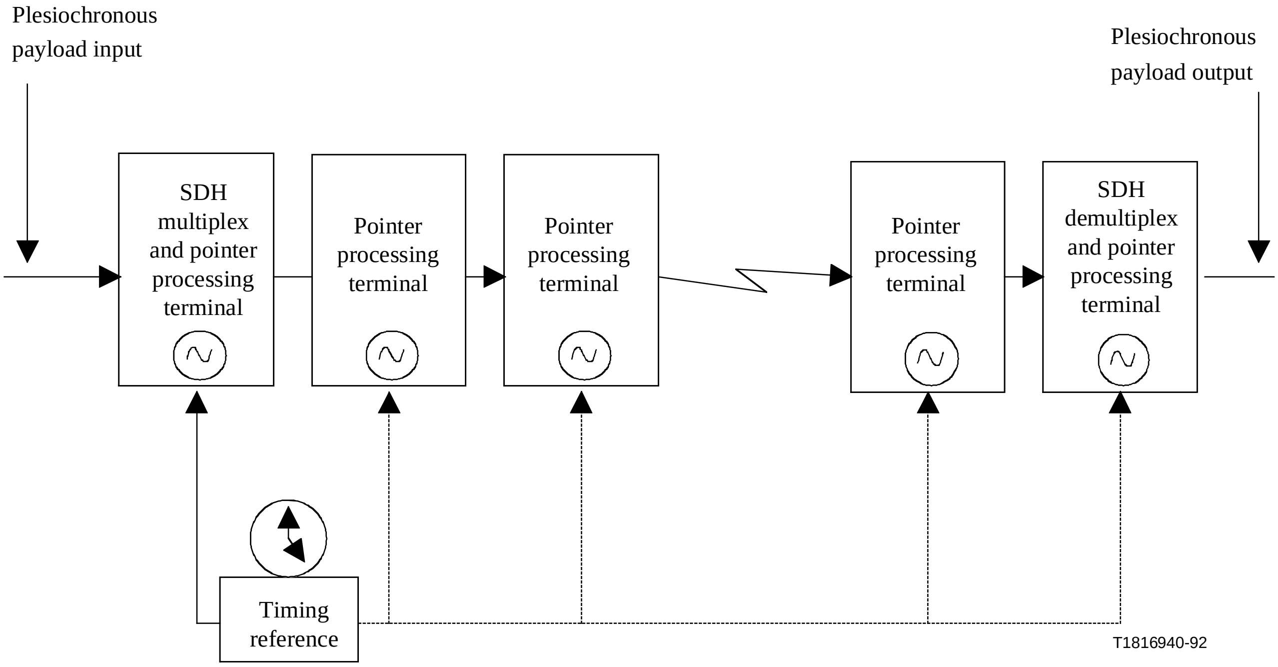


Figure 8-7/G.803 – SDH network model for pointer activity simulation

8.4 PDH/SDH interworking implications

In many evolutionary scenarios, there is a need to carry a PDH payload across multiple SDH islands. This is shown in Figure 8-8. Although the payload jitter and wander specification in Recommendation G.783 have been determined with this application in mind, there is no absolute guarantee that every PDH multiplex chain will accept the output jitter appearing at the SDH/PDH boundary. This is because there is no specified lower limit to the corner frequency of the PDH demultiplex transfer characteristic.

If synchronous islands are put in tandem, a certain accumulation of the phase transients caused by more or less simultaneous pointer adjustments in multiple islands will occur. The nature of the pointer statistics is such that this will limit the maximum number of cascaded islands for the transport of 34 368, 44 736 and 139 264 kbit/s signals, unless the desynchronizer specification is enhanced to provide adequate attenuation of jitter and wander appearing at the input of the SDH island. The trade-off between the maximum number of islands, short-term clock stability and desynchronizer specification is for further study.

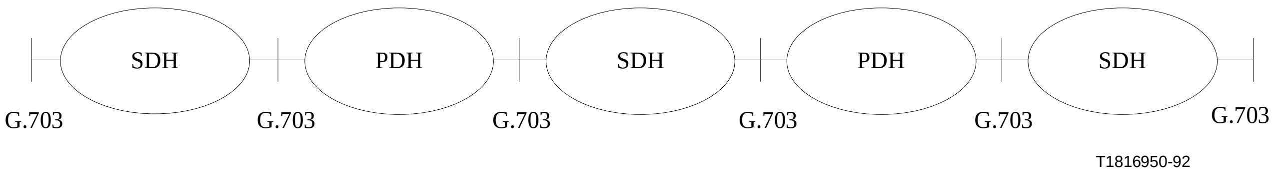


Figure 8-8/G.803 – PDH/SDH interworking

9 Selection of a primary rate mapping

There are three ways of mapping 1544 and 2048 kbit/s primary rate signals into the VC-11 and VC-12, respectively, as defined in Recommendation G.707: asynchronous, bit synchronous and byte synchronous. These mappings have different features and networking considerations. The choice of mapping is application-dependent.

Given the features of the mappings the following is recommended for SDH networking:

a) asynchronous mapping should be used only for asynchronous/plesiochronous type signals. This includes PDH path mappings into SDH paths (i.e. 64 kbit/s signals in PDH format may be carried via the asynchronous mapping);

b) bit synchronous mapping should not be used in international interconnection;

c) byte synchronous floating mode mapping should be used for primary rate signals as defined in Recommendation G.704, provided that the bit rate of the signal can, under normal operating conditions, be traced to a Primary Reference Clock. This applies, for example, to the use of a V5.1 or V5.2 interface as defined in Recommendations G.964 and G.965 respectively. In the case where a network operator chooses to use the asynchronous mapping for such a synchronous signal that is intended to be interconnected via a SDH LOP to another network operator that uses the recommended byte synchronous mapping, then responsibility for providing the interworking functionality rests with the operator that used the asynchronous mapping unless otherwise agreed bilaterally.

Appendix II provides more information on interworking of 64 and *N*×64 kbit/s signals between PDH-based transport networks and SDH-based transport networks.

APPENDIX I

Client layer	**Server layer**	**Client characteristic information**
1544 kbit/s asynch	VC-11 LOP	1544 kbit/s ± 50 ppm
1544 kbit/s byte synch	VC-11 LOP	1544 kbit/s nominal G.704 octet structured
2048 kbit/s asynch	VC-12 LOP	2048 kbit/s ± 50 ppm
2048 kbit/s byte synch	VC-12 LOP	2048 kbit/s nominal G.704 octet structured
6312 kbit/s asynch	VC-2 LOP	6312 kbit/s ± 30 ppm
34 368 kbit/s asynch	VC-3 LOP or HOP	34 368 kbit/s ± 20 ppm
44 736 kbit/s asynch	VC-3 LOP or HOP	44 736 kbit/s ± 20 ppm
139 264 kbit/s asynch	VC-4 HOP	139 264 kbit/s ± 15 ppm
ATM virtual path	VC-11, VC-12, VC-2 or VC-3 LOP or: VC-3, VC-4 or VC-4-Xc HOP	53-octet cells
VC-11 LOP	VC-3 or VC-4 HOP	VC-11 + frame offset
VC-12 LOP	VC-3 or VC-4 HOP	VC-12 + frame offset

Client layer	Server layer	Client characteristic information
VC-2 LOP	VC-3 or VC-4 HOP	VC-2 + frame offset
VC-3 LOP	VC-4 HOP	VC-3 + frame offset
VC-3 HOP	STM-N Multiplex section	VC-3 + frame offset
VC-4 HOP	STM-N Multiplex section	VC-4 + frame offset
STM-N Multiplex section	STM-N Regenerator section	STM-N rate, N = 1, 4, 16, 64

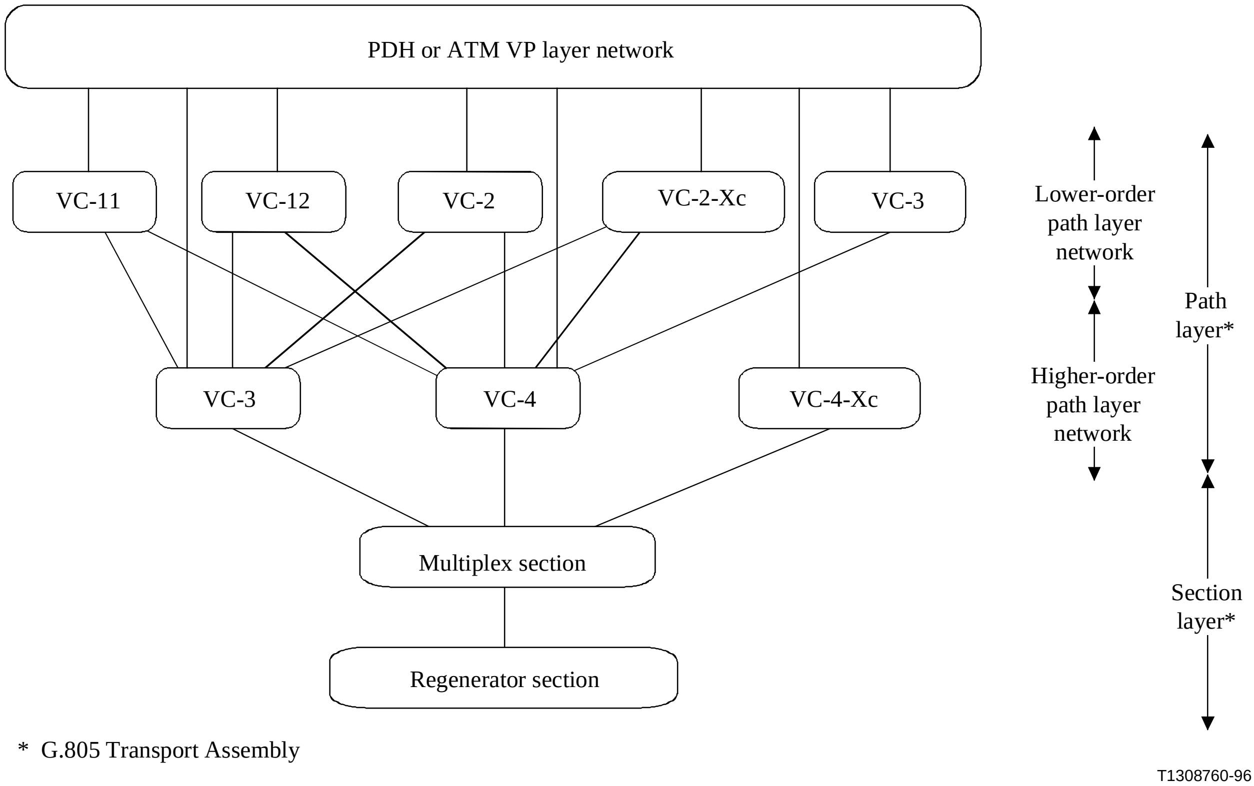


Figure I.1/G.803 – SDH Layer networks

APPENDIX II

Introduction of SDH-based transport networks

II.1 General

This appendix provides information on how a transport network could evolve to one based on SDH. There are many choices which must be made when introducing SDH-based transport networks. These choices, such as the time order in which different types of SDH-based equipment are introduced and the types of mapping used, will affect subsequent stages of evolution to SDH-based transport networks and may pose networking or PDH/SDH interworking constraints. These choices and the level of deployment of SDH-based transport networks compared with PDH or other transport networks are a matter for the network operator concerned. Although this appendix illustrates the issues by discussing the steps required to migrate to fully SDH-based transport networks, fully SDH-based transport networks are not necessarily the goal.

This appendix firstly identifies the types of client layer signals which can be supported on SDH paths and the types of client layer signals which can be supported on PDH paths. It then describes the three basic introductory scenarios for SDH-based equipment. For each type of SDH client layer signal and introductory scenario, this appendix describes the consequences on networking, PDH/SDH interworking and subsequent transport network evolution.

Figure II.l shows the introductory paths that are available and illustrates the basic choices and provides a reference during the following discussion.

II.2 Types of client layer signals

II.2.1 SDH case

SDH path layers support the following client layer signals in accordance with the mappings defined in Recommendation G.707. For the purpose of interworking two cases must be considered:

a) client layer signals such as:

   i) 64 kbit/s-based signals (adapted into the SDH path layers using byte synchronous mappings);

   ii) leased line signals at G.702 bit rates at or above the primary rate;

   iii) other signals (e.g. ATM VP cells), the bit rate of which might be optimized to the payload of the SDH path layers;

b) PDH path layer signals (at G.702 bit rates at or above the primary rate) which, in turn, support either:

   i) client layer signals as in II.2.1 a);

   ii) lower-order PDH path layer signals.

SDH-based transport network equipment is concerned with control of connectivity of SDH paths and not with control of connectivity of the client layer. Therefore, in case b) above, the SDH-based equipment cannot be used to individually network the signals identified in b) i) and ii); primary rate and/or higher-order PDH multiplexing functionality is required to facilitate this connectivity. This constraint could be significant in cases where SDH-based transport networks become widespread. Where this is likely to be the case, it is recommended that the support of such signal is minimized from the outset or, that during subsequent stages of transport network evolution, steps are taken to minimize the redundant PDH path layer signals.

II.2.2 PDH case

In the case of PDH, path layer signals support the following two types of client layer signals which must be considered for interworking:

a) client layer signals such as:

   i) 64 kbit/s-based signals (adapted into the PDH path layers in accordance with Recommendation G.704);

   ii) leased line signals at G.702 bit rates at or above at the primary rate;

   iii) other signals (e.g. ATM VP cells), the bit rate of which might be optimized to the payload of the PDH layers;

b) SDH path layer signals which, in turn, support the client layer signals identified in II.2.1 (see Note below).

NOTE – Mappings of SDH path layer signals into PDH path layer signals are defined in Recommendation G.832. The possibility is mentioned in this appendix in order to outline a possible transitional stage of transport network evolution. The functionality required to provide these mappings is referred to below as "modem" functionality (since it is analogous to the transition from the "old" analogue network to the "new" digital network where modems allowed signals from the "new" network to be supported over the "old" network). In cases where the modem functionality provides multiplexing of several SDH path layer signals into the PDH path layer, control of the connectivity of the individual SDH path layer signals is not possible in the PDH path layer network.

II.3 Initial introduction of SDH-based equipment

There are three basic ways of initially introducing SDH-based equipment:

a) Deployment of an overlay network comprising the simultaneous deployment of SDH line systems and VC-*n* cross-connect functionality to provide widespread path layer connectivity (see Note below). In addition, to increase geographical coverage in such overlay network, the link connections in the SDH path layer could be adapted into PDH paths using the modem functionality as mentioned in II.2.2 b). Initially, this overlay network is likely to be "thin" and might be targeted at supporting particular client layer types (e.g. a leased line service) but later "thickened" to include other services.

NOTE – VC-*n* cross-connect functionality is realized in SDH digital cross-connect equipment (DXC) and/or add/drop multiplex equipment (ADM). Such functionality is referred to below as DXC/ADM.

b) Deployment of SDH DXC/ADMs only with interfaces at G.702 bit rates. This is likely to take the form of DXCs in central locations where control of the connectivity of PDH paths at the site is the desired initial benefit. In terms of the functional network architecture, VC-*n* paths in the DXC/ADMs provide subnetwork connections in the PDH path layer. SDH line systems could be deployed at a later stage to provide more widespread VC connectivity. Similarly, PDH paths with the modem functionality could be used as mentioned in a) above to provide more widespread VC-*n* connectivity.

c) Deployment of SDH line systems only with intra-office interfaces at G.702 bit rates. Such systems are functionally similar to PDH line systems in that they support link connections in the PDH path layer. In terms of the functional network architecture, VC-*n* paths in the SDH line systems provide link connections in the PDH path layer. SDH DXC/ADMs could be deployed at a later date to provide more widespread VC-*n* connectivity.

Each option is valid and the choice of one or more options is determined by the initial requirements of the network operator. The choice of one option by one network operator need not affect the choice of another network operator. The three options can coexist.

II.4 Interworking between PDH and SDH-based transport networks

II.4.1 Interworking levels

Interworking between PDH-based transport networks and SDH-based transport networks can occur at one of the following three levels:

a) at the client layer for signals identified in II.2.1 a) and II.2.2 a): Such interworking generally requires the termination of the respective PDH and SDH paths and the adaptation functions between the respective path layers and the client layer. This combination of functions is referred to below as transmultiplexing (TMUX). This approach does not necessarily imply additional physical interfaces. In the particular case of 64 kbit/s client layer signals, the byte synchronous mappings given in Recommendation G.707 allow client layer interworking without necessarily terminating the PDH path. In the particular case of leased line signals at G.702 bit rates at or above the primary rate, the asynchronous mappings given in Recommendation G.707 allow client layer interworking. In cases where the PDH and SDH client layer signals have the same bit rate, interworking at the client level does not necessarily require processing of the client layer signal.

b) at the PDH path level for signals identified in II.2.1 b): Such interworking requires the adaptation of the PDH path layer signals into appropriate SDH path layers using the asynchronous mappings described in Recommendation G.707 for G.702 bit rates.

c) at the SDH path level where the SDH path layer signals, described in II.2.2 b), are adapted into PDH paths using the modem functionality: This case is described in Recommendation G.832.

The choice of interworking level and SDH equipment introduction scenario will have an impact on subsequent transport network evolution stages as discussed below.

II.4.2 SDH overlay

The two interworking levels are considered as follows:

a) The requirements for interworking at the client level are given in II.4.1 a).

In cases where PDH paths are used to provide VC-*n* connectivity, "modem" functionality will be required for adaptation to the PDH path layer.

In cases where subsequently STM-N interfaces are provided on network elements which process the client layer signals identified in II.2.1 a) (e.g. a 64 kbit/s switch), there are no interworking requirements between such network elements and the SDH transport network.

b) The requirements for interworking at the PDH path level are given in II.4.1 b). Primary rate and/or higher-order PDH multiplexing functionality will continue to be required in the PDH-based transport network.

In cases where PDH paths are used to provide VC-*n* connectivity, "modem" functionality will be required for adaptation to the PDH path layer.

In cases where subsequently STM-N interfaces are provided on network elements which process the client layer signals identified in II.2.1 a), primary rate and/or higher-order PDH multiplexing functionality and G.707 asynchronous mappings of G.702 bit rates will continue to be required to provide interworking functionality between such network elements and the SDH transport network.

In cases where it is subsequently desired to interwork at the client level, it will be necessary to cease the SDH paths supporting PDH path layers and provide new SDH paths which directly support the client layer. Primary rate and/or higher-order PDH multiplexing functionality will not be required.

II.4.3 SDH DXC/ADMs

The two interworking levels are considered as follows:

a) The requirements for interworking at the client level are given in II.4.1 a).

In cases where subsequently more widespread SDH path layer networking is required, SDH line systems could be deployed; interworking functionality is not required between DXC/ADM and the SDH line systems. The considerations in II.4.2 a) also apply.

b) The requirements for interworking at the PDH path level are given in II.4.1 b).

In cases where subsequently more widespread SDH path layer networking is required, SDH line systems could be deployed; interworking functionality is not required between the DXC/ADM and the SDH line systems. The considerations in II.4.2 b) also apply.

II.4.4 SDH line systems

The two interworking levels are considered as follows:

a) The requirements for interworking at the client level are given in II.4.1 a).

In cases where subsequently more widespread SDH path layer networking is required, SDH DXC/ADMs could be deployed; interworking functionality is not required between DXC/ADM and the SDH line systems. The considerations in II.4.2 a) also apply.

b) The requirements for interworking at the PDH path level are given in II.4.1 b).

In cases where subsequently more widespread SDH path layer networking is required, SDH DXC/ADMs could be deployed; interworking functionality is not required between the DXC/ADM and the SDH line systems. The considerations in II.4.2 b) also apply.

II.5 Introduction of STM-N interfaces on 64 kbit/s switches (and DXCs)

In the case of PDH-based transport networks, 64 kbit/s switches are interconnected by G.704 structured primary or secondary rate synchronous paths. In terms of the functional architecture, the link connections between subnetworks in the 64 kbit/s layer network are supported by paths in the PDH path layer network. The introduction of STM-N interfaces on one of two interconnected 64 kbit/s switches requires PDH/SDH interworking.

Interworking can take place at either the 64 kbit/s level or the PDH path level. Considering these two cases:

a) interworking at the 64 kbit/s level requires the use of byte synchronous mappings to adapt the 64 kbit/s layer signals into the SDH path layer (see NOTE below);

NOTE – Recommendation G.707 defines byte synchronous mappings into VC-11 and VC-12 only. Current ITU-T Recommendations do not define byte synchronous mappings into higher bit rate VC-*n*s.

b) interworking at the PDH path level requires the use of asynchronous mappings to adapt the PDH paths into the SDH path layer.

In the case where subsequently STM-N interfaces are introduced on the other 64 kbit/s switch and there is the potential for SDH path layer connectivity between the two switches, interworking functionality will be required if one switch uses byte synchronous mapping and the other switch uses asynchronous mapping. In cases where the two switches are in different operators networks, responsibility for providing the interworking functionality (if required) rests with the operator of the switch which uses asynchronous mapping unless otherwise agreed bilaterally.

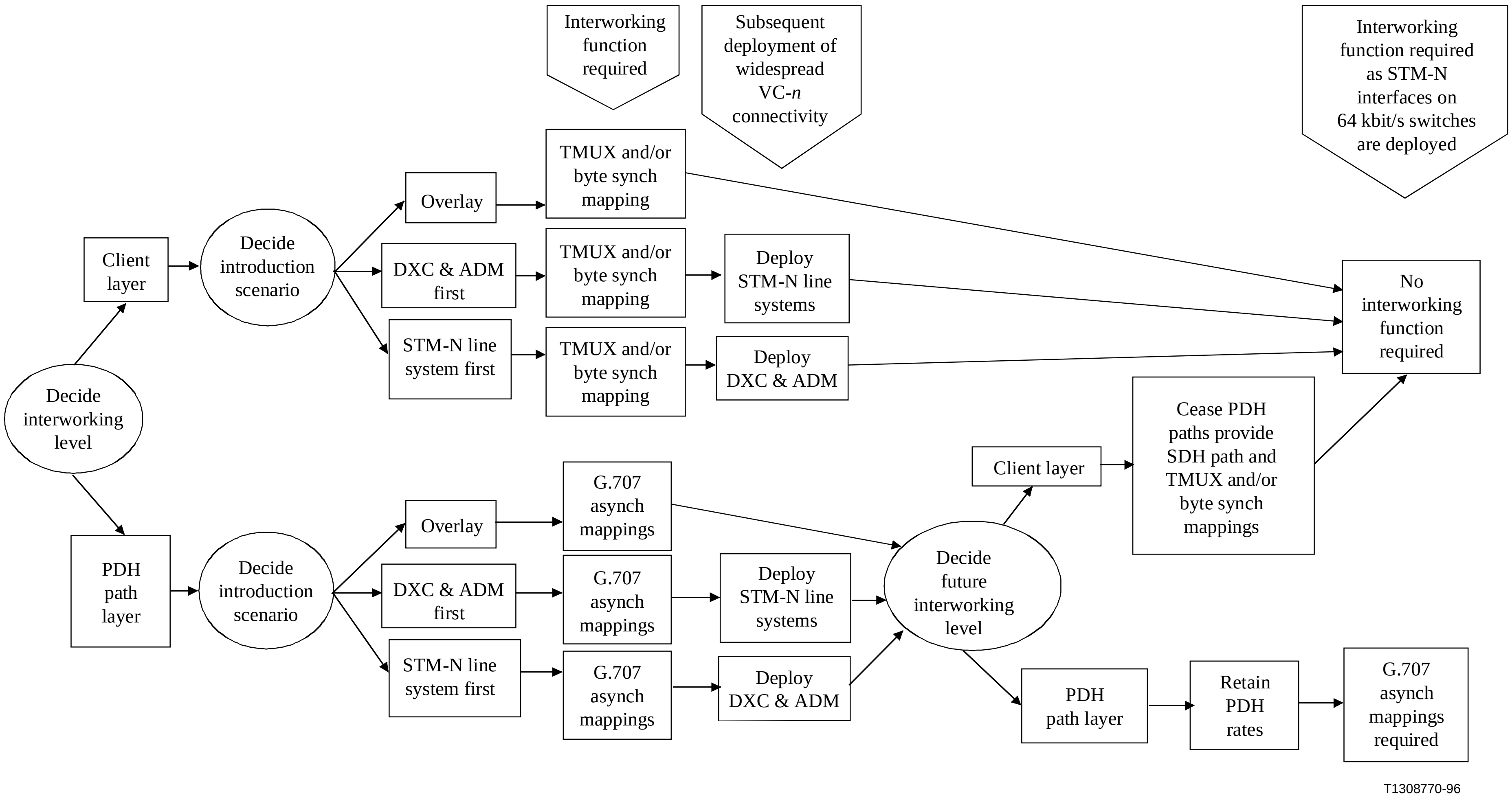


Figure II.1/G.803 – Introductory paths for SDH transport networks

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