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Digital transmission systems – Digital networks – General aspects

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

ITU-T Recommendation G.803

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

FOREWORD

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CONTENTS

ITU-T Recommendation G.803

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

1 Scope

This ITU-T Recommendation describes the functional architecture of transport networks including network synchronization principles for networks that are based on the SDH. This ITU-T Recommendation uses the architectural description defined in ITU-T 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 ITU-T Recommendation uses the terminology defined in ITU-T Recommendations G.783, G.805 and G.841; the following terms are specific to this ITU-T Recommendation. The layer networks defined below terminate and generate the overheads defined in ITU-T Recommendation G.707.

3.1   SDH higher-order path layer networks: Those layer networks with characteristic information of VC-3[1], VC-3-Xv (X = 2 … 48)[2], VC-4, VC-4-Xc (X = 4, 16)[3] or VC-4-Xv (X = 2 … 16)[3].

3.2   SDH lower-order path layer networks: Those layer networks with characteristic information of VC-11, VC-11-Xv (X = 2 … 84), VC-12, VC-12-Xv (X = 2 … 63), VC-2, VC-2-Xc (X = 2 … 7)[4], VC-2-Xv (X = 2 … 21)[5] or VC-3[1] or VC-3-Xv (X = 2 … 3)[5].

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 ITU-T 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 ITU-T 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.

[2] Values of X larger than 48 may be required.

[3] Values of X larger than 16 may be required.

[4] Transported in one higher order VC-3.

[5] Transported in one higher order VC-4.

4 Abbreviations

This ITU-T 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 Telephone 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-X   Concatenation of X virtual containers (of level n)

VC-n-Xc   Contiguous concatenation of X virtual containers (of level n)

VC-n-Xv   Virtual 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 ITU-T 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 ITU-T Recommendation. This ITU-T Recommendation uses the terminology and functional architecture and diagrammatic conventions defined in ITU-T 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 shown in Figure 5-1.
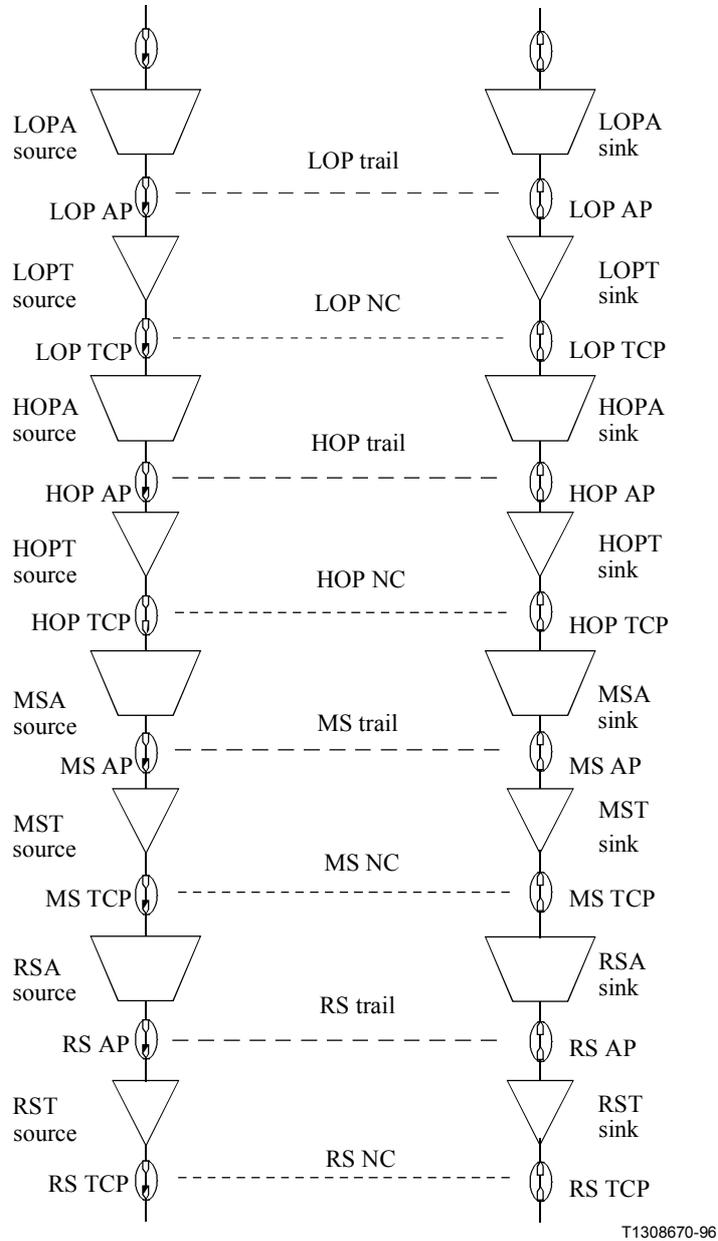
AP   Access Point
HOPA   Higher-Order Path Adaptation
HOPT   Higher-Order Path Termination
LOPA   Lower-Order Path Adaptation
LOPT   Lower-Order Path Termination
MSA   Multiplex Section Adaptation
MST   Mutiplex Section Termination
NC   Network Connection
RSA   Regenerator Section Adaptation
RST   Regenerator Section Termination
TCP   Termination Connection Point

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

For the purposes of description of the SDH, the interlayer adaptation function is named in relation to the server layer network. In this ITU-T Recommendation, the G.805 transport assembly is called a "layer" to maintain continuity of the terminology used in the 1992 version of ITU-T 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 ITU-T Recommendation G.783.

5.1 Multiplexing of multiple clients

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 ITU-T Recommendation G.707. Note that the TUG only describes grouping and does not change the format of the signal.
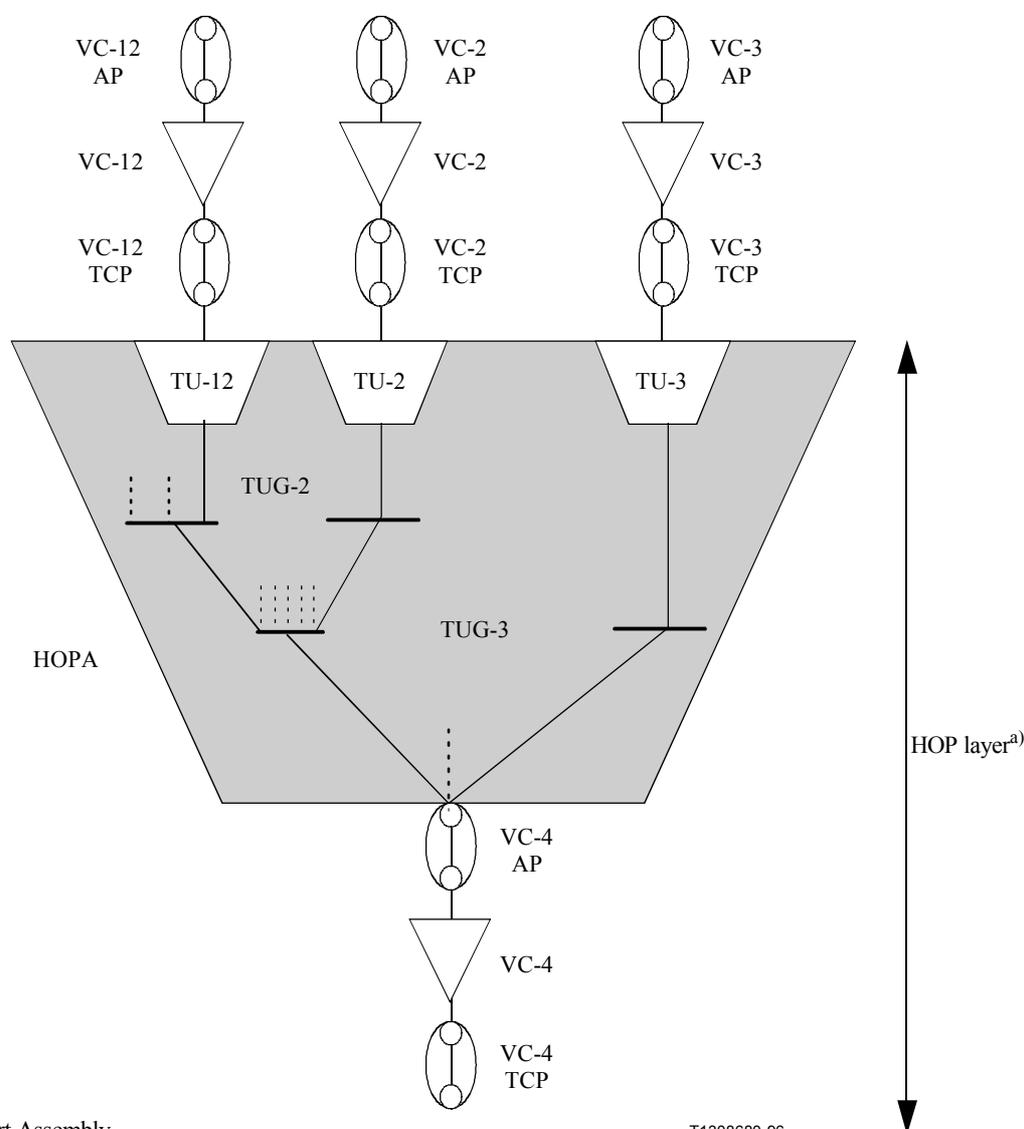
a) G.805 Transport Assembly.

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

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 ITU-T Recommendation G.774 using the indirect adaptor object class.
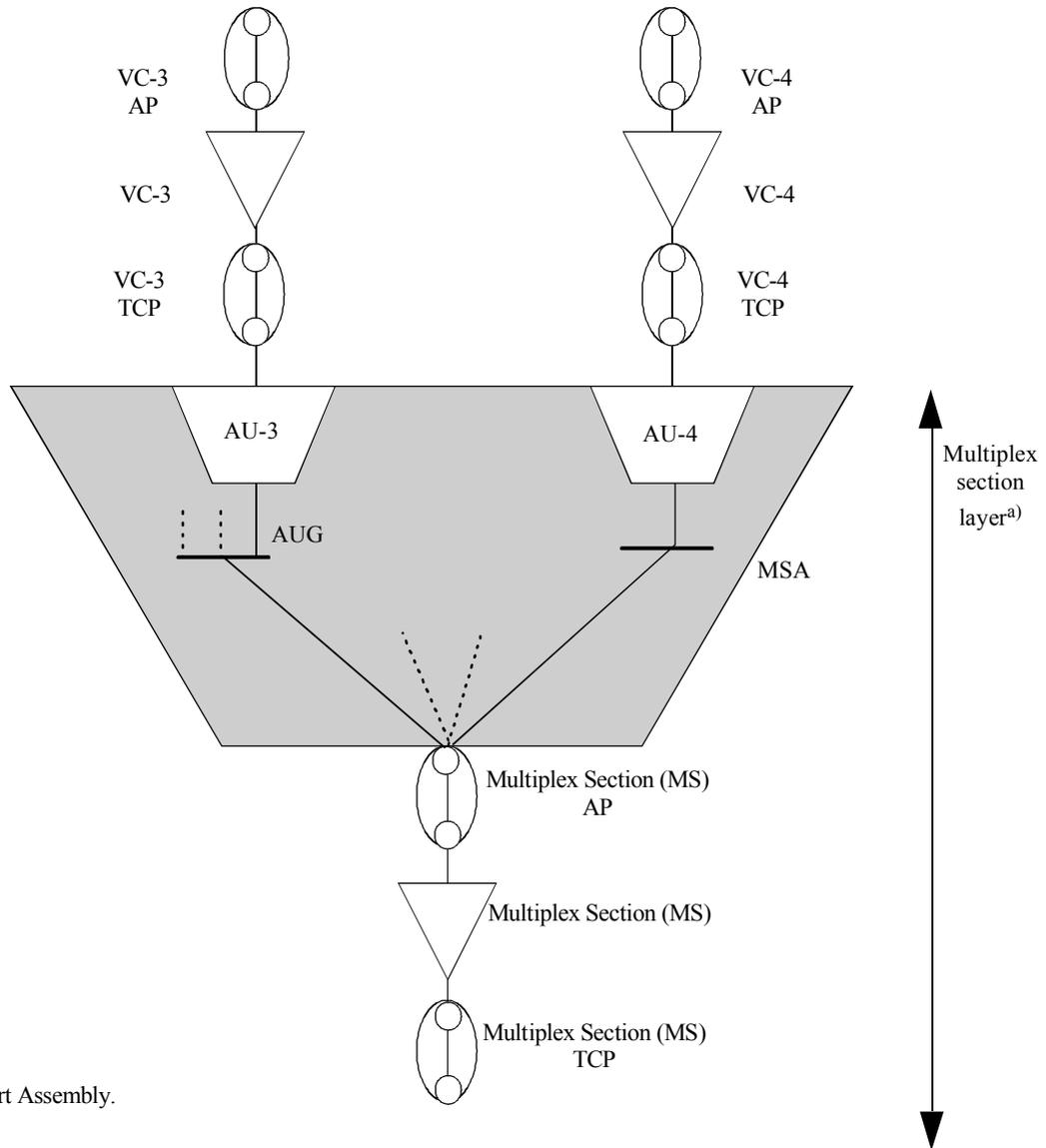
a) G.805 Transport Assembly.

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

5.2   Support of ATM over SDH

For the purpose of describing transport networks based on ATM, ITU-T Recommendation I.326 shows the ATM transport assembly that groups the VP to VC-n, VC-n-Xv and VC-n-Xc adaptation functions 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 one of these VC-n, VC-n-Xv and VC-n-Xc layer networks is the access point.

Note that when the client is an ATM VP layer network, the VC-n, VC-n-Xv and Vc-n-Xc server layer networks can only support a single client layer network.

5.3 Concatenation

For the transport of client layer signals with transmission rates above or between the transmission rate of any single SDH VC the payload capacity of individual VCs can be combined by means of concatenation.

Two types of concatenation are defined in ITU-T Recommendation G.707: contiguous (VC-n-Xc) and virtual concatenation (VC-n-Xv). ITU-T Recommendation G.707 defines contiguous and virtual concatenation in such a way that the payload capacities of a VC-n-Xc and a VC-n-Xv are identical. By implication the adaptation functions for a particular client layer network to either a VC-n-Xc or a VC-n-Xv for the same index X are also the same. The current set of client server associations for concatenated layer networks is listed in Appendix I and depicted in Figure I.1.

5.3.1 Contiguous concatenation

The characteristic information of a contiguous concatenated VC-n-Xc layer network is transported via a VC-n-Xc network connection.

Figure 5-4 shows the functional architecture for contiguous concatenation.
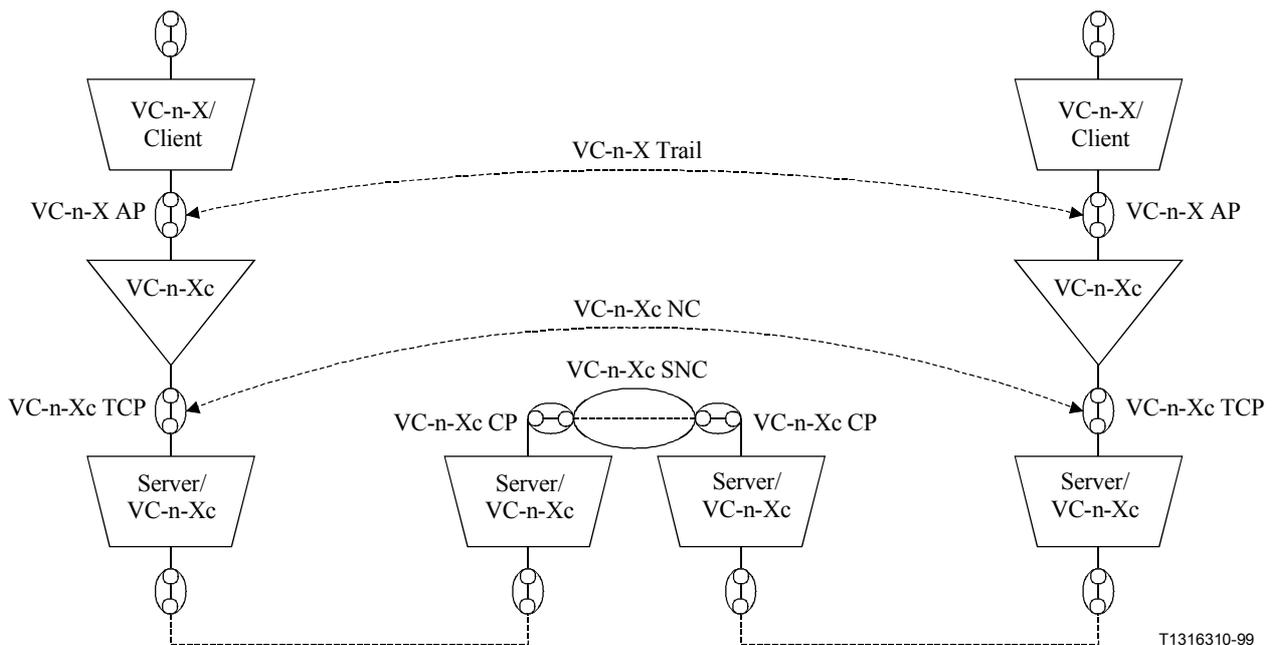
Figure 5-4/G.803 – Functional architecture for contiguous concatenation

5.3.2 Virtual concatenation

Virtual concatenation is the SDH implementation of inverse multiplexing as described in ITU-T Recommendation G.805. The characteristic information of a virtual concatenated VC-n-Xv layer network is transported via a bundle of X VC-n network connections. The VC-n-Xv trail termination sink function has to compensate this differential delay in order to provide a contiguous payload at its output.

The differential delay that has to be compensated for, for virtual concatenated VC-n, is at least 125 μsec.

The connection monitoring techniques defined in clause 7 are applied per data stream on the VC-n characteristic information.

Figure 5-5a shows the functional architecture for a VC-n-Xv.
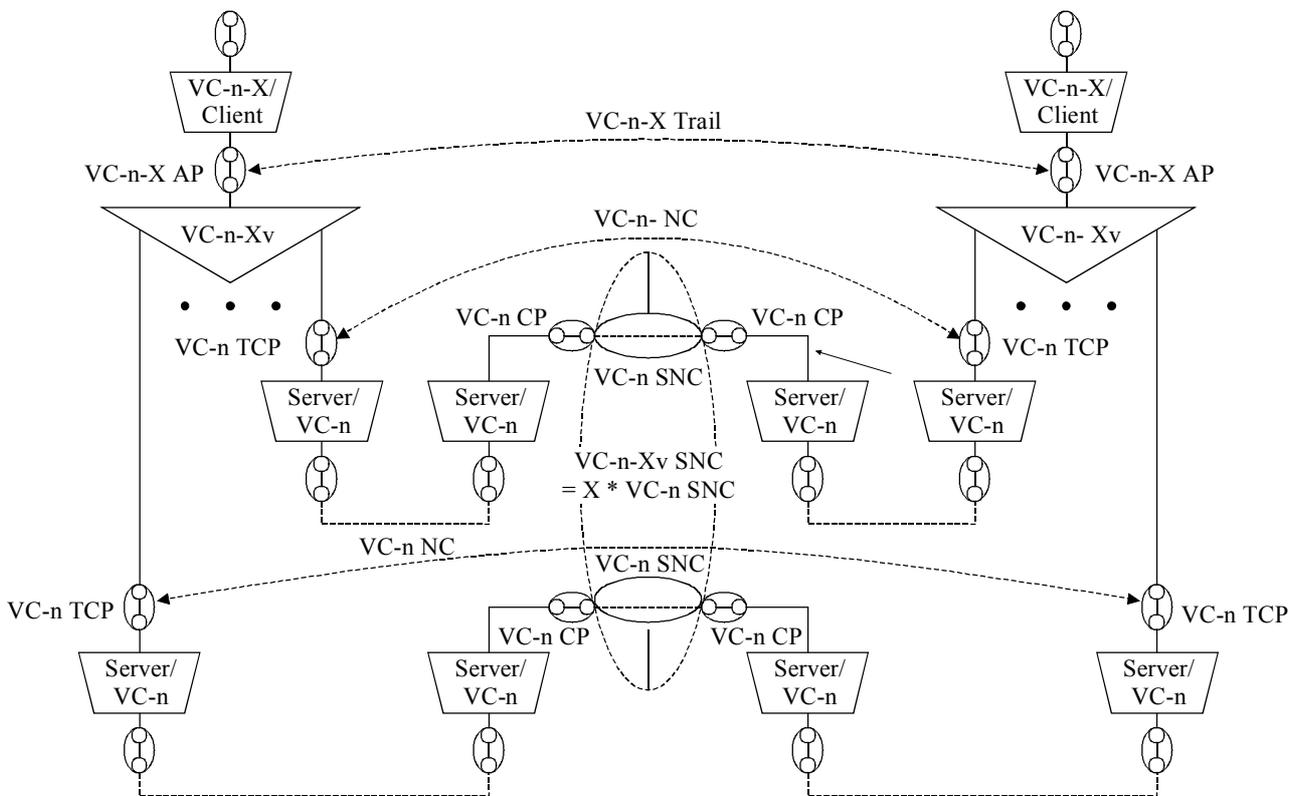
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Figure 5-5a/G.803 – Functional architecture for virtual concatenation

The compound function VC-n-Xv indicated in Figure 5-5a is further composed to basic atomic functions as shown in Figure 5-5b.
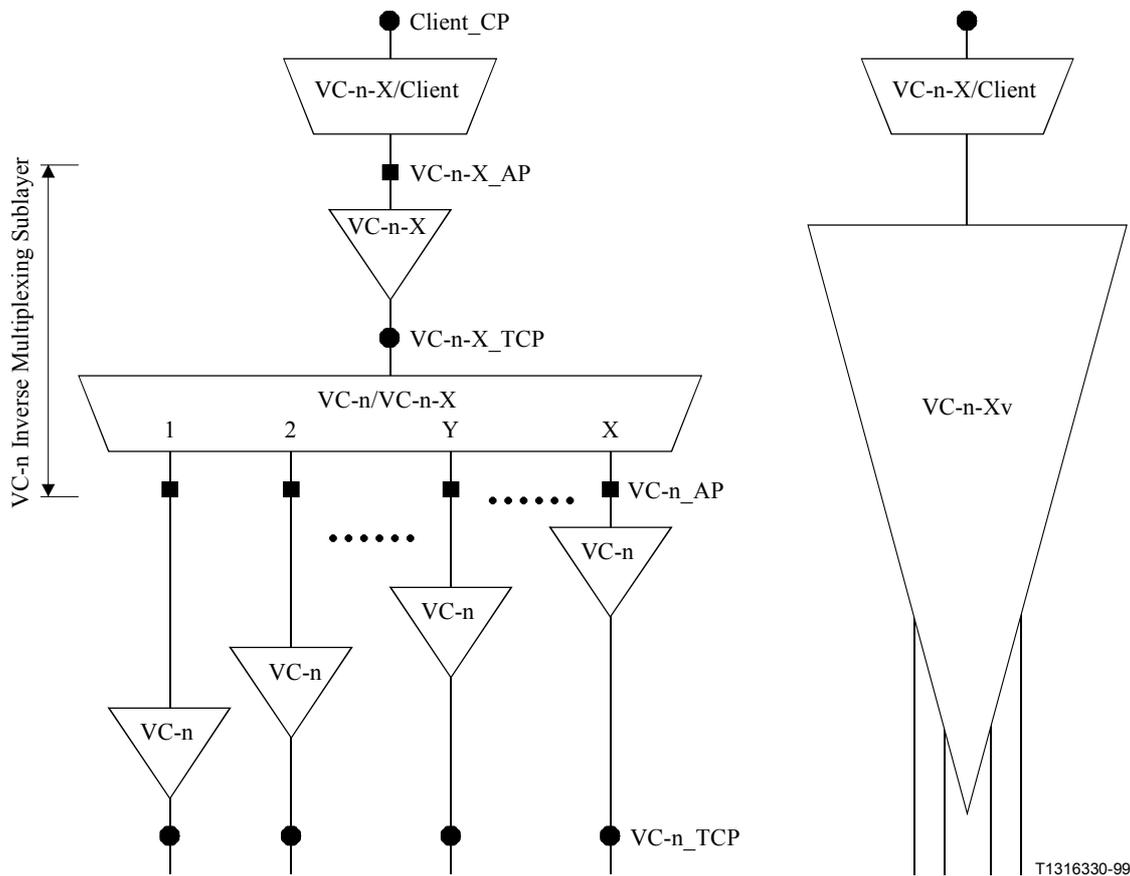
Figure 5-5b/G.803 – Inverse multiplexing/virtual concatenation model

The VC-n/VC-n-Xv_A_So function performs the following processing between its input and output:

– determine if variable group size can be handled by client signal;

– determine maximum size of the group (X);

– determine actual size of the group (Y);

– determine temporarily failed signals in actual group;

– support temporarily group size reduction, and support hitless addition of a previously failed signal coordinated with remote end;

– support hitless increase and decrease of the actual group Y, coordinated with the remote end;

– perform 8-bits or byte disinterleave operation of incoming signal; map 8-bits/byte into payload of signal T_i, the next 8-bits/byte into signal T_{i+1}, etc. that belong to the actual group and are not temporarily removed;

– insert differential delay detecting multiframe indicator in each of the signals;

– insert sequence number (need is to be confirmed in SDH) in each of the signals;

– insert payload type identification into the signal label of each of the signals.

The VC-n/VC-n-X_A_Sk function performs the following processing between its input and output:

– compare payload type identification within the signal label of each of the signals with the expect value, detect defect payload mismatch, report the received values;

– determine if variable group size can be handled by client signal;

– determine maximum size of the group (X);

– determine actual size of the group (Y);

- determine temporarily failed signals in actual group;

- support temporarily group size reduction, and support hitless addition of a previously failed signal coordinated with remote end;

- support hitless increase and decrease of the actual group Y, coordinated with the remote end;

- recover multiframe start phase of each of the individual signals;

- compare sequence number (need is to be confirmed in SDH) in each of the signals with expected one, detect defect and report received values;

- realign all individual signals that belong to the actual group and are not temporarily removed by means of compensation of the differential delay;

- perform interleave operation of incoming signals that belong to the actual group and are not temporarily removed;

- determine signal fail status and if failed insert AIS.

The VC-n-X_TT_So function performs the following processing between its input and output:

- report signal fail status;

- for case of interworking with contiguous concatenated remote endpoint, report approximated composite status and performance.

The VC-n-X_TT_So function performs the following processing between its input and output:

- no specific processing is foreseen for the moment.

5.3.3 Interworking between contiguous and virtual concatenation

Contiguous and virtual concatenation for the same index X transport the same adapted information and have similar characteristic information. This enables the possibility for layer network interworking as defined in ITU-T Recommendation G.805 between a VC-n-Xc and a VC-n-Xv layer network with the same index. Figure 5-6 shows the functional architecture. The interworking processing function performs the semantically "transparent" conversion of the virtual concatenation trail overhead to contiguous concatenation trail overhead and vice versa. A VC-n-X trail may contain one or more interworking processing functions.
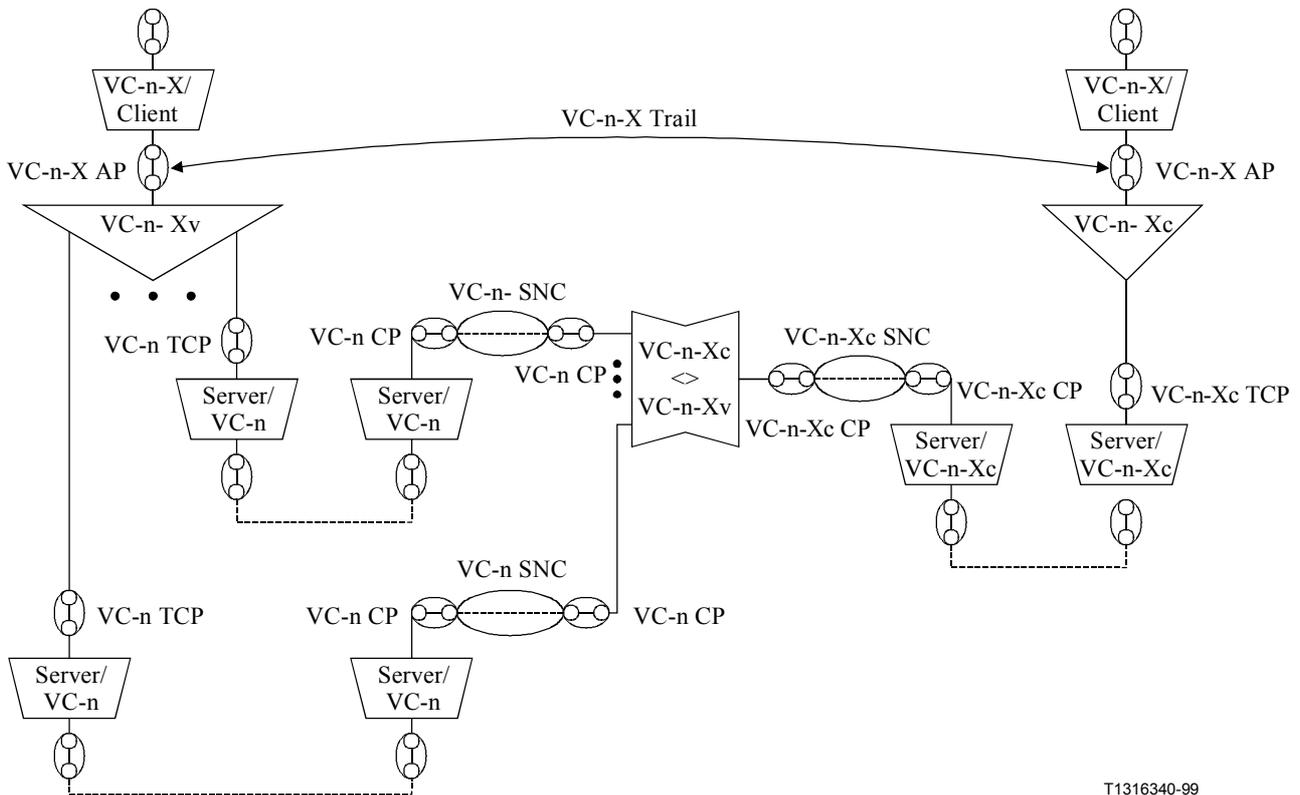
Figure 5-6/G.803 – Contiguous/virtual concatenation interworking

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 ITU-T Recommendation G.805 is shown in Figure 6-1.
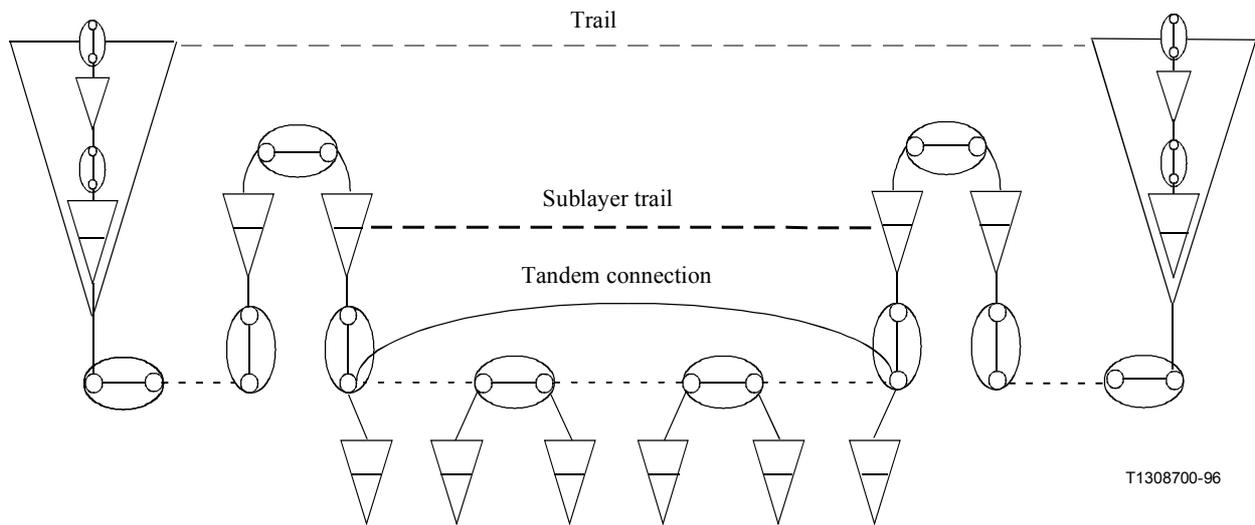
Figure 6-1/G.803 – Tandem connection monitoring by means of a sublayer trail

Figure 6-2 illustrates a SDH network application of tandem connection monitoring within the administrative domain of a network operator. A tandem connection may however also extend across multiple administrative domains with the cooperation of the operators involved. Also in the latter case there is in general no need to support consecutive tandem connections within a single network element.

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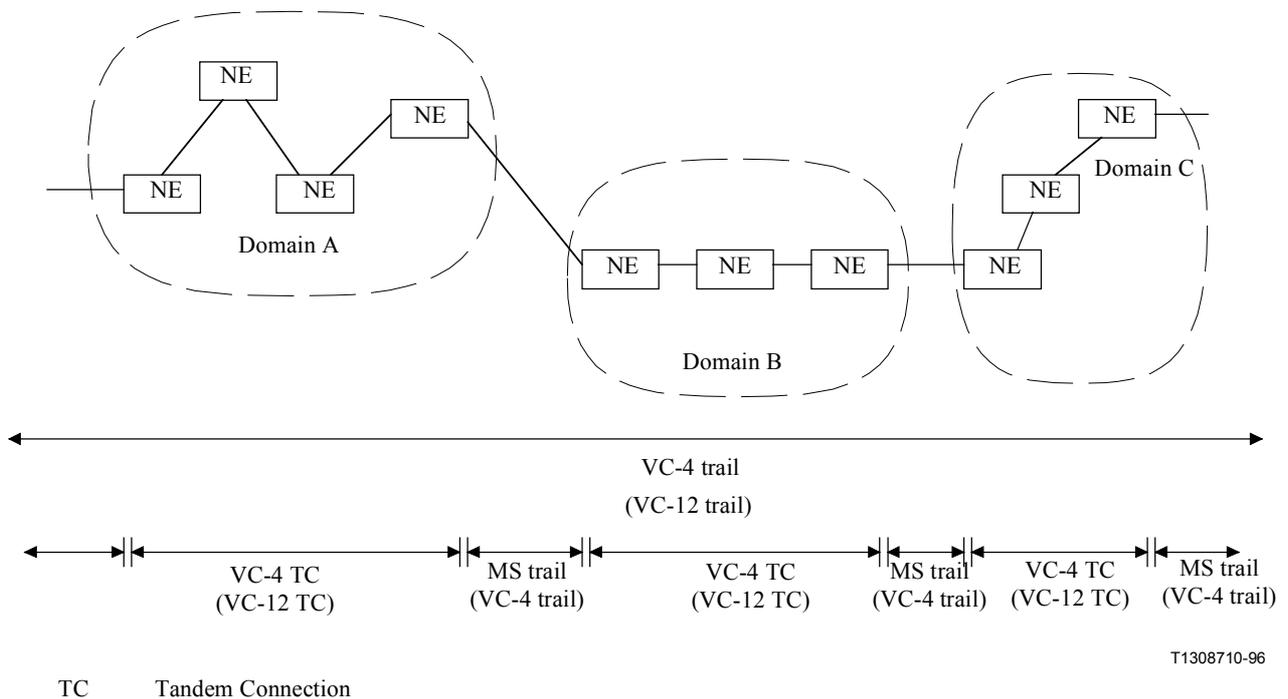
Figure 6-2/G.803 – Multi-operator domain VC-*n* trail,
monitored via tandem connections

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.

VC-4 trail

HOPT

VC-4 network connection

HOPT

(Network A) Tandem connection

(Network B) Tandem connection

HOTCA (TC A) Trail HOTCA

HOTCA (TC B) Trail HOTCA

HOTCT (TC A) Network connection

HOTCT

HOTCT

(TC B) Network connection

HOTCT

Link connection

Link connection

Link connection

Link connection

Link connection

HOPM HOPM HOPM

HOPM HOPM HOPM

MSA MST MSA MST MSA MST MSA MST

MSA MST MSA MST

MSA MST MSA MST MSA MST MSA MST

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

MSA Multiplex Section Adaptation
MST Multiplex Section Termination

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

VC-4 trail

HOPT

VC-4 network connection

VC-4 tandem connection

HOTCA   (TC) Trail   HOTCA

HOTCT   (TC) Network connection   HOTCT

Link connection

HOPM   HOPM   HOPM

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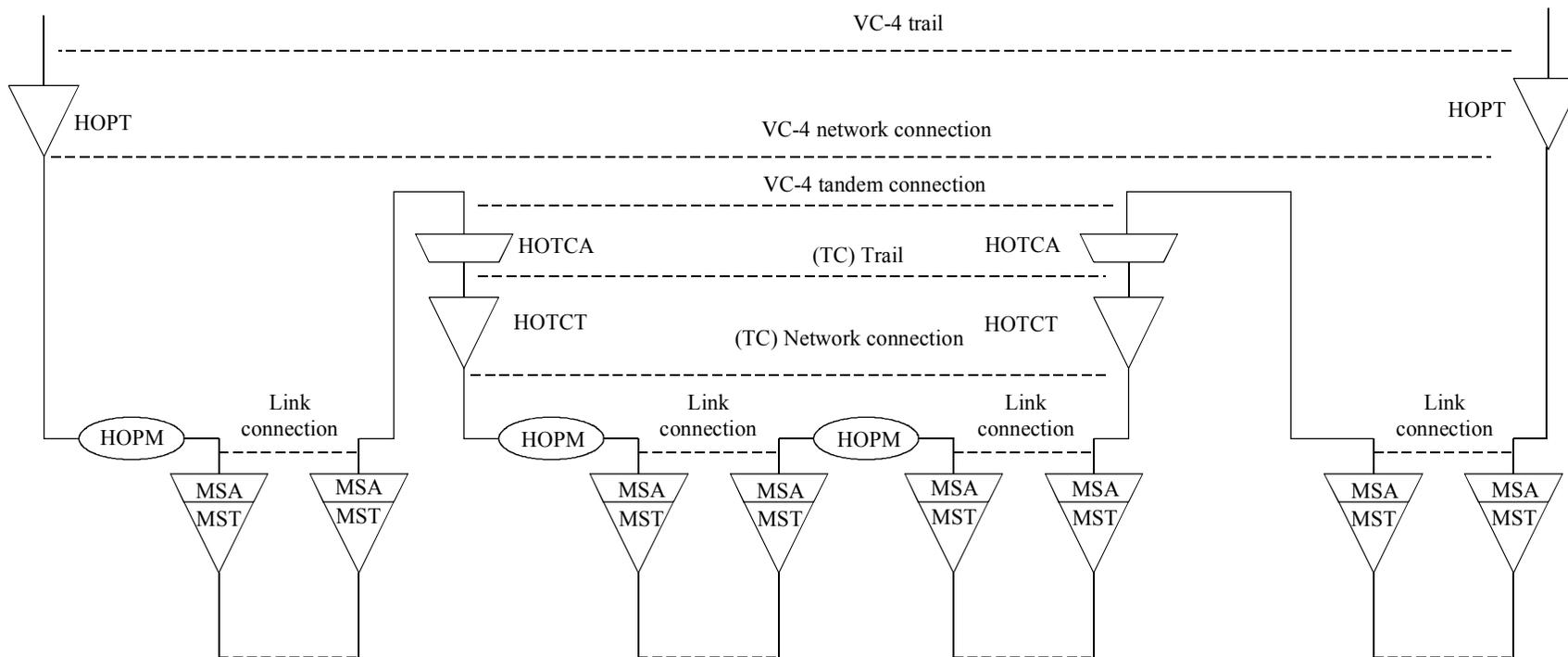
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HOPM   Higher-Order Path Matrix   MSA   Multiplex Section Adaptation
HOPT   Higher-Order Path Termination   MST   Multiplex Section Termination
HOTCA   Higher-Order Tandem Connection Adaptation
HOTCT   Higher-Order Tandem Connection Termination

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 ITU-T Recommendation G.805. This ITU-T 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 ITU-T 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 ITU-T 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 ITU-T 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 ITU-T 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 ITU-T 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 ITU-T 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 ITU-T 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 ITU-T Recommendation G.841.

8 Architecture of synchronization networks

8.1 Introduction

This clause 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 ITU-T 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.

Appendix III provides additional guidance on the subject of network synchronization with the focus on the practical engineering aspects.

8.2 Synchronization network aspects

8.2.1 Synchronization methods

There are two fundamental methods of synchronizing nodal clocks. These are identified in ITU-T 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 ITU-T 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.
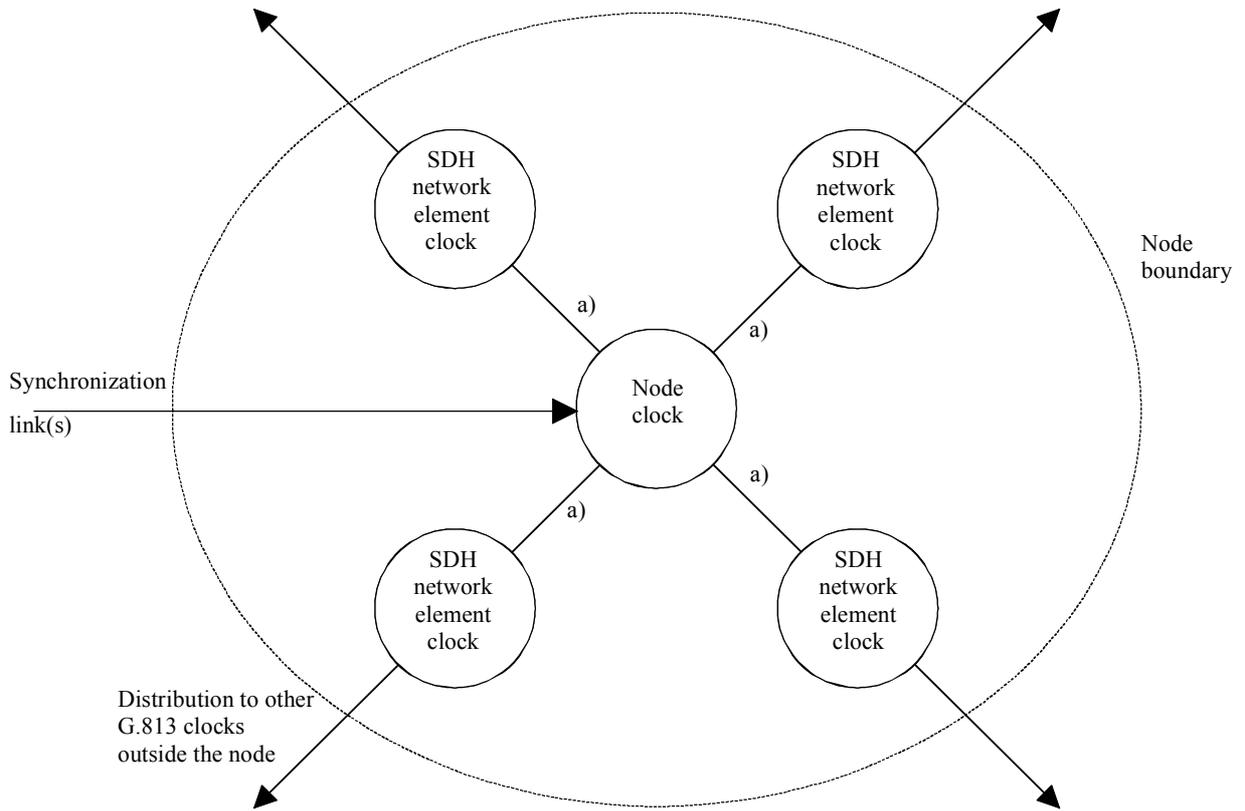
Figure 8-1/G.803 – Synchronization network architecture intra-node distribution

a) Timing only.
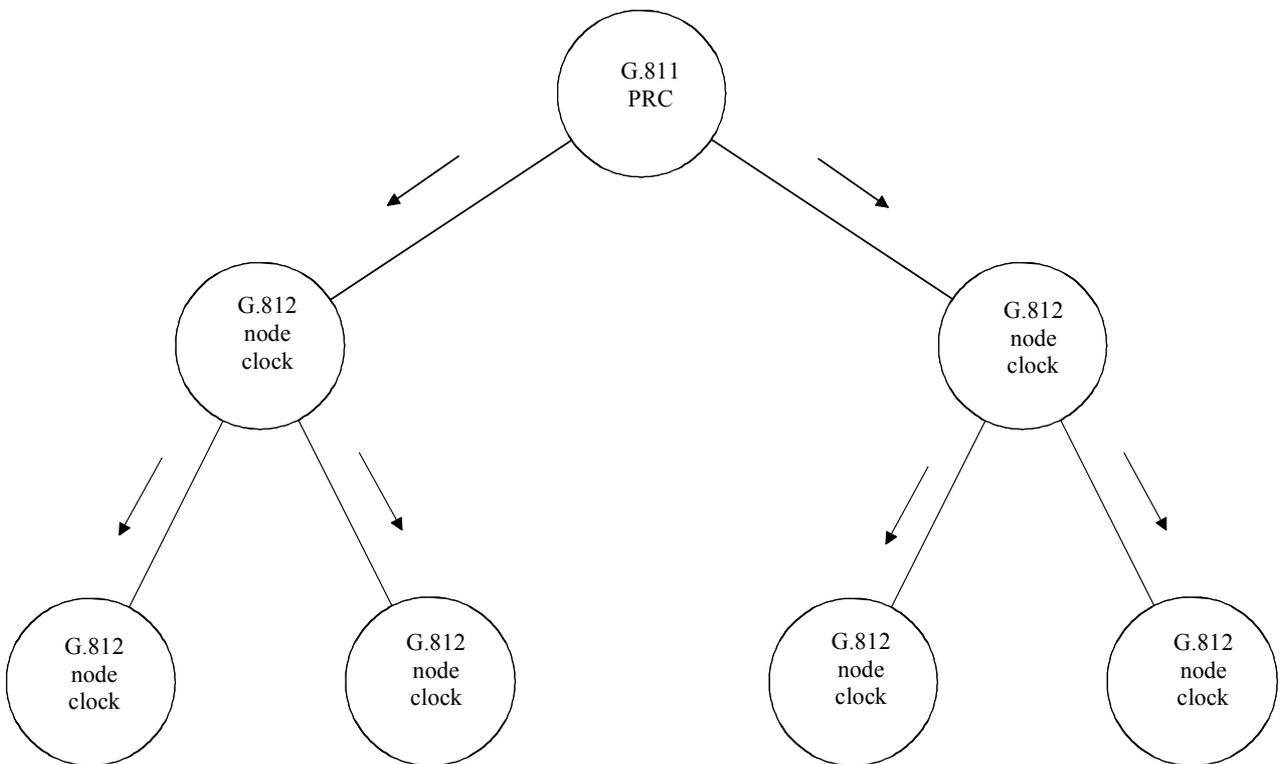
Figure 8-2/G.803 – Synchronization network architecture inter-node distribution

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 ITU-T 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

MS/SD	MS to SD adaptation	SD	Synchronization Distribution
MST	Multiplex Section Termination	SD/NS	SD to NS adaptation
NS	Network Synchronization	UTC	Universal Time Coordinated
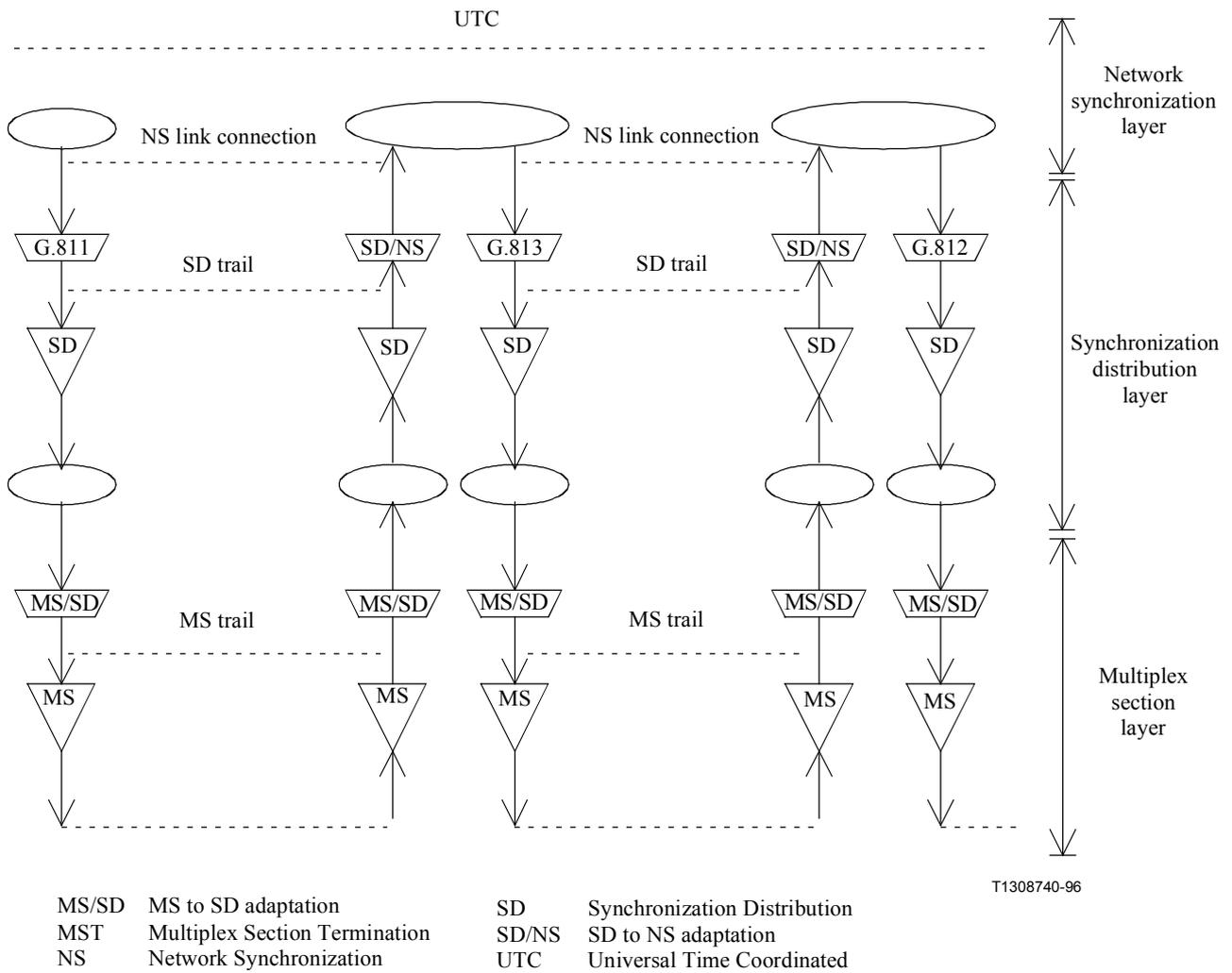
**Figure 8-3/G.803 – Example of synchronization distribution showing
the synchronization layers**
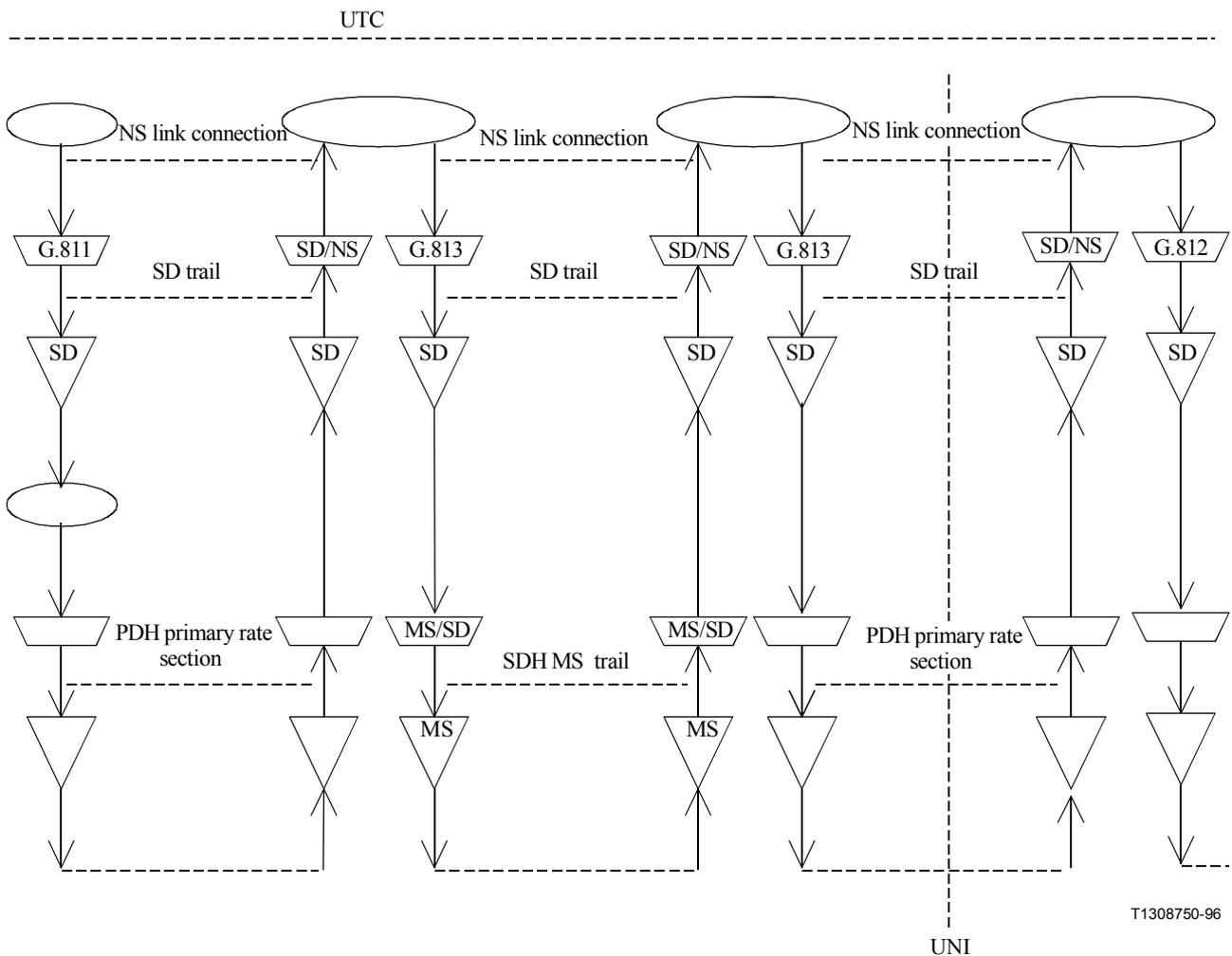
MS/SD	MS to SD adaptation	SD	Synchronization Distribution
MST	Multiplex Section Termination	SD/NS	SD to NS adaptation
NS	Network Synchronization	UTC	Universal Time Coordinated

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 ITU-T 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 ITU-T Recommendation G.813.

The longest chain should not exceed K slave clocks compliant with ITU-T 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 Appendix I/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 ITU-T 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.
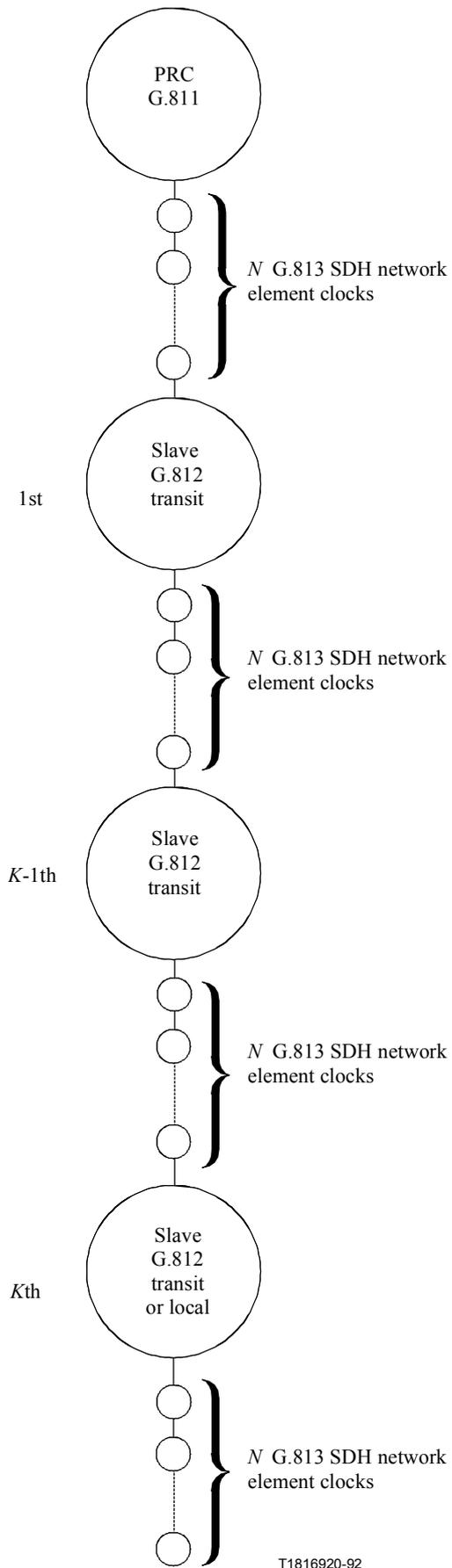
For worst-case scenario
calculation purposes:

$K = 10$

$N = 20$ with restriction
that total number of SDH
network element clocks
is limited to 60

T1816920-92

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 marking scheme is provided to allow selection and confirmation of the synchronization trail, where a choice is available, with the highest hierarchical clock source quality level (including under synchronization failure conditions).

The quality marking scheme provides an indication of the clock source quality level of the timing using a status messaging approach. The status message is conveyed in the multiplex section overhead as described in ITU-T 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 clock source quality level 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 ITU-T Recommendation G.707. In PDH distribution trails, it is possible to convey the status message as described in ITU-T Recommendation G.704. For PDH distribution trails carrying ATM, the status message is described in ITU-T Recommendation G.832.

Synchronization status messages contain clock source quality level information that may assist 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.
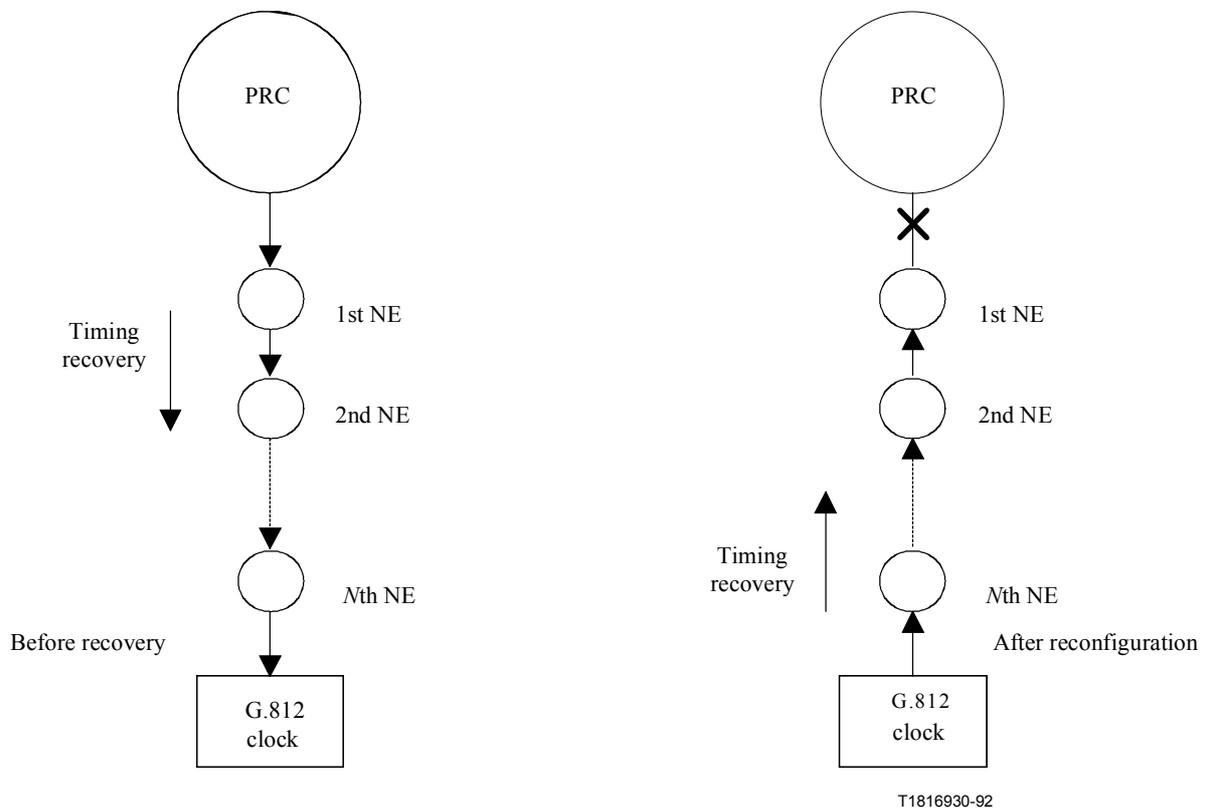
Figure 8-6/G.803 – Reconfiguration example

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 ITU-T Recommendations G.823 and G.824. In addition, reference configurations are specified that may occur when SDH is introduced in the existing PDH environment.

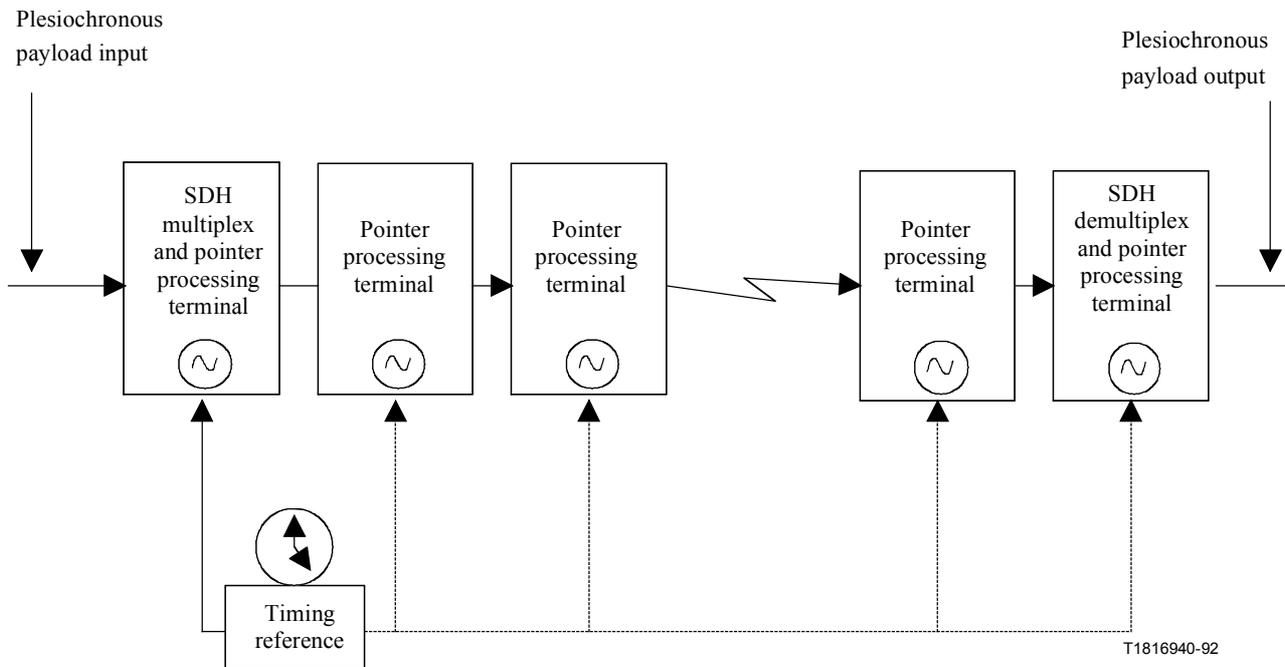### 8.3.1 SDH network model for pointer activity simulation

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 ITU-T 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 ITU-T 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 narrow-band 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 ITU-T 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 ITU-T 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.
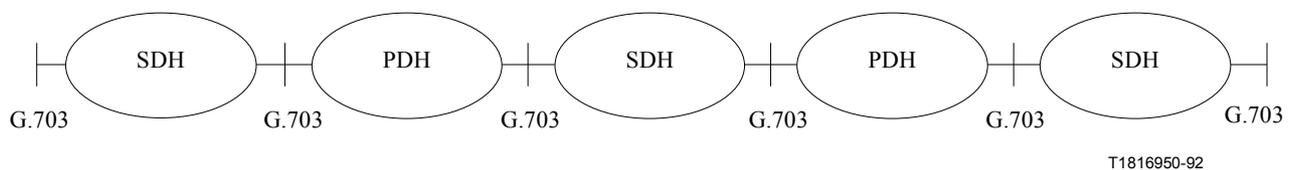
Figure 8-8/G.803 – PDH/SDH interworking

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 ITU-T 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 ITU-T 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 ITU-T 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 $N \times 64$ kbit/s signals between PDH-based transport networks and SDH-based transport networks.

APPENDIX I

Client server associations of SDH layer networks

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, VC-2-Xc, VC-2-Xv or VC-3 LOP or: VC-3, VC-4, VC-4-Xc or VC-4-Xv HOP	53-octet cells
HDLC framed signals	VC-11, VC-12, VC-2, VC-2-Xc, VC-2-Xv or VC-3 LOP or: VC-3, VC-4, VC-4-Xc or VC-4-Xv HOP	variable length frames
VC-11 LOP	VC-3 or VC-4 HOP or sSTM 2n Multiplex section (TUG-2 based)	VC-11 + frame offset

Client layer	Server layer	Client characteristic information
VC-12 LOP	VC-3 or VC-4 HOP or sSTM-1k Multiplex section (TU-12 based) or sSTM-2n Multiplex section (TUG-2 based)	VC-12 + frame offset
VC-2 LOP	VC-3 or VC-4 HOP or sSTM-2n Multiplex section (TUG-2 based)	VC-2 + frame offset
VC-2-Xc LOP	VC-3 HOP	VC-2-Xc + frame offset, X = 2 … 7
VC-2-Xv LOP	VC-4 HOP	VC-2-Xv + frame offset, X = 2 … 21
VC-3 LOP	VC-4 HOP	VC-3 + frame offset
VC-3 HOP	STM-0 or STM-N Multiplex section	VC-3 + frame offset
VC-4 HOP	STM-N Multiplex section	VC-4 + frame offset
VC-4-Xc HOP	STM-N Multiplex section	VC-4-Xc + frame offset, X = 4, 16 (>16 tbd)
VC-4-Xv HOP	STM-N Multiplex section	VC-4-Xv + frame offset, X = 2…16 (>16 tbd)
sSTM-1k Multiplex section (TU-12 based)	sSTM-1k Regenerator section (TU-12 based)	sSTM-1k rate, k = 1, 2, 8 or 16 TU-12s
sSTM-2n Multiplex section (TUG-2 based)	sSTM-2n Regenerator section (TUG-2 based)	sSTM-2n rate, n = 1, 2 or 4 TUG-2s
STM-0 Multiplex section	STM-0 Regenerator section	STM-0 rate
STM-N Multiplex section	STM-N Regenerator section	STM-N rate, N = 1, 4, 16, 64
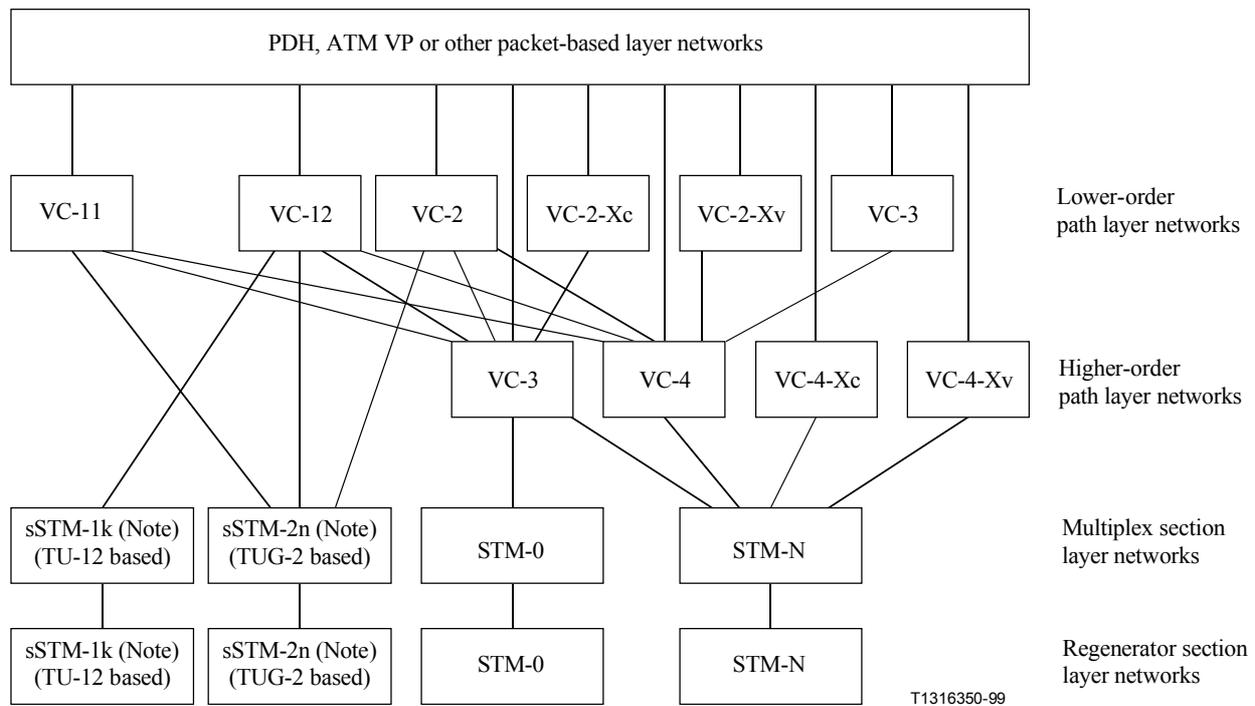
NOTE – Collectively referred to as sub-STM-0 layer networks.

Figure I.1/G.803 – Client server associations and corresponding 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 ITU-T 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 ITU-T Recommendation G.704);

    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 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 ITU-T 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 ITU-T 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 ITU-T 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 ITU-T 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 ITU-T 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 – ITU-T 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-ns.

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.

Interworking
function
required

Subsequent
deployment of
widespread
VC-*n*
connectivity

Interworking
function required
as STM-N
interfaces on
64 kbit/s switches
are deployed

Client
layer

Decide
introduction
scenario

Overlay

TMUX and/or
byte synch
mapping

DXC & ADM
first

TMUX and/or
byte synch
mapping

Deploy
STM-N line
systems

No
interworking
function
required

Decide
interworking
level

STM-N line
system first

TMUX and/or
byte synch
mapping

Deploy
DXC & ADM

Client layer

Cease PDH
paths provide
SDH path and
TMUX and/or
byte synch
mappings

PDH
path
layer

Decide
introduction
scenario

Overlay

G.707
asynch
mappings

DXC & ADM
first

G.707
asynch
mappings

Deploy
STM-N line
systems

Decide
future
interworking
level

STM-N line
system first

G.707
asynch
mappings

Deploy
DXC & ADM

PDH
path layer

Retain
PDH
rates

G.707
asynch
mappings
required

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

APPENDIX III

Guidelines for synchronization network engineering

III.1   Introduction

This appendix presents additional guidance on the subject of network synchronization as it is provided in this ITU-T Recommendation, clause 8, with a focus on the practical engineering aspects. It builds on the principles described in the main body of this ITU-T Recommendation. In particular, the following principles:

–   the use of master-slave synchronization;

–   the synchronization reference chain;

–   the use of STM-N for timing transport in SDH networks; and

–   the rules for intra-node synchronization engineering,

are, for the purpose of this appendix, taken as a given starting point and are not further discussed.

The guidelines outlined in this appendix are applicable to both Option I and Option II networks. However, the examples given in this appendix are only drawn from Option I type networks. To apply them to Option II networks, the 2048 kbit/s and 2048 kHz timing links between SSUs and SECs have to be substituted by 1544 kbit/s "derived DS1" links.

III.2   Purpose of the synchronization network

The synchronization network is the network that is responsible for distributing synchronization information to network elements that need to operate synchronously in order to meet ITU-T Recommendation G.822 octet slip performance requirements. These network elements are in principle all types of network elements that perform routing or multiplexing functionality on the 64 kbit/s or 2048 kbit/s signals, like switches, primary multiplexers, ISDN equipment, PBXs, PDH DXCs, etc.

The "physical layer" for transportation of synchronization information is formed by 2048 kbit/s signals over PDH transport networks and STM-N signals over SDH transport networks and, in addition, some dedicated 2048 kHz or 2048 kbit/s links for intra-office synchronization transport. Finally, clock equipment, stand-alone or built-in, in network elements, are part of the synchronization network. Added to this can be a management system that is used specifically for synchronization purposes or is integrated in a general network management system.

Synchronous operation of the above-mentioned network element types is usually arranged over a certain geographic area, in which all such network elements are synchronized to a "master-clock". Such an area in which all relevant network elements are (in normal operation) synchronized to a master-clock is called a "synchronization area".

The master-clock of a synchronization area should meet the requirements described in ITU-T Recommendation G.811. An end-to-end traffic connection may cross several synchronization areas. The nominal controlled octet slip-rate between adjacent synchronization areas is 1 slip per 70 days or better. ITU-T Recommendation G.822 presents a model and performance objectives involving traffic crossing multiple synchronization areas.

III.3 Requirements for synchronization networks

Impairments in the synchronization network may force clocks to operate (temporarily) without reference. This leads in general to increased octet-slip rates, which degrades the performance of the end-to-end service. Three methods exist to counter these problems:

• using clocks with very good hold-over performance, which allows operation without reference during the repair period of the reference link;

• duplication (or triplication, etc.) of the clock reference inputs, preferably over geographically separated links from independent sources, in order to minimize the probability of losing all references; or

• a combination of the two methods mentioned above.

All three methods are used in the designs of clocks and synchronization networks. In the upper parts of the synchronization network hierarchy the first approach tends to be favoured, while in the lower parts of the synchronization network hierarchy it is the second approach that is prevalent. In general a balance must be struck between initial investment, "cost of ownership" and reliability.

As soon as multiple references are offered to a clock, there needs to be a reference selection mechanism in the clock. Several reference selection mechanisms are possible:

– manually controlled restoration from a central management system;

– automatic restoration from a central management system;

– automatic restoration based on local decisions of the clock equipment using pre-programmed reference priorities; or

– automatic restoration based on local decisions of the clock equipment using the SSM protocol.

Using a combination of clock types and restoration mechanisms, it is the objective of the synchronization network engineer to construct a synchronization network that reliably distributes synchronization using the following principles:

1) The synchronization network in each synchronization area forms a tree shaped topology with the master-clock in the top of the tree. No parts of the synchronization network operate isolated from the master-clock and no internal loops are present.

2) The lengths of the branches of the synchronization tree are kept as short as possible. The longer a certain synchronization trail becomes, the more susceptible it will be to impairments and wander accumulation. The synchronization reference chain presented in clause 8 is a model for a "reasonable worst case" synchronization link.

3) A clock should never lock to a reference which is traceable, at that time, to a clock of lower quality. In such a case this clock should revert to hold-over operation.

In general, it is not possible to fulfil the above objectives under all (combinations of) failure conditions. The following guidelines can be applied:
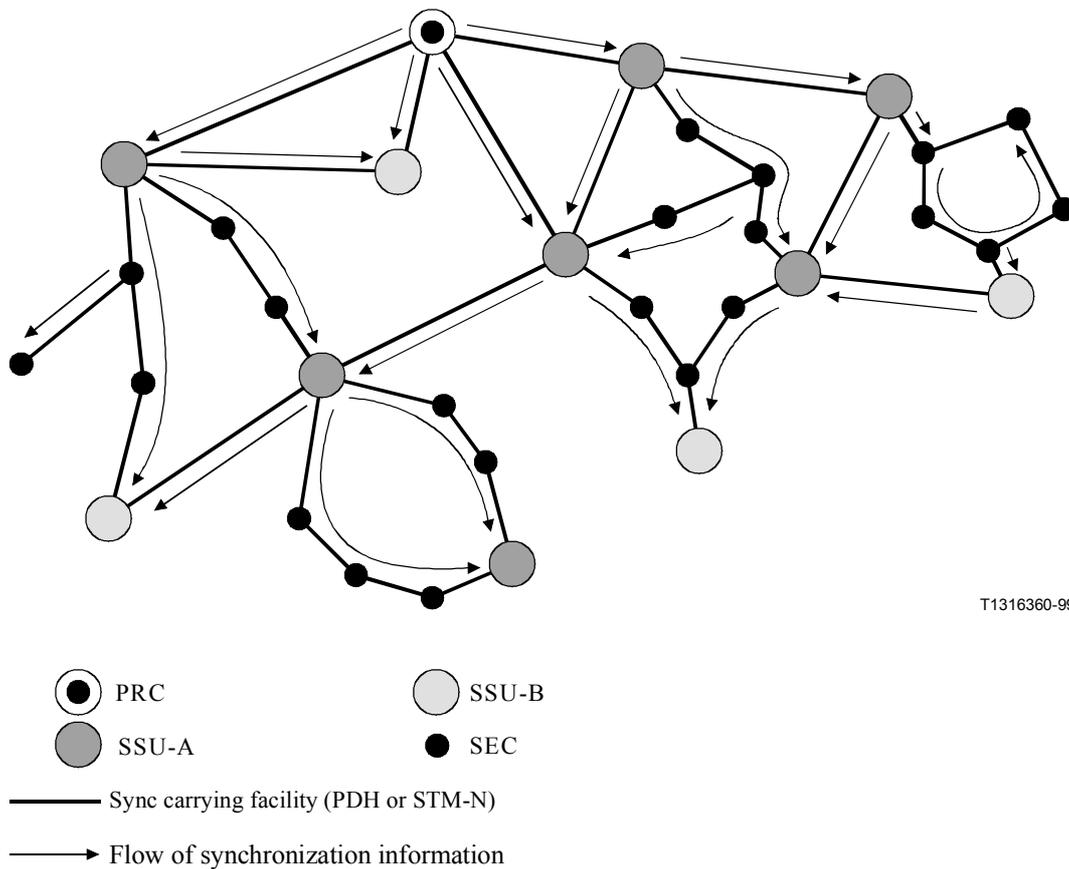
• during all single failures, all clocks in the synchronization area should remain synchronized to the master-clock;

• in most cases of double failures, most clocks should remain synchronized to the master clock; and

• no combination of two simultaneous failures should lead to the formation of timing loops, or the slaving of a clock to a clock of worse traceability, or an oscillating or unstable behaviour of reference selectors.

III.4   Analysis of synchronization networks

To simplify the process of engineering the synchronization network in a certain synchronization area, it is suggested to define several stages, which can be handled in order, one at a time:

1)   Engineer the synchronization network considering only PRCs and SSUs (the "SSU-Level") in a synchronization area.

2)   Engineer the synchronization network considering only SECs (the "SEC-Level") in a synchronization area.

3)   Engineer the intra-office synchronization of each office. This stage is not further discussed in this appendix. See clause 8 for more information.
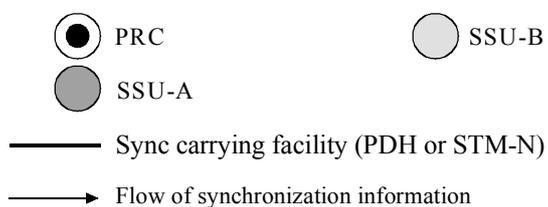
In the first stage the "SSU-Level" is considered. The SSU-Level of the synchronization network consists of the PRCs and SSUs in a synchronization area plus all transport facilities that are active or stand-by carriers for synchronization information between these clocks. The transport facilities between the PRCs and SSUs are considered transparent for the timing information in the SSU-Level view. The resulting network contains only the SSUs and PRCs of the synchronization area. Figures III.1a and III.1b present an example where the SSU-Level is constructed from the complete synchronization network.

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| ● PRC | ◯ SSU-B |
| ⬤ SSU-A | ● SEC |

——— Sync carrying facility (PDH or STM-N)

——▶ Flow of synchronization information

Figure III.1a/G.803 – Synchronization network map in a synchronization area (example)

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PRC

SSU-B

SSU-A

——— Sync carrying facility (PDH or STM-N)

———▶ Flow of synchronization information
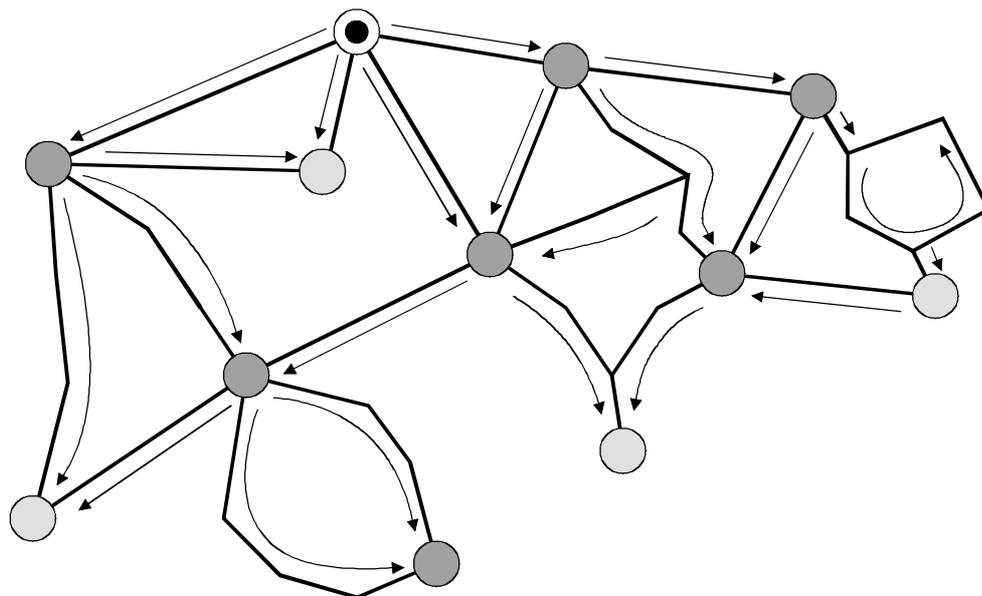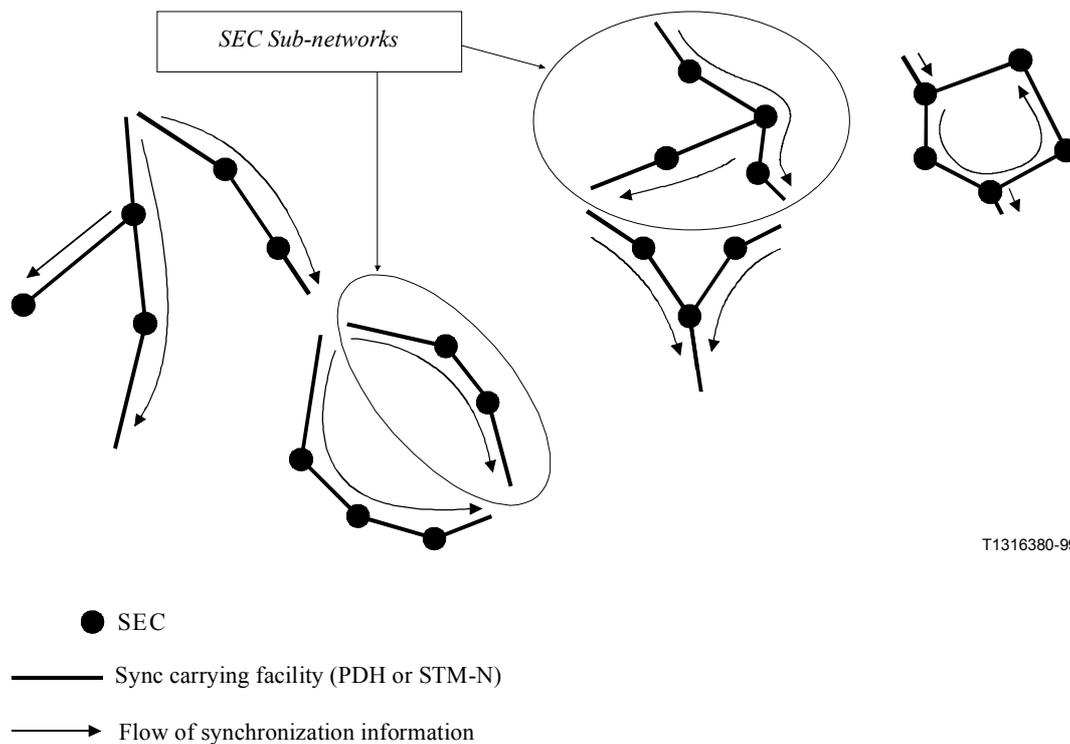
Figure III.1b/G.803 – SSU-Level constructed from Figure III.1a/G.803

In the second stage the "SEC-Level" is considered. The SEC-Level part of the synchronization network can be constructed by considering all SSUs (and PRCs) as "no-pass" filters, i.e. barriers for synchronization information. The result is that the SEC-Level consists of a number of unconnected "SEC subnetworks", each consisting of SECs connected by STM-N connections. These SEC subnetworks can be engineered separately. See Figure III.1c for an example.

● SEC

──── Sync carrying facility (PDH or STM-N)

───► Flow of synchronization information

Figure III.1c/G.803 – SEC-Level with SEC subnetworks constructed from Figure III.1a/G.803

III.5 PRC-Level options

Before embarking on the first stage of the synchronization network engineering, the synchronization islands have to be known. This defines the PRC-Level.

The PRC-Level determines the way in which a certain operator domain is divided in synchronization areas. In each synchronization area at most one PRC is active at any moment (but additional stand-by PRCs can be part of a synchronization area). Two strategies can be followed to determine the size of each synchronization area. Strategy I is to make one big synchronization area and strategy II is to make each office a separate synchronization area. In fact, these two strategies can be considered as "extremes" on a continuous scale. Actual sizes of synchronization areas can be anywhere in between these "extreme" positions.

Strategy I (one big synchronization area covering the whole operator domain) has the advantage that the number of synchronization areas that an end-to-end traffic connection has to cross is minimized and hence the impact on controlled octet slip-rate performance (as defined in ITU-T Recommendation G.822) under normal conditions is minimized. However, the synchronization network is more complex, so harder to engineer, and the synchronization trails become longer, hence more susceptible to impairments and wander accumulation (which may eventually have a negative effect on the octet-slip rate).

Strategy II (each telecommunication office forms a synchronization area) makes the engineering of each synchronization area almost trivial. The synchronization network will be very reliable, since the length of the synchronization trail is reduced to some (dedicated) intra-office cabling.

Generally, for an actual synchronization network a strategy somewhere between I and II is selected, i.e. some (major) nodes have a PRC supplying the synchronization for a certain sub-domain of the total operator domain. Networks closer to a strategy II implementation have shorter, thus more reliable, synchronization trails and also have smaller, hence easier to engineer, synchronization areas. Networks closer to a strategy I implementation have fewer synchronization areas, hence fewer plesiochronous area boundary crossings in end-to-end connections and fewer installed PRC clocks.

III.6 SSU-Level solutions

The synchronization network that is obtained by considering all SSUs, PRCs and all potential synchronization transport facilities (viewed as transparent connections) is called the SSU-Level. The SSU clocks in this network can be classified according to their ability to maintain their output phase/frequency, in case all input references are disqualified, within the network limits that can be derived from ITU-T Recommendation G.825 for STM-N synchronization connections[6]. The time period over which these limits can be maintained is called the "PRC Autonomy Period" of a clock. In general, the higher the stability of the internal oscillators, the longer the PRC Autonomy Period. See Figure III.2.
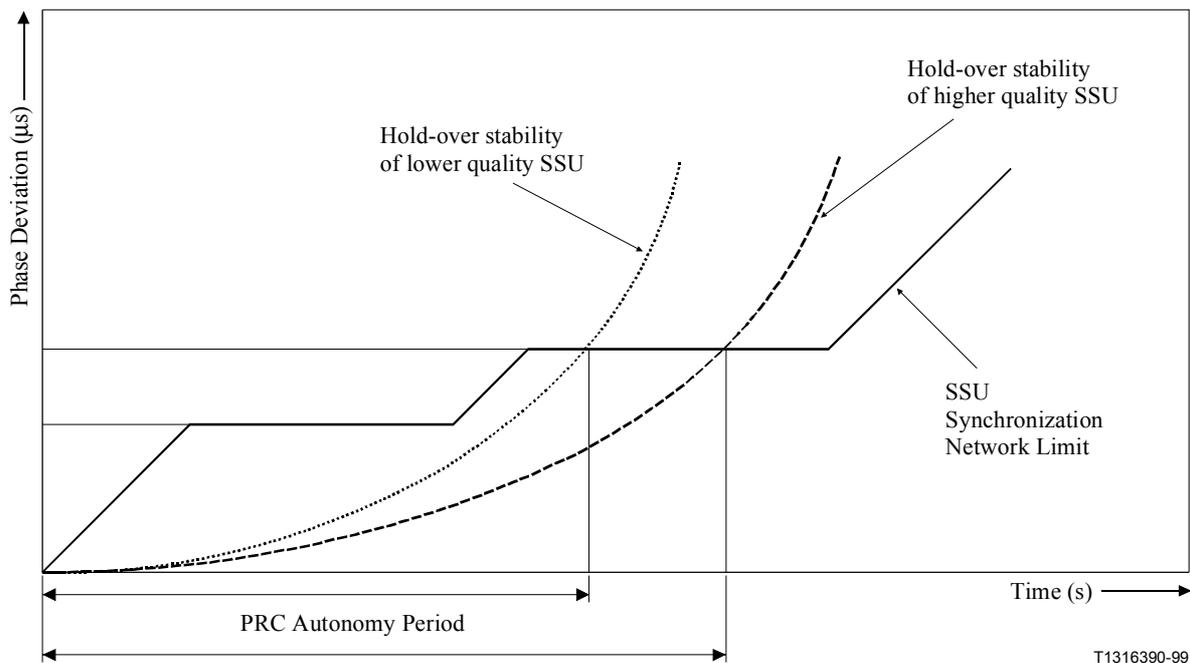
Figure III.2/G.803 – Determining the PRC Autonomy Period of an SSU

The notion of "PRC Autonomy Period" sets a quality parameter for a clock. Knowing the PRC Autonomy Period of a clock, one can determine the following:

- Are multiple references necessary? If the PRC Autonomy Period is longer than the time it takes to repair a failure in the only reference, operation with a single reference is sufficient.

- How much time is available for a reference switch? If the PRC Autonomy Period is very long, one can make reference switches manually after judging the impairments and consequences. On the other hand shorter PRC Autonomy Periods require some kind of automatic reference switch process, which can be from a central manager (generally a slower process) or made locally by the clock itself (generally a faster process).

- What staffing levels are required to maintain the synchronization network? Do they need to be, for example, on a 24-hour/7-day week stand-by or is an 8-hour/5-day week sufficient?

The PRC Autonomy Period can be used to classify all SSUs in a synchronization area. The purpose of such a classification is to be able to provide a hierarchy, based on the above defined "PRC Autonomy Period", among the SSUs in the synchronization network. A division of SSUs according

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[6] Strictly speaking, ITU-T Recommendation G.825 only specifies the Jitter and Wander Network Limits for SDH networks. In practice, these same limits are often applied for other transport networks like GSM, ATM, etc. as currently no alternative ITU-T Recommendations exist for such networks.

to their PRC Autonomy Period, the number of Classes and their boundaries, will in general turn out to be different for different operators, depending on the size of the synchronization areas, the number of SSUs per area and their quality. In most cases two Classes will suffice, but more (or fewer) Classes are possible.

In general one should avoid an SSU of a "lower Class of PRC Autonomy" providing the active reference for an SSU of a "higher Class of PRC Autonomy". This means that in the tree diagram of the SSU network, the PRCs are at the top and that in a downward direction the SSUs are ordered according to their PRC Autonomy classification; the best ones close to the top, the lowest at the bottom of the tree.

The restoration mechanism for most SSUs will in general be automatic, based on local decisions by the SSUs themselves. All SSUs support a reference selection mechanism locally controlled by pre-programmed priorities (in addition they may also support other selection mechanisms). The method outlined here to design the SSU-Level synchronization network is based on the presence of this selection mechanism in all SSUs. Other methods, e.g. based on centralized management can also be applied, but are not considered here.

III.6.1   Checking reference provisionings at the SSU-Level

SSUs below a certain PRC Autonomy Class need to have at least two independent references. It is important to verify that no timing loops are formed or can be formed, especially during or after reference rearrangements in the SSU-Level. A labelling scheme can be applied in the engineering stage as a simple tool to check whether a proposed scheme of service and stand-by reference provisionings (i.e. 1st, 2nd, etc. reference priorities) for the SSU-Level is consistent in this respect. This labelling scheme is described below. Several alternative methods exist to perform this type of checking.

The idea is to assign to each SSU a label of the format N(m), where the N represents the PRC Autonomy Class to which the SSU belongs and m is a sub-number within that Class. A *lower* value of N or m represents an SSU that is *higher* in the hierarchy. The PRC gets the value N = 1 assigned. The SSUs are labelled according to the following rules:

- Rule A: Any SSU that belongs to Class N and which gets all its references (i.e. including the stand-by references) from clocks of Class N-1 or better, gets the label N(1) assigned.

- Rule B: If an SSU of Class N gets some reference(s) from other clocks of the same Class N that have labels N(k1), N(k2), etc., then it gets the label N(m) assigned, where m = 1 + MAX{k1, k2, … }.

- Rule C: An SSU of Class N should never be allowed to use a reference of an SSU of Class N + 1 or worse.

If it is possible to label all SSUs in a certain synchronization area according to the above rules, no timing loops can be formed in the SSU-Level during, or after, synchronization reference switching with the proposed scheme of service and stand-by reference assignments. In order to apply N(m) labelling successfully and to provide each SSU with at least two independent references, a sufficient number of interconnections between the SSUs in the SSU-Level needs to be present (in other words the SSU-Level network needs to be sufficiently meshed).

Each time new SSUs are added to the SSU-Level or new interconnections are assigned to act as reference (service or stand-by), the complete SSU-Level has to be checked again for potential timing loops.

Figures III.3a and III.3b give examples of a network where N(m) labelling can be applied successfully and one where it is not possible.
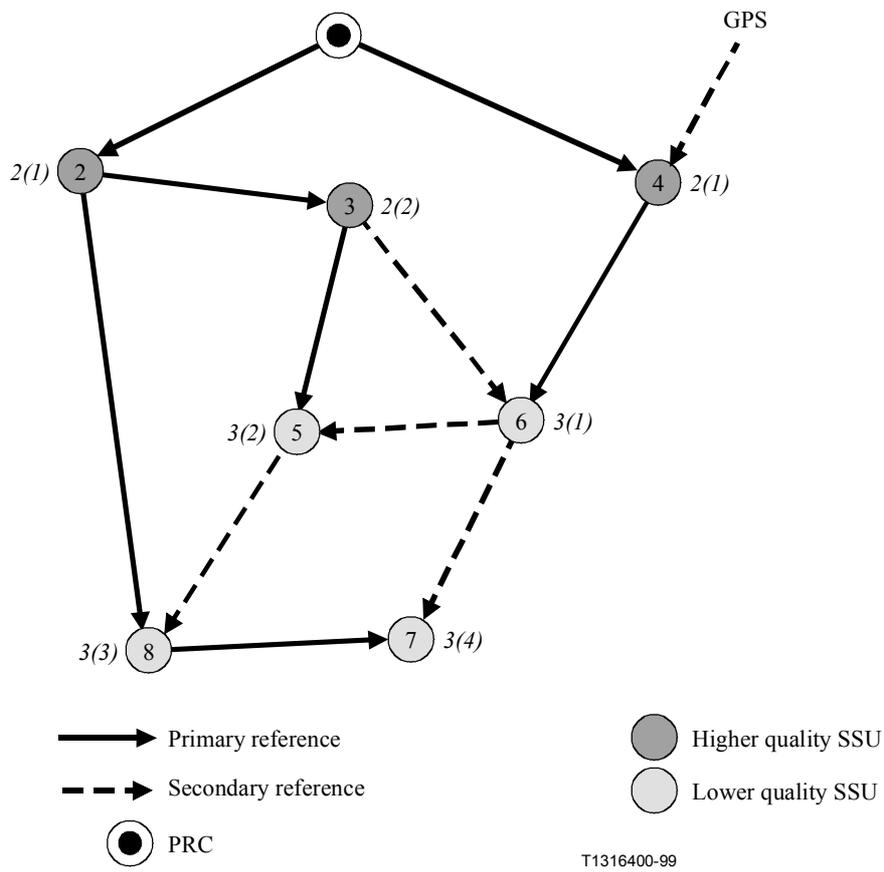
Figure III.3a/G.803 – Successful N(m) labelling of SSUs: No potential timing loops
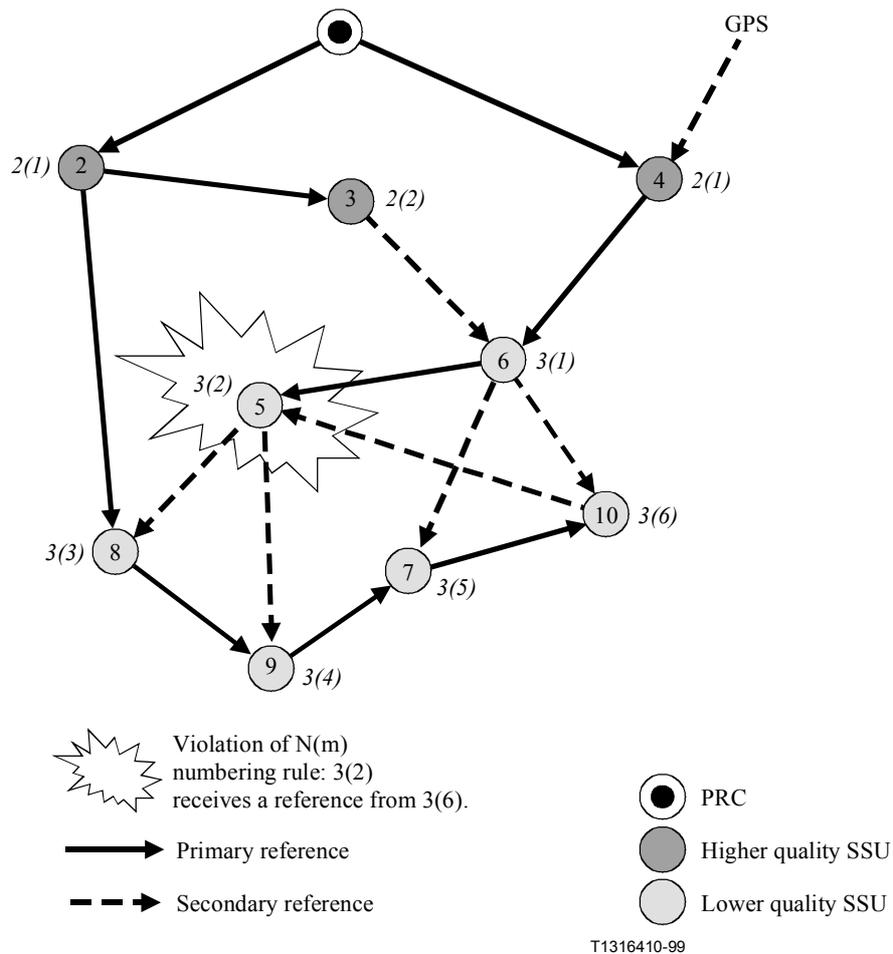
Figure III.3b/G.803 – N(m) labelling is not possible: Potential timing loop(s)

The scheme described above assumes that reference assignments and priorities are static. If the information regarding all active and stand-by synchronization trails and their status is known at some central location, priorities and assignments can in principle be dynamically re-provisioned, to counter failure situations. Each re-provisioning should be checked for potential timing loops. This whole process could be performed manually or automatically.

III.6.2 Absolute frequency offset guarding

Although timing loops should always be avoided by applying sound engineering of the synchronization network, the insertion of SSUs with an absolute frequency offset detection at strategic places in the network can provide an additional safeguard. Whenever a timing loop is formed, the clocks in the loop, as a group, will start drifting in frequency in an uncontrolled manner. This may increase the slip-rate on traffic between equipment timed by clocks in the loop and equipment outside the loop to unacceptable levels. Eventually, large frequency deviations may cause the network to stop processing traffic altogether.

However, if one of the clocks in the loop is capable of detecting absolute frequency deviations (sustained over some period of time) at an early stage, it can disqualify its current reference and thereby break the loop. The better this frequency offset detection is, the lower the maximum slip-rate will be that can affect traffic from/to/via equipment in the loop. For example, an absolute frequency guard at 1×10^{-8} will limit the slip rate to 6.9 slips/day, i.e. almost within the limits for acceptable performance (5 slips/day) according to ITU-T Recommendation G.822.

The more clocks in the network that support this frequency guarding, the higher the probability that one of those clocks is actually part of a timing loop if it is accidentally created. Moreover, the size of the affected area will generally be smaller in cases where timing loops are formed without a clock with frequency guarding being part of it.

The frequency guard method is not able to anticipate generation of timing loops but is only able to measure their effects when they already may have a significant effect on the network performance.

Note that the presence of absolute frequency offset guard functionality is not specified in ITU-T Recommendation G.812.

III.7 SEC-Level solutions

The SEC-Level consists of many separated islands of SDH equipment with SEC clocks built in (see Figure III.1c). Each island is called an "SEC subnetwork". Within the SEC subnetwork automatic restoration is mandatory because the PRC Autonomy Period of an SEC is typically well below 1 minute. Restoration based on local SEC decisions is the fastest method. It is in most cases not practical to apply the N(m) numbering scheme of the SSU-Level also in the SEC-Level. The number of available independent references is usually not large enough to apply N(m) numbering successfully (i.e. the SEC network is in general not sufficiently "meshed"). For example in linear or ring-type networks reference can only be from both neighbours, but only the upstream one can have a "lower" N(m) number and so be a suitable reference. A back-up reference is then not available.

By enhancing the priority selection with traceability information this problem can be overcome. This mechanism is described in the Synchronization Status Message (SSM) protocol, specified in ITU-T Recommendation G.781. This protocol is proposed to be used as reference restoration control mechanism at the SEC-Level.

When the synchronization network for an SEC subnetwork is engineered, the SSUs that directly interface with this subnetwork have to be considered as well. Such an SSU is either:

1) providing synchronization reference signals to the SEC subnetwork; or

2) is taking a reference from the subnetwork; or

3) is filtering a synchronization signal by taking reference from an SDH network element and feeding the filtered signal back to its SEC. SSUs in this role require special attention.

The task of the synchronization engineer is to determine the provisionable parameters of the SSM algorithm in each SEC subnetwork, such that under normal conditions the flow of the timing information between the SSUs is according to the plan engineered for the SSU-Level and that in failure situations the synchronization restores as well as possible without creating timing loops, hierarchy violations (i.e. references with insufficient traceability becoming active), or instabilities. The variables at his disposal are the selection of possible references (assignments/un-assignments), the setting of priorities for the assigned references, using fixed SSM assignments to certain reference inputs and setting the squelch thresholds for synchronization outputs. Assignment and priority setting have in general to be provisioned both for the internal oscillator (denoted as "T0" in ITU-T Recommendation G.783) and for the external clock output (denoted as "T4" in ITU-T Recommendation G.783) of an SDH network element. The interface between stand-alone SSUs and SECs is assumed to be a 2048 kHz interface according to clause 13/G.703 or a non-SSM carrying dedicated 2048 kbit/s link according to clause 9/G.703.

The number of possible different SEC subnetwork topologies is very big, but the size of the SEC subnetworks will be restricted, since in most cases the recommendation to limit the number of SECs between SSUs that are adjacent in the SSU-Level, to at most 20 clocks, will be honoured. Although the number of possible SEC subnetworks is very big, they mostly do not differ much in principle, hence it is possible to come up with a limited number of example SEC subnetworks, work out the SSM parameters for those, and adapt those examples for application to real SEC subnetworks.

III.7.1 Application of the SSM protocol in the SSU-Level

ITU-T Recommendation G.704 defines the message set and transmission format for the transport of Synchronization Status Messages over the 2048 kbit/s interface between a Network Element (with an SEC) and an SSU.

Such an interface makes it in principle possible to include the SSU-Level in the application of the SSM algorithm. However, this issue is for further study. In today's installed base the interface between the SSU and SDH NE in general does not support the transport of SSMs. Moreover, additional study is required to investigate the engineering and the stability of the SSM algorithm when it encompasses both SECs and SSUs. A result of further study could be that the SSM protocol needs to be amended when it is applied on the SSU-Level as well.

One property of SSM controlled synchronization restoration is that, once the protocol is set up, it runs autonomously. The operator has no direct control. This fact makes it highly desirable that rigorous simulation is performed before an SSM scheme is deployed. The more complex the network, the more important this will be. Obviously, the inclusion of SSUs in synchronization restoration schemes controlled by SSMs may complicate the synchronization network enormously, since in that case it could cover the whole synchronization area, instead of just one SEC subnetwork.

For these reasons, the assumption made in this appendix is that the SSM protocol is only supported on the SEC-Level and that the interface between the SSU and the SEC does not support transmission of SSMs.

III.7.2 Examples of SEC subnetworks with SSM parameters

This subclause gives a number of principally different SEC subnetworks and their SSM parameters. The parameters of other SEC subnetworks can be worked out by adapting the principal schemes presented here. The number of principal schemes may grow over time.

In Figures III.5 through III.9 a certain notation is used to indicate how the parameters of the SSM protocol are provisioned and what the resulting traceability messages are on the outgoing STM-N signals under normal conditions (no failures). The notational conventions are shown in Figure III.4. The network element (grey box) has two parts separated by a dotted line to depict the independent selection processes for the internal SEC (T0) and the external synchronization output (T4). If T4 is slaved to T0 this is indicated by a direct arrow between the two parts (not shown in Figure III.4). The arrows arriving at and leaving from the network element denote the synchronization carrying in- and outputs (either STM-N, 2048 kHz or non-SSM-carrying 2048 kbit/s). The solid arrows denote the active carrier under normal conditions, while stand-by reference inputs are represented by dashed arrows. Unassigned references are shown by dotted arrows. Note that the fact whether a reference is currently active, stand-by or unassigned is determined by the receiving equipment. Some arrows are split to show that they serve as an input to both the T0 reference selection process and the T4 reference selection process. If such a split input fails, it fails for both inputs simultaneously.

The numbers in white circles denote the assigned priorities (no number means that a reference is not assigned to participate in the reference selection process). The labels in the ellipses denote the computed outgoing synchronization status messages (which will be the received message by the downstream network element). The "≥ SSM" in the external synchronization output box indicates the squelch level (all signals with traceability "SSM" or better are passed through). Finally, the "= SSM" in a grey box denotes that the fixed value "SSM" assigned to a reference input. In these cases "SSM" can be "PRC", "SSU-A", "SSU-B" or "SEC".
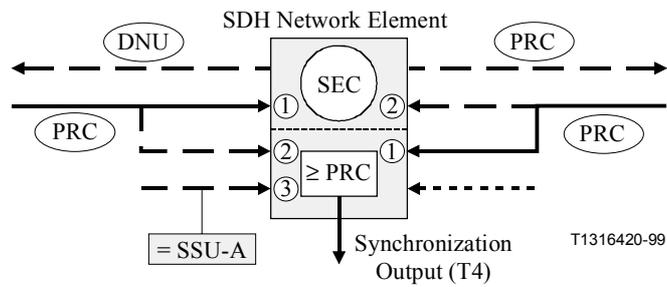
≥ PRC   Assigned squelch threshold for synchronization output

⟶   Assigned reference (active)

·—— ⟶   Assigned reference (stand-by)

······ ⟶   Unassigned reference

②   Assigned priority

= SSU-A   Assigned (fixed) SSM value to input
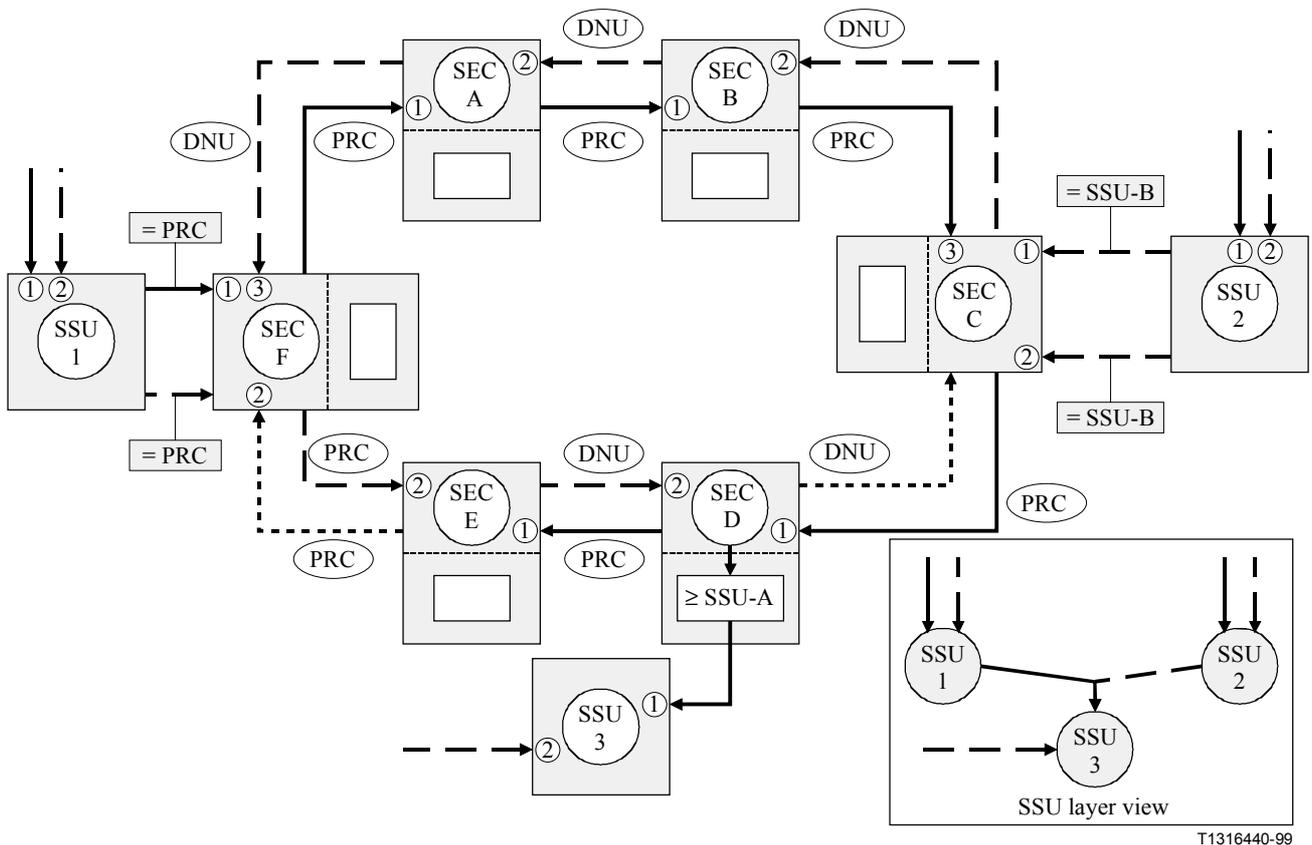
PRC   Computed output message

Figure III.4/G.803 – Conventions used in SEC subnetwork drawings
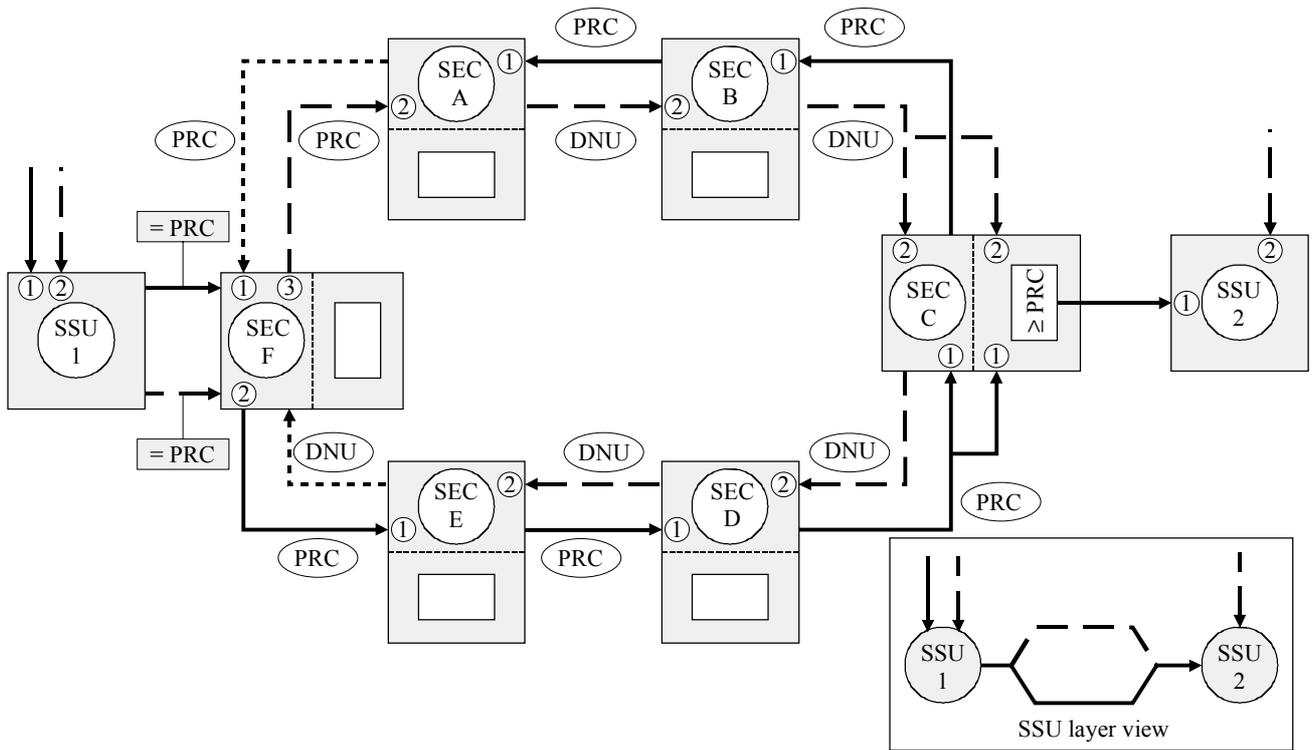
Figure III.5/G.803 – SDH ring network with one source SSU source and one sink SSU
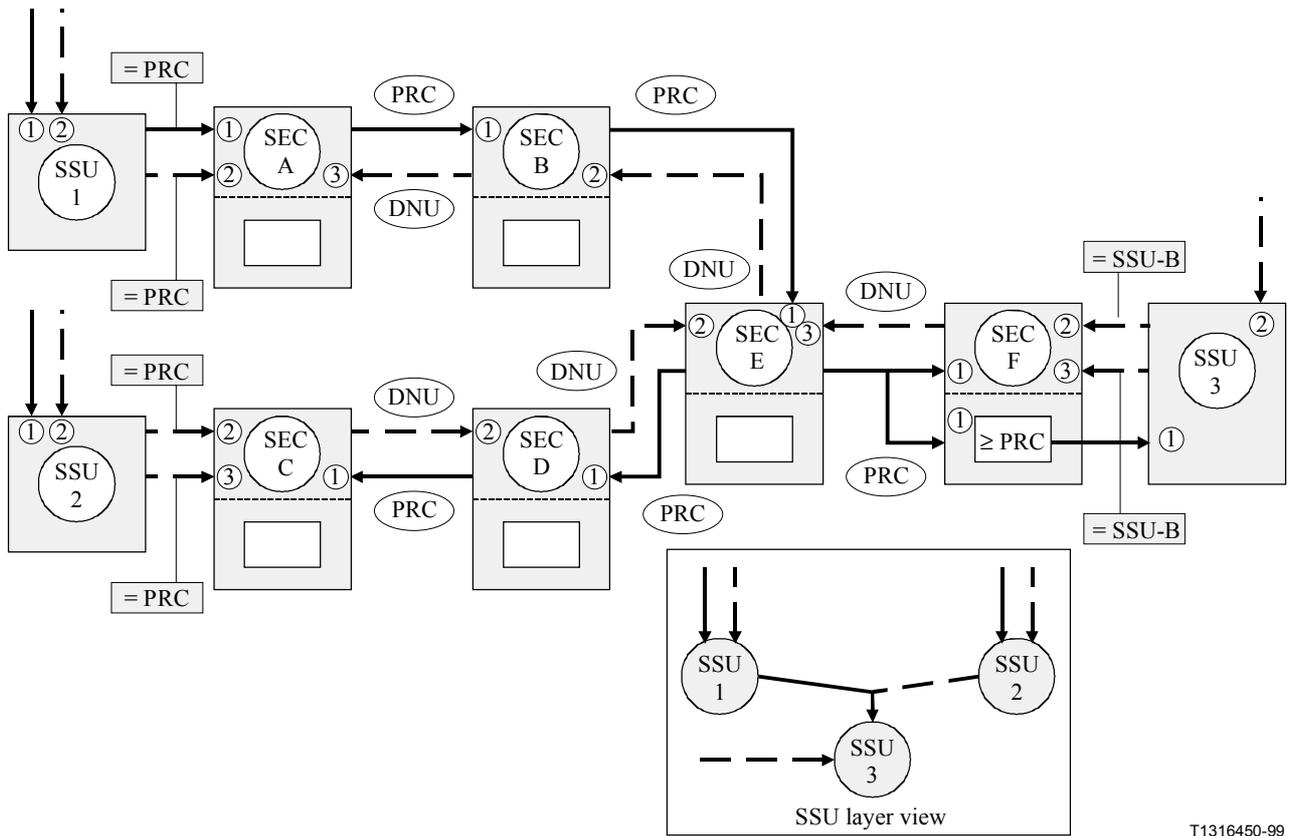
In the SSU-Level the synchronization flow is from SSU-1 to SSU-2. SSU-2 needs another reference from another source, this is outside the scope of this SEC subnetwork, as well as the references of SSU-1.

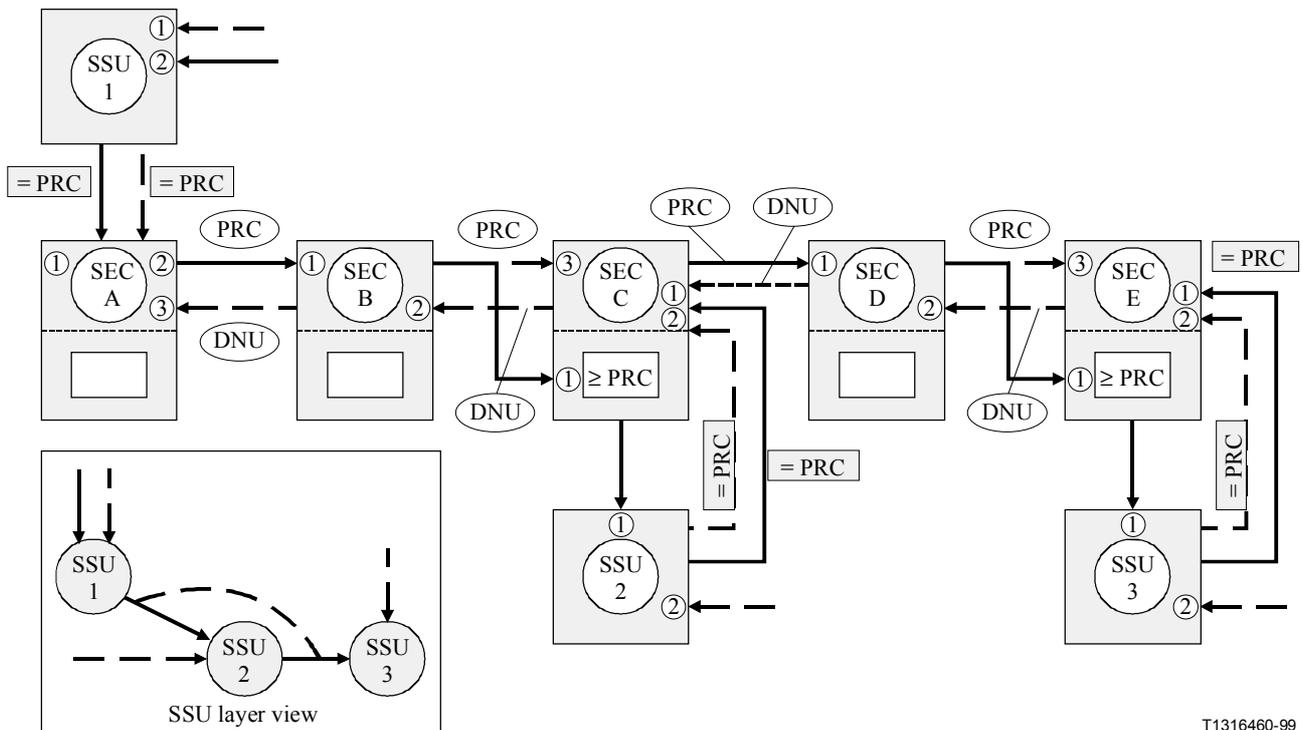**Figure III.6/G.803 – SDH ring network with two source SSUs and one sink SSU**

Normally the synchronization flow in the SSU-Level is between SSU-1 and SSU-3, the path between SSU-2 and SSU-3 is a back-up.
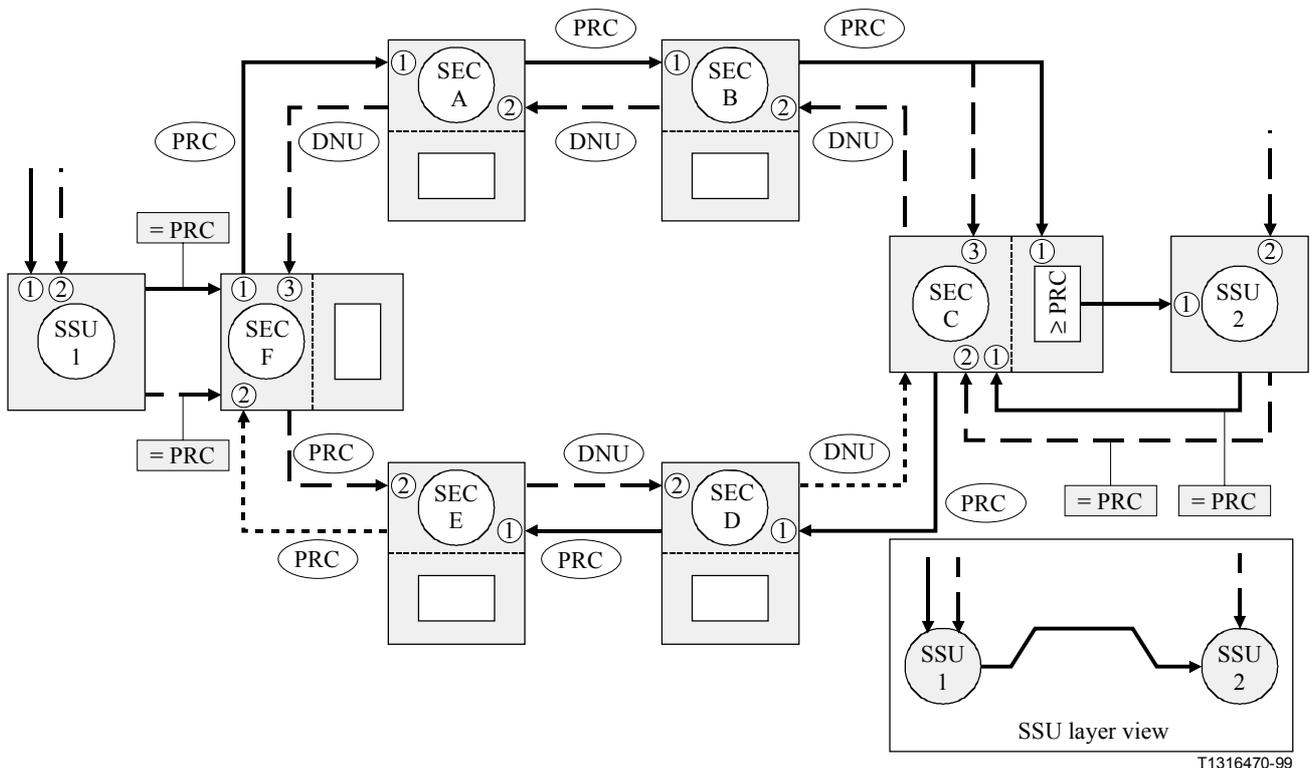
Figure III.7/G.803 – SDH Y-network with two source SSUs and one sink SSU

Normally the synchronization flow in the SSU-Level is between SSU-1 and SSU-3, the path between SSU-2 and SSU-3 is a back-up.

Figure III.8/G.803 – SDH linear network with filtering SSUs

Figure III.9/G.803 – SDH ring network with filtering SSU

III.8 Synthesis of the synchronization network

The methodology of engineering a synchronization network, as outlined in this appendix, consists of several steps:

a)   Divide a synchronization area into an SSU-Level and SEC subnetworks.

b)   Group the SSUs according to their quality, defined as PRC Autonomy Period, in a number of Classes.

c)   Assign primary and secondary, etc. references to each SSU in a manner compliant with the N(m) labelling scheme (or an equivalent alternative).

d)   Define the SSM protocol parameters for each SEC subnetwork using the body of example networks, taking the directly interconnected SSUs into account.

e)   Design the intra-office synchronization for each office. This last stage is not further discussed in this appendix.

The engineering of the synchronization area should be carried out before the equipment is commissioned. The results of the network synchronization engineering process are often described in a synchronization plan. This plan may contain maps of the area and all offices with the normal and fall-back references indicated, the values of all provisioned parameters that affect the synchronization in the area and a log of all synchronization related maintenance activities. The plan may also contain results of measurements and evaluations on the synchronization network. The synchronization plan should be revised each time new equipment is installed in a synchronization area. A synchronization coordinator is usually nominated to maintain the synchronization plan and to coordinate the synchronization related activities in the synchronization areas.

III.9   Definitions used in Appendix III

PRC Autonomy (Period)   The period of time over which a clock, after it disqualified all its reference inputs, can restrict its phase drift within the bounds given by the network limits for synchronization signals.

PRC-Level   The collection of G.811 compliant clocks in an operator domain that are the master-clocks for the different synchronization areas when the synchronization network does not experience failures.

SEC-Level   The collection of G.813 compliant clocks in a synchronization area and their interconnections. SSUs are not part of the SEC-Level.

Note that some networks may have SDH Network Elements containing clocks other than G.813 clocks. Provided that the quality level of these clocks is of lower quality than the SSUs deployed in the network, for the purposes of this appendix they can be considered as SEC clocks.

SEC subnetwork   A collection of SEC clocks in SDH network elements interconnected by STM-N reference carriers. When engineering the synchronization in an SEC subnetwork, the directly connected SSUs need also to be considered.

SSU-Level   The collection of G.812 compliant clocks in a synchronization area and their interconnections. SECs are not part of the SSU-Level, but are considered to be transparent on connections between SSUs. Under failure-free conditions, there is only one interconnected SSU-Level in a synchronization area.

Synchronization area   Geographic area in which all equipment which needs to operate synchronously is synchronized to the one master-clock in that area.

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