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*ETSI Guide*

# Transmission and Multiplexing (TM); Synchronization network engineering

Reference
DEG/TM-01080

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synchronization, SDH, network, performance, transmission

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# Contents

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# Foreword

This ETSI Guide (EG) has been produced by ETSI Technical Committee Transmission and Multiplexing (TM), and is now submitted for the ETSI standards Membership Approval Procedure.

# 1 Scope

## 1.1 Purpose of the present document

Many types of equipment in the telecommunication network need a synchronization reference signal with a certain degree of quality in order to operate satisfactorily. The purpose of the synchronization network is to deliver to each of these equipment such a synchronization signal in a reliable and efficient manner. The present document gives guidance on the manner in which the involved rules, specifications and principles, as laid out in various ETSI and ITU documents, can be applied to practical networks, both new and existing: it provides guidelines in planning, implementing and maintaining the Synchronization Network in an efficient manner.

## 1.2 Relationship with other Documents

Today, there are no standardization documents describing the architecture of the synchronization network other than a number of documents describing the need of certain traffic networks for synchronization. There are also a large number of documents describing the individual network element requirements on synchronization.

As examples: Synchronization Interface Networks limits are described in EN 300 462-3 [3], Synchronization requirements of network clocks are described in EN 300 462-4-1 [4], 5-1 and 6-1. Jitter and Wander requirements of traffic interfaces including those carrying synchronization are described in EN 302 082 [11].

# 2 References

The following documents contain provisions which, through reference in this text, constitute provisions of the present document.

- References are either specific (identified by date of publication, edition number, version number, etc.) or non-specific.
- For a specific reference, subsequent revisions do not apply.
- For a non-specific reference, the latest version applies.
- A non-specific reference to an ETS shall also be taken to refer to later versions published as an EN with the same number.

[1] ETSI EN 300 462-1-1: "Transmission and Multiplexing (TM); Generic requirements for synchronization networks; Part 1-1: Definitions and terminology for synchronization networks".

[2] ETSI EN 300 462-2-1: "Transmission and Multiplexing (TM); Generic requirements for synchronization networks; Part 2-1: Synchronization network architecture".

[3] ETSI EN 300 462-3-1: "Transmission and Multiplexing (TM); Generic requirements for synchronization networks; Part 3-1: The control of jitter and wander within synchronization networks".

[4] ETSI EN 300 462-4-1: "Transmission and Multiplexing (TM); Generic requirements for synchronization networks; Part 4-1: Timing characteristics of slave clocks suitable for synchronization supply to Synchronous Digital Hierarchy (SDH) and Plesiochronous Digital Hierarchy (PDH) equipment".

[5] ETSI EN 300 462-5-1: "Transmission and Multiplexing (TM); Generic requirements for synchronization networks; Part 5-1: Timing characteristics of slave clocks suitable for operation in Synchronous Digital Hierarchy (SDH) equipment".

[6] ETSI EN 300 462-6-1: "Transmission and Multiplexing (TM); Generic requirements for synchronization networks; Part 6-1: Timing characteristics of primary reference clocks".

[7] ETSI EN 300 462-7-1: "Transmission and Multiplexing (TM); Generic requirements for synchronization networks; Part 7-1: Timing characteristics of slave clocks suitable for synchronization supply to equipment in local node applications".

[8] ETSI EN 300 166: "Transmission and Multiplexing (TM); Physical and electrical characteristics of hierarchical digital interfaces for equipment using the 2 048 kbit/s-based Plesiochronous or Synchronous Digital Hierarchies".

[9] ETSI EN 300 417-4: "Transmission and Multiplexing (TM); Generic requirements of transport functionality of equipment; Synchronous Digital Hierarchy (SDH) path layer functions".

[10] ETSI EN 300 417-6: "Transmission and Multiplexing (TM); Generic requirements of transport functionality of equipment; Synchronization layer functions".

[11] ETSI EN 302 082: "Transmission and Multiplexing (TM); The control of Jitter and Wander in Transport Networks".

[12] ETSI EN 300 912: "Digital cellular telecommunications system (Phase 2+); Radio subsystem synchronization (GSM 05.10 version 7.1.1 Release 1998)".

[13] ITU-T Recommendation G.703: "Physical/electrical characteristics of hierarchical digital interfaces".

[14] ITU-T Recommendation G.704: "Synchronous frame structures used at 1.544, 6312, 2 048, 8488 and 44736 kbit/s Hierarchical Levels".

[15] ITU-T Recommendation G.706: "Frame alignment and cyclic redundancy check (CRC) procedures relating to basic frame structures defined in Recommendation G.704".

[16] ITU-T Recommendation G.707: "Network node Interface for the Synchronous digital hierarchy (SDH)".

[17] ITU-T Recommendation G.742: "Second order digital multiplex equipment operating at 8448 kbit /s and using positive justification".

[18] ITU-T Recommendation G.751: "Digital multiplex equipment operating at the third order bit rate of 34268 kbit /s and at the fourth order bit rate of 139264 kbit/s and using positive justification".

[19] ITU-T Recommendation G.803: "Architecture of transport networks based on the synchronous digital hierarchy (SDH)".

[20] ITU-T Recommendation G.822: "Controlled slip rate objectives on an international digital connection".

[21] ITU-T Recommendation M.2130: "Operational procedures in locating and clearing transmission faults".

[22] ETSI TR 101 685: "Transmission and Multiplexing (TM); Timing and synchronization aspects of Asynchronous Transfer Mode (ATM) networks".

[23] ITU-T Recommendation G.812: "Timing requirements of slave clocks suitable for use as node clocks in synchronization networks".

[24] ITU-T Recommendation G.958: "Digital line systems based on the synchronous digital hierarchy for use on optical fibre cables".

[25] ITU-T Recommendation G.813: "Timing characteristics of SDH equipment slave clocks (SEC)".

[26] EN 302 084: "Transmission and Multiplexing (TM); The control of jitter and wander in transport networks".

# 3 Definitions and abbreviations

## 3.1 Definitions

**Synchronization Status Message (SSM):** It is defined in EN 300 417-6-1 [10]. This is a signal that is passed over a synchronization interface to indicate the Quality-Level of the clock sourcing the synchronization signal. This signal was originally defined for use over STM-N interfaces in the S1 byte. It has since been proposed for use over 2 Mbit/s interfaces as well.

The SSM code transmitted reflects the quality of the clock that the interface is ultimately traceable to; i.e. the grade-of-clock to which it is synchronized directly or indirectly via a chain of network element clock's (the synchronization trail), or how long this chain of clocks is. For example, the clock-source quality-level may be a Primary Reference Clock (PRC) complying with EN 300 462-6 [6], or it may be a Slave Clock in holdover-mode, complying with EN 300 462-4 [4], or an EN 300 462-5 [5] Clock in holdover or free-run.

The clock-source quality-level is essentially, therefore, an indication only of the long-term accuracy of the network element clock.

In a fully synchronized network all sources should be ultimately traceable to a PRC and this should be indicated using a ‘0010’ code. The "Do Not Use for Synchronization" code is used to prevent timing loops and is transmitted in the opposite direction on interfaces used to synchronize an equipment’s clock. The "Quality Unknown" code was originally proposed for connection to equipment that did not use SSM codes. ETSI has proposed that this coding is not used as it cannot be sensibly used in a quality based selection algorithm.

**Synchronization Supply Unit (SSU):** This unit is a high quality slave clock deployed in the synchronization network. The SSU gives two key benefits: it filters out short term phase noise (jitter) and short term wander and provides a highly accurate clock if there is a failure of synchronization supply from the PRC. There are a number of different SSU implementations, these are usually differentiated on their Frequency Accuracy in holdover mode. They vary from more expensive Rubidium based oscillators to cheaper Quartz oscillators. There are also a number of Higher Quality Quartz Oscillators which use improved techniques to reduce the temperature and ageing effects of Quartz.

**Stand Alone Synchronization Equipment (SASE):** This is a piece of synchronization equipment that contains an SSU. This term is used to differentiate from the SSU clock function itself which can be located within another piece of equipment for instance an SDH DXC or 64 kbit/s switch.

**Timing Loops:** Timing loops are created when a clock is directly or indirectly synchronized to itself.

Timing loops must be prevented because all clocks in a timing loop are isolated from a Primary Reference Clock and are subject to unpredictable frequency instabilities. There is no simple way of detecting Timing loops as no alarms are generated on their creation. They can go undiscovered until service is effected by poor slip or error performance leading to an investigation which will eventually locate the timing loop.

**Primary Reference Clock (PRC):** These are the highest quality Clocks in a network and are usually based on a free-running Caesium Beam oscillator giving a very accurate clock performance.

**Global Positioning System (GPS):** System using a number of Satellites orbiting the earth, these satellites are primarily intended to give positioning information for navigation but can also be used to derive a highly accurate timing source of PRC Quality. To use GPS an antenna and a post processing unit are required.

## 3.2 Abbreviations

For the purposes of the present document, the following abbreviations apply:

| | |
|---|---|
| ADM | Add Drop Multiplexer |
| AIS | Alarm Indication Signal |
| ATM | Asynchronous Transfer Module |
| Cs-PRC | PRC realized with a Caesium beam |
| DNU | Do Not Use (for synchronization) code |
| EC | Equipment Clock |
| GPS | Global Positioning System |

| | |
|---|---|
| GPS-PRC | PRC realized with use of GPS |
| IP | Internet Protocol |
| LE | Line East |
| LOF | Loss Of Frame |
| LOS | Loss of Signal |
| LW | Line West |
| MTIE | Maximum Time Interval Error |
| NE | Network Element |
| PDH | Plesiochronous Digital Hierarchy |
| QL | Quality Level |
| PRC | Primary Reference Clock |
| SASE | Standalone Synchronization Equipment |
| SDH | Synchronous Digital Hierarchy |
| SETS | Synchronous Equipment Timing Source |
| STM-N | Synchronous Transport Module level N |
| SDL | Symbolic Diagram Language |
| SEC | SDH Equipment Clock |
| SSM | Synchronization Status Message |
| SSU | Synchronization Supply Unit |
| T0 | signal for internal NE synchronization distribution |
| T1 | timing signal derived from an STM-N signal |
| T2 | timing signal derived from a 2 Mbit/s data signal |
| T3 | timing signal derived from a 2 MHz (2 Mbit/s) station clock input signal |
| T4 | timing towards a 2 MHz (2 Mbit/s) station clock output signal |
| TG | Timing Generator |
| UNI | User Network interface |

# 4 The importance of and need for Synchronization

The synchronization network is a network that shall be able to provide all types of telecommunication traffic networks with reference timing signals of required quality. The objective for the traffic networks, for example switching, transport, signaling, mobile, is to not lose information. Loss of information is often caused by poor synchronization. This can be avoided by properly connecting the traffic network to an adequate synchronization network (how to connect to a synchronization network is normally called network synchronization).

In the best case, poor synchronization causes only limited inconvenience to the traffic network. In the worst case, it can make the entire telecommunication network stop passing traffic.

Poor synchronization causes loss of information in varying degrees. Examples of results of poor synchronization are:

- degraded traffic throughput;
- inhibition of set-up of calls (#7 signaling) due to re-transmission;
- re-sending of files;
- corrupt fax messages;
- degraded speech quality;
- freeze-frames on video;
- disconnection of calls during hand-over in mobile networks;
- partial or complete traffic stoppage.

The results for network operators providing poor synchronization to their networks are: reduced short and long term income, decreased customer satisfaction, low network availability and low traffic throughput.

# 5 The need for Synchronization in specific Traffic Networks

## 5.1 General

Synchronization is required in order to meet network performance and availability requirements. Poor network synchronization will lead to large amounts of Jitter and Wander. This Jitter and Wander can lead to transmission errors and buffer under/overflow. Both these faults will result in service problems causing high error rates and can lead to service unavailability.

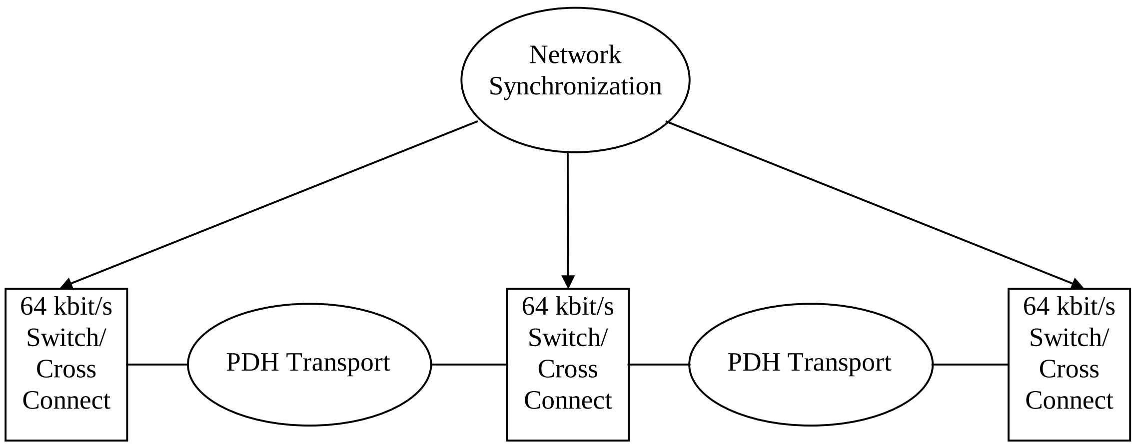
Network Synchronization needs must be carefully considered when networks are deployed.

## 5.2 PDH Network Needs

In networks using PDH transport it is typically only necessary to synchronize primary rate multiplexers, 64 kbit/s switches and cross connects. The PDH transport network works plesiochronous and does not require synchronization, the situation is illustrated in Figure 1.

The plesiochronous multiplexing aligns PDH tributaries into aggregate signals using a bit stuffing mechanism as specified in ITU Recommendations G.742 [17] and G.751 [18].

In PDH networks, 2 Mbits signals are often used to transport timing between network elements requiring synchronization. The plesiochronous multiplexing normally allows for that without significant degradation of the performance.




NOTE: This figure gives a logical representation in which timings are represented by arrows.

**Figure 1: PDH Network Synchronization**

Higher order multiplexers do not require synchronization since they align PDH tributaries into the aggregates signal using the bit stuffing mechanism (refer to ITU-T Recommendation G.751 [18]).

## 5.3 SDH Network Needs

SDH equipment requires synchronization as shown in Figure 2.

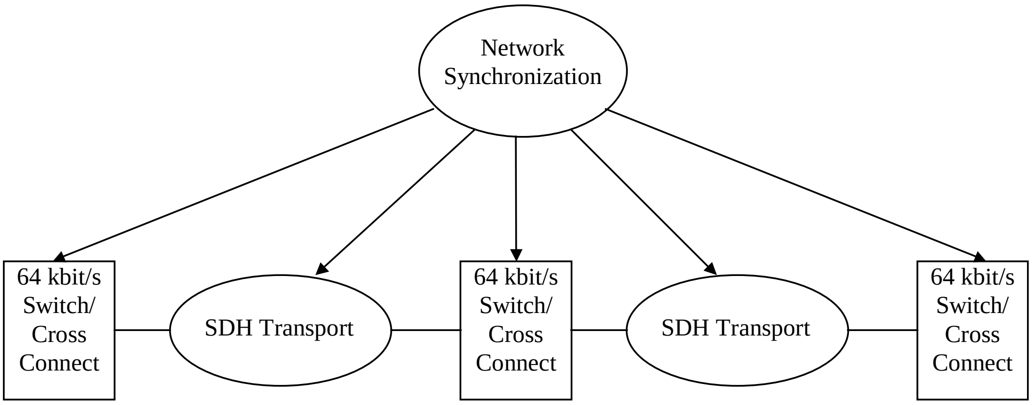



**Figure 2: Network Synchronization with SDH**

If SDH Equipment is not synchronized then jitter and wander will be generated. SDH has a pointer mechanism which allows for any expected phase differences in a network to be accommodated. However the pointer mechanism will generate both jitter and wander for example on the signal present at the PDH output interface (desynchronizer) due to low rate bytewise stuffing. Most of the jitter is filtered out but it is not possible to filter out the wander that is generated.

In a properly synchronized network these pointer movements are minimal and there should be no problems caused by jitter and wander.

In addition to the requirement to synchronize the SDH equipment, the deployment of SDH also increases the complexity of transporting synchronization between sites as it will not transparently transport synchronization in its payload (e.g.: 2 Mbit/s. If there is a problem with the SDH synchronization network then pointers will be generated and this may cause degraded wander performance on the 2 Mbit/s data of the PDH output port of the SDH network, feeding into Switch 2. This is why it is not recommended to transport 2 Mbit/s signals over SDH for synchronization purpose, as illustrated in Figure 3.

Clause 10 provides information on the retiming technique that can be used to prevent generation of wander on 2 Mbit/s signals when they are extracted from SDH VC12, It shall be noted that this technique causes the loss of transparency of the 2 Mbit/s timing.

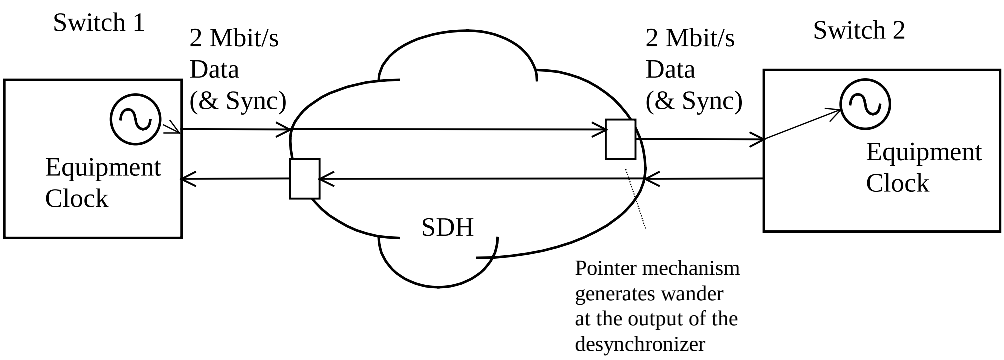



**Figure 3: Synchronization Technique that should not be used with SDH**

The best way to provide synchronization through an SDH network is described in Figure 4. In this method the SDH network is synchronized to the clock and this is distributed via the SDH network to the two switches, using the STM-N signal between nodes. This is detailed in clause 7.

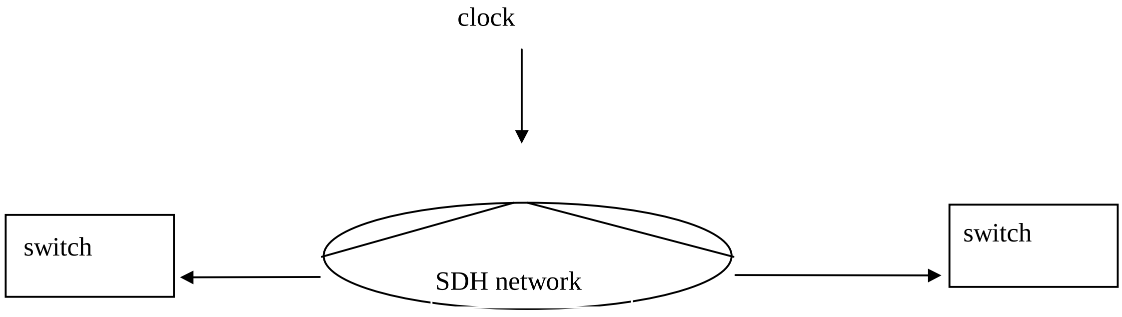



**Figure 4: Recommended synchronization technique**

## 5.4 Switching needs

### 5.4.1 Analogue Switches

Analogue switches do not require synchronization.

### 5.4.2 Digital 64 kbit/s Switches

The introduction of digital 64 kbit/s switches and cross connects drove the need for network synchronization.

This equipment can only switch/cross-connect in a synchronous manner. To accommodate wander, buffers were required on the input to these switches. When the early synchronization standards were being defined an 18 µs buffer hysteresis was assumed because this was implemented on a commonly used switch. Today slip buffers tend to be much larger.

### 5.4.3 Packet/ATM Switches

Packet/ATM switches generally do not require synchronization for switching. However Packet/ATM network elements do require synchronization if they are terminating certain services. Examples of such services are a circuit emulated 2 Mbit/s service over ATM and an IP Router providing a Voice over IP service that is connected digitally to the PSTN. The needs for synchronization of ATM equipment is described in TR 101 685 [22].

## 5.5 GSM needs

In the GSM radio sub-system a requirement of 0.05 ppm for the frequency accuracy is required in the radio interface (see EN 300 912 [12]). In order to fulfil the frequency accuracy requirements, a number of solutions are possible.

The first solution to achieve the requirements for the GSM radio interface is to use autonomous clocks, for example rubidium or GPS disciplined clocks directly connected to the BS. These clocks are either of PRC quality or of a quality better than any of the ITU-T Recommendation G.812 [23] types. An alternative is to use lower quality clock using periodic recalibration.

The other and more common solution is to distribute accurate frequency from a PRC clock through a synchronization chain. In the synchronization chain the quality of the clocks has to be chosen in order to distribute the needed quality in a reliable way towards the clock of the base station, that eventually generates the radio signal with a frequency accuracy better than 0,05 ppm. Proper filtering of base station may be needed to provide correct short-term stability.

In designing an appropriate synchronization network, several aspects have to be considered. In particular the clocks in the chain shall be able to handle failure in the synchronization network. An appropriate holdover has to be provided.

Both the EN 300 462-4-1 [4] and EN 300 462-7-1 [7] provide a proper holdover quality. Where the SSU should be deployed (e.g. MSC or BSC site) is a task of the synchronization network planner.

In designing the synchronization network, proper duplication of the synchronization references and a proper supervision and maintenance strategy have to be provided in order to maintain the required frequency accuracy at the radio interface.

# 6 Elements of a Synchronization Network

## 6.1 Introduction

As pointed out earlier, the switches in digital communication networks in which time division multiplexing is applied, need a common timing reference. The requirements on the accuracy and stability of the reference result from the connection quality objectives (measured in terms of the slip rate) of a digital connection, specified in ITU-T Recommendation G.822 [20]. Currently those requirements can only be met with atomic (Caesium-beam) clocks used as the network primary reference clock (PRC: Primary Reference Clock) or with use of GPS receivers; but by deploying different strategies on clock holdover, repair time and network planning, these objectives can also be met under failure condition for a limited period of time.

The task of network synchronization is to distribute the reference signal from the PRC to all network elements requiring synchronization. The architecture of synchronization networks is described in clause 7.

The method used for propagating the reference signal in the network is the master-slave method. Figure 5 shows a typical chain of master-slave-connected clocks.

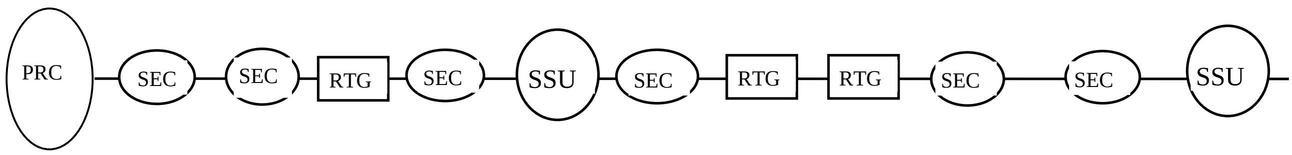



**Figure 5: Example of synchronization chain**

Several classes of slave clocks with different properties and different roles appear in the network:

- The PRC determines the long-term stability of the reference frequency.
- SSUs (Synchronization Supply Units) regenerate the clock signal after it has passed a chain of SECs and serve as temporary references for parts of the network when the connection to the PRC is lost in failure situations. Usually SSUs are located in network nodes where they distribute a timing signal to all network elements in the node.
- SECs (SDH Equipment Clocks) are the clocks incorporated in SDH network elements. SECs offer great flexibility in the selection of references and support automatic reconfiguration mechanisms in rings or chains of SDH network elements.
- RTGs (Regenerator Timing Generators) do not appear in the reference chain because due to their simple architecture and their relevant properties their influence in the synchronization chain is negligible.

The following clauses give more details on the properties and applications of the clocks in a synchronous network.

## 6.2 PRC (Primary Reference Clock)

The PRC represents a set of performance specifications for a clock generator function which is defined in EN 300 462-6-1 [6]. These specifications aim at:

- providing a master clock source for a network;
- sufficient frequency accuracy for pseudo-synchronous operation of international (multi operator) 64 kbit/s switched networks (see EN 300 462-1-1 [1] for the definition of pseudo-synchronous).

The network operator may run two (or more) PRC's at different locations in their network in order to achieve a very high availability of PRC reference signals to the network. In case of a fault of the currently active PRC the standby PRC will takeover the role of the failed PRC.

## 6.2.1 Application

A Caesium-beam tube is always used in the generation of a PRC signal because the underlying physical principle assures that there is no systematic effect like aging which could lead to gradual frequency deviation. The only wear-out mechanism is the limited reservoir of Caesium for the atomic particle beam. This limits the lifetime of a Caesium-beam tube to about 10 years, depending on the manufacturer and the type of tube.

Two types of PRCs have evolved:

- Autonomous PRCs with one or several (up to three) Caesium tubes incorporated in the PRC and used as a reference for an SSU.
- Radio-controlled PRCs which use remote Caesium tubes, e.g. in the satellites of the GPS navigation system. In this case radio signals are generated on the basis of Caesium tubes, received at the location of the PRC and used as the reference signal for an SSU.

Two types of radio controlled PRCs exist, land based and satellite based radiocontrolled PRCs. Only satellite based PRcs are available worldwide.

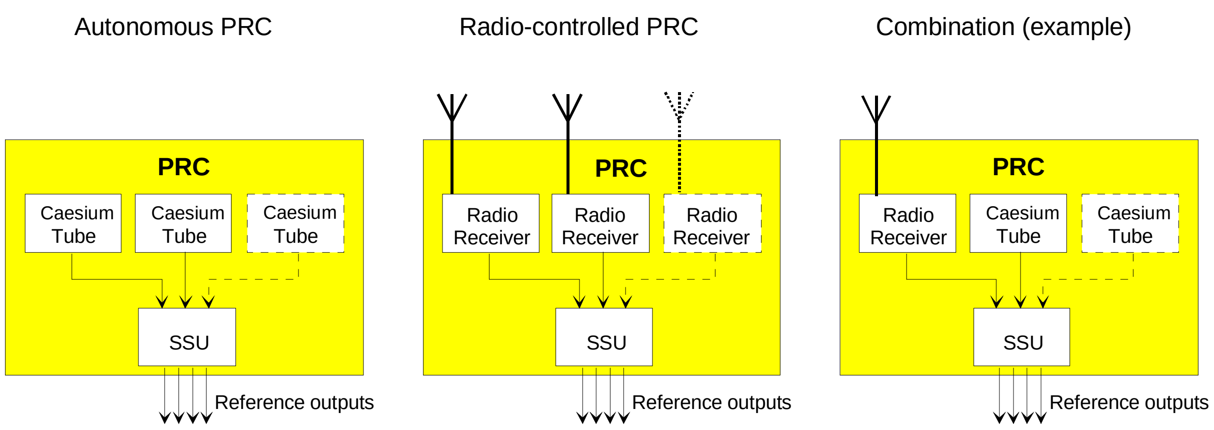



**Figure 6: Configurations of PRCs**

This figure shows configurations of PRCs, purely autonomous, purely radio-controlled and an example of a combination of both methods which gives a very high degree of availability.

Advantages, disadvantages and network scenarios with the different methods are described in more detail in clause 7 (Synchronization Distribution Architecture).

## 6.2.2 Properties

**Reference input interfaces:**

- None (autonomous PRC);
- Radio receiver (radio-controlled PRC, satellite based PRC).

**Output interfaces:**

- 2,048 MHz (EN 300 166 [8]);
- 2 048 kbit/s HDB3-coded (EN 300 166 [8]);

other output interfaces available.

**Basic properties:**

Freerun Accuracy: ± 1 x 10-11

**Reference:** ETSI EN 300 462-6 [6]: Timing characteristics of primary reference clocks.

## 6.3 SSU

The SSU represents a set of performance specifications for a clock generator function which is defined in EN 300 462-4-1 [4] and in EN 300 462-7-1 [7]. These specifications aim at:

- low bandwidth jitter filtering for removing efficiently jitter and short term wander from the synchronization reference signals;
- high degree of frequency accuracy in the holdover mode for providing a local synchronization backup and to allow for delayed maintenance response on synchronization faults;
- limited phase transient response on switching between input reference signals.

The physical implementation of the SSU function may either be integrated as the timing generator of a network element or it may be stand alone equipment, the so called SASE (Stand Alone Synchronization Equipment).

ETSI provides only a limited set of equipment specifications for the SSU in EN 300 417-6-1 [10]. SASE implementations of the SSU may have the following additional features:

- Distribution of 2 MHz and / or 2 Mbit/s synchronization reference output signals via a scalable number of G.703 [13] interfaces.
- Continuous monitoring of the input signals for frequency offset and excessive jitter and wander.
- Provisioning of dedicated monitoring interfaces for continuous sync network performance measurement and surveillance.
- Provisioning of processed phase measurement data: MRTIE and TDEV.
- 2 Mbit/s re-timing function.

### 6.3.1 Application

An SSU is normally not connected directly to traffic signals: The network elements (NEs) terminating the transport signals connected to the node extract a synchronization reference signal out of suitable transport signals and deliver it via the T4 output to the node clock.

Two types of SSUs have been specified in EN 300 462-4-1 [4] and EN 300 462-7-1 [7], the later is intended to be used for local application; it can be located only as the last SSU of the synchronization reference chain defined in Figure 12.

### 6.3.2 Properties

**Reference input interfaces:**

- 2 048 kHz (EN 300 166 [8]);
- 2 048 kbit/s HDB3-coded (EN 300 166 [8]);
- STM-N interfaces (ITU-T Recommendation G.707 [16]);

Other input interfaces are available.

**Output interfaces:**

- 2 048 kHz (EN 300 166 [8]);
- 2 048 kbit/s HDB3-coded (EN 300 166 [8]);
- STM-N interfaces (ITU-T Recommendation G.707 [16]);

Other output interfaces are available.

**Basic properties:**

**Table 1: Holdover characteristics**

| SSU type | transit | local |
|---|---|---|
| **holdover: initial frequency offset** | $5x10^{-10}$ | $10^{-9}$ |
| **holdover: ageing, per day** | $2x10^{-10}$ | $10^{-9}$ |

**References:**

EN 300 462-4-1 [4] : "Timing characteristics of slave clocks suitable for synchronization supply to SDH and PDH equipment".
EN 300 462-7-1 [7] : "Timing characteristics of slave clocks suitable for synchronization supply to equipment in local node applications".

## 6.4 SETS (SDH Equipment Timing Source),SEC (SDH Equipment Clock)

The SEC represents a set of performance specifications for a clock generator function which are defined in EN 300 462-5-1 [5]. These specifications aim at:

- moderate frequency accuracy in holdover mode in order to allow for moderate cost oscillator application;
- tight intrinsic phase noise generation in order to allow for cascading of many of such clocks in the synchronization distribution network without suffering from excessive phase noise accumulation;
- filtering bandwidth optimized for tight tracking of the input reference signals but with sufficient jitter filtering capability;
- synchronization performance to be supported by the SSM protocol which allows for automatic re-configuration of SEC sub-networks in order to limit the time intervals of holdover mode operation after synchronization faults.

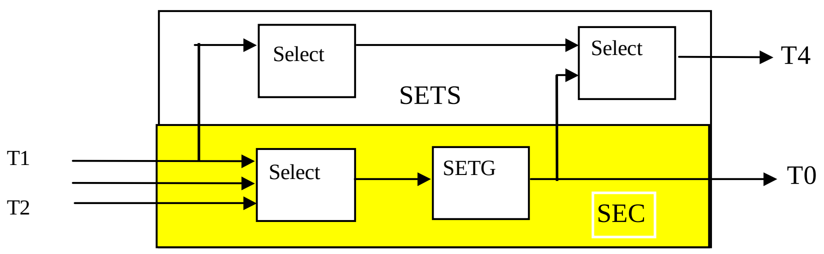
The SEC has been defined as the performance feature set for the equipment timing generator of synchronous (especially SDH) telecom equipment (SETG). Its transfer performance is defined between the (SDH) traffic port input and the (SDH) traffic port output.

Such timing generator is part of the Synchronous Equipment Timing Source (SETG) function. This function adds a reference clock output selection scheme (selectors A and C) for providing the T4 output. This output signal can either be a copy of the internal system clock (T0, i.e. the SETG output) or it may be a reference signal derived directly from one of those SDH traffic port input signals which are configured as input references for the SETG.

The SETS functional specification (excluding the SEC function) is provided in EN 300 417-6-1 [10]. The SEC specification is in EN 300 462-5-1 [5]. The SETS is described in Figure 7.

## 6.4.1 Application

A SETS, as specified in ITU-T, is the combination of an SEC with selectors A and C used for selection of the T4 output signal.




T1,T2,T3, T0 and T4: input and output

SETG: internal oscillator

**Figure 7: Block circuit of an SETS and an SEC**

NOTE: Input signals to Selector A are only T1 according EN 300 462-2 [2] but selection of T2 and T3 signals is not prevented by the model of atomic functions used for synchronization distribution defined in EN 300 417-6-1 [10].

The SETS is not directly connected to input or output signals of the network element, but via the traffic interfaces or specific synchronization interfaces. Figure 8 shows the block circuit of a typical SDH network element. For clarity PDH interfaces and consequently the T2 reference signals to the SETS have been omitted and the interfaces are shown separately for the incoming and the outgoing signals.

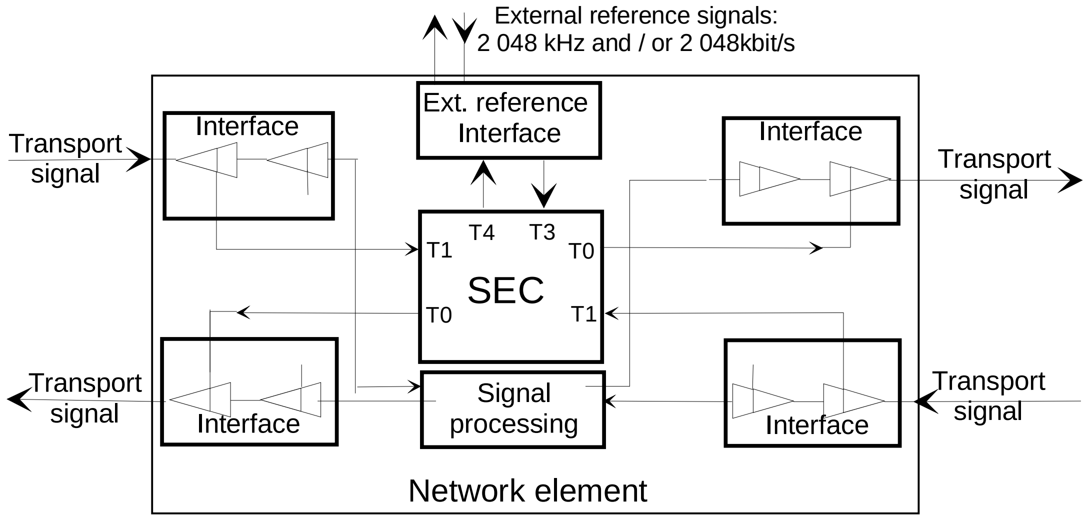



**Figure 8: SETS environment**

## 6.4.2 Properties

**Typical application:** Clock of synchronous multiplexers and line equipment

**Reference input signals:**

T1, derived from:
STM-N (ITU-T Recommendation G.707 [16])
34 368 kbit/s with 125µs frame structure
139 264 kbit/s with 125µs frame structure

T2, derived from
2 048 kbit/s (EN 300 166 [8])

T3, derived from
2 048 kHz (EN 300 166 [8])
2 048 kbit/s (EN 300 166 [8]) with SSM according to (ITU-T Recommendation G.704 [14]).

**Output signals:**

T4: External reference signal,
2 048 kHz (ITU-T Recommendation G.703 [13]) (after physical interface)
2 048 kbit/s (EN 300 166 [8]) with SSM according to (ITU-T Recommendation G.704 [14]) (after physical interface)

NOTE: The main application of 2 048 kbit/s signals with SSM is the exchange of synchronization status information between an SSU and an SDH network element within a node.

T0: Timing signals for equipment-internal signal processing and for generating outgoing SDH traffic signals: Frequencies are implementation-specific.

**Basic properties for T0:**

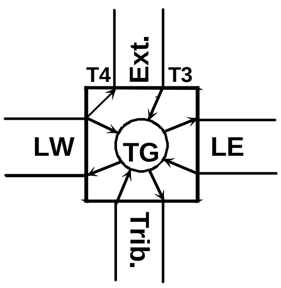
| | | |
|---|---|---|
| Frequency Accuracy: | $\pm 4,6 \times 10^{-6}$ | |
| Holdover: | $5 \times 10^{-8}$ | (initial frequency offset) |
| | $2 \times 10^{-6}$ | (temperature) |
| | $1 \times 10^{-8}$/day | (aging) |

**Reference:** EN-300 462-5 [5]: "Timing characteristics of slave clocks suitable for operation in SDH equipment".

## 6.4.3 Timing modes

The SETS (SDH Equipment Timing Source) offers many timing options. The selection of the reference sources for the internal timing generator (SETG) and, independently, for the external reference output (T4) allows flexible adaptation to the needs of synchronization distribution in the network.

The following representation is used to describe the different following timing modes:




LW / LE: Line West / East;

Trib: Tributary (SDH or PDH);
Ext: External reference input (T3) and output (T4);
TG: Timing generator (SETG).

Thick lines indicate the synchronization flow (signals actually in use for synchronization).

STM-N tributaries are locked to TG but not the PDH ones (with the exception of 2 Mbit/s retiming, see clause 10).

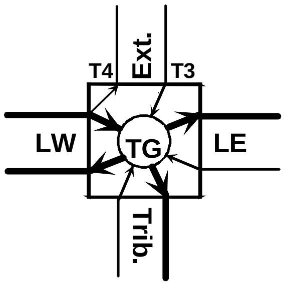
Characteristics common to all timing modes:

The outgoing STM-N signals at all ports, including the selected reference port, are synchronized from the TG, based on the selected reference signal. In order to prevent timing loops between neighbour network elements, the SSM in the STM-N signals is used.

Outgoing PDH tributary signals are normally not synchronized from the SETS. An exception is retimed 2 Mbit/s signals as described in clause 10.

An equipment with one SETS function (which may be physically duplicated for reliability reasons) can be operated in the following modes:

**Line Timing**



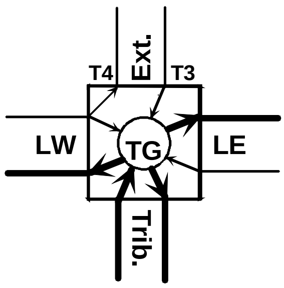

**Characteristics:**

The reference signal for the TG is derived from the west or east line signal.

NOTE: The outgoing signal at the LW port (in this example) is marked with the SSM "Do not use for sync" to avoid timing loops.

Application: Usual timing mode of network elements in chains or rings.

**Tributary Timing**

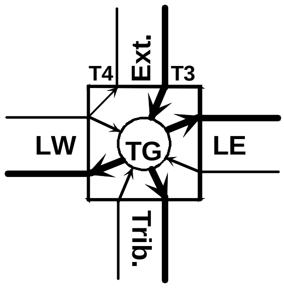



**Characteristics:**

The reference signal for the TG is derived from a tributary port which may be an STM-N signal or a PDH signal.

If a PDH tributary is used, the signal must meet the requirements for the input jitter and wander tolerance specified in EN 300 462-5 [5] which are more stringent than the requirements for PDH signals not used for synchronization purposes. Outgoing PDH signals usually are not synchronized by the TG (exception: retiming).

**External Timing**

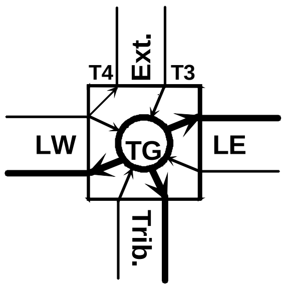



**Characteristics:**

The network element uses an external reference signal dedicated for synchronization (without traffic). Signal types: 2 048 kHz or 2 048 kbit/s.

Application: Synchronization distribution from higher-level clocks (e.g. PRCs or SSUs) to network elements or directly between network elements in a network node.

**Internal Timing**




**Characteristics:**

The clock of the network element is not locked to a reference signal. Internal timing comprises freerun and holdover mode.

Freerunning SECsk elements (never locked to a reference source) are not allowed in synchronous networks.

Holdover mode is entered when the selected reference source fails and no suitable alternative is available. The network element should return to locked operation as soon as possible, e.g. with automatic reconfiguration mechanisms.

## 6.4.4 Examples for timing modes

Figure 9 illustrates the most important timing modes. The lower part is a chain of network elements operated in line timing. It is assumed that the SSU receives its reference not via the incoming line but via some path traceable to the PRC. In the same way synchronization can be supplied to a ring.

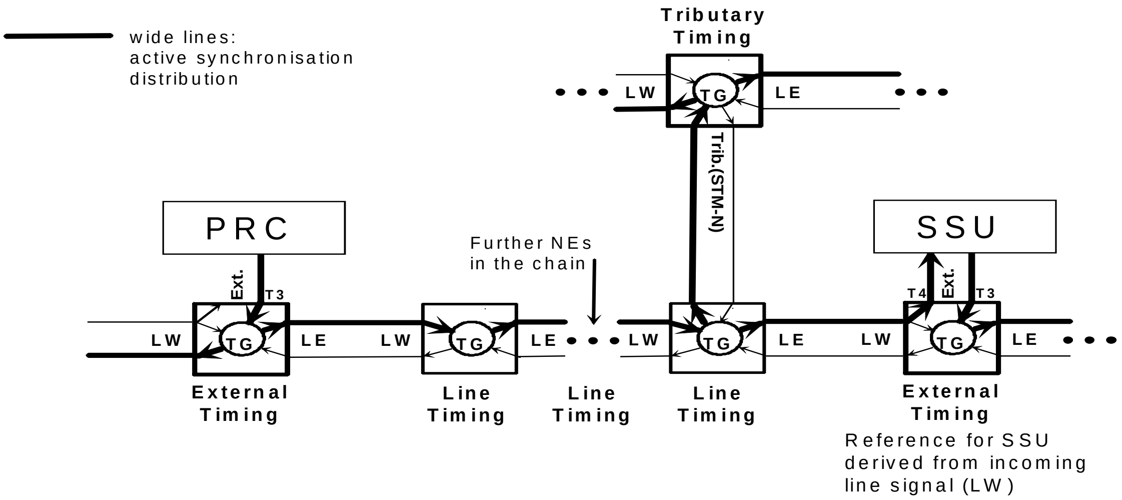



**Figure 9: Application example of timing modes**

From the network element connected to the PRC, synchronization is transported via a chain of network elements in line timing mode to a network element connected to an SSU. For details on this typical inter-node synchronization see clause 7.

The tributary-tributary connection at the penultimate network element of the chain shows a method for transporting synchronization to another subnetwork like a short chain or a small ring. When synchronization is transferred to larger subnetworks, usually an SSU is placed between the networks.

# 6.5 Regenerator Timing Generator (RTG)

## 6.5.1 Application

RTGs are very simple timing sources, next figure shows their position in a regenerator. As opposed to network elements equipped with an SETS supplying timing to all functions, the RTG consists of a separate timing source for each signal direction of the bidirectional signal, so that each signal keeps its timing.

Under normal operation an RTG receives a reference signal extracted from the incoming STM-N signal and distributes a timing signal to the signal processing functions and the output interface. If one of the incoming STM-N signals is lost, the RTG provides timing for the generation of an AIS (Alarm Indication Signal) downstream.

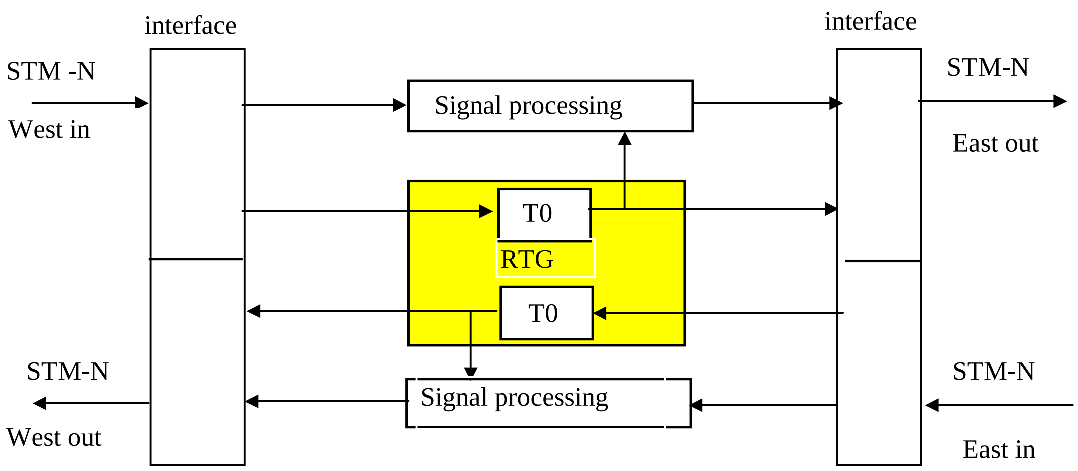



**Figure 10: Position of the RTG in the block circuit of a regenerator**

The wander contribution of RTGs is negligible. Some jitter is added to the signal which is filtered out in the next SETS. Only in very long regenerator chains (order of magnitude: 50) will jitter accumulate significantly.

Consequently RTGs can be considered as fully timing transparent clocks and may be omitted when the number of network elements in a master-slave chain is counted.

### 6.5.2 Properties

**Reference input signals:**

T1: derived from STM-N (ITU-T Recommendation G.707 [16]).

**Output signals:**

T0: Timing signals for equipment-internal signal processing and for the generation of outgoing SDH traffic signals: Frequencies are implementation-specific.

**Basic properties:**

Freerun Accuracy: $\pm 20 \times 10^{-6}$

Holdover: no holdover

**Reference:**

ITU-T Recommendation G.958 [24] : "Digital line systems based on the Synchronous Digital Hierarchy for use on optical fibre cables".

### 6.5.3 Timing modes

Regenerators operate in through timing mode, in which the timing from the outgoing line west signal is derived from the incoming line east signal and vice versa.

# 7 Synchronization Distribution Architecture

## 7.1 Introduction

EN 300 462-2 [2] has defined various schemes for SDH synchronization distribution. Based on these schemes, two arrangements can be used to deliver to SSUs good synchronization quality signals. One of this arrangement is a distributed architecture where the SSUs in the network are directly connected to the PRCs. The second arrangement is a centralized architecture, where a PRC quality signal is distributed via a master-slave clock arrangement. In this scheme, the highly accurate and stable master clock signal is passed to all the SSU's via chain of slave clocks. There are two ways to distribute synchronization; it can be done with a totally dedicated network or in a non dedicated network superimposed on the traffic.

In order to meet the performance requirements for international digital links (ITU-T Recommendation G.822 [20]) the master clock must comply to the standards for Primary Reference Clocks (PRCs), (EN 300 462-6 [6]).

In large networks long chains of slave clocks may occur. This leads to phase jumps caused by pointer actions (in mixed SDH/PDH networks) and to degradation of the synchronization signal due to:

- jitter and wander;
- clock noise;
- increasing probability of an interruption in the chain, possible disconnection of large parts of the network from the PRC.

Because of its importance for the proper operation of the telecommunication network special care must be taken to avoid the above-mentioned effects by:

- deploying high-quality slave clocks at suitable locations in the network, usually in network nodes. Those node clocks, which may be stand-alone equipments (SASEs) or may be integrated into telecommunication equipment (e.g. exchanges or cross connects) should comply with EN 300 417-4 [9].
- creating subnetworks with network elements supporting SSM-controlled automatic reconfiguration mechanisms.
- planning the synchronization network so that, as far as possible, each network element has access to several signals suitable as reference signals. This applies particularly to node clocks.

For the distribution of the PRC signal to the network elements two methods are currently being used:

- The "traditional" master-slave synchronization network, generally referred to as "master-slave synchronization" which uses the communication network for the transport of the synchronization information from the PRC to the network nodes. In this type of synchronization network usually several hierarchy levels of node clocks exist.
- The radio controlled distribution of the PRC signal to the network elements. With this method which is referred to as "distributed master synchronization" or "distributed PRC" it is in theory possible to supply a reference signal to each network element directly from the PRC, as described in subclause 7.4. Realistic approaches use radio distribution to the node clocks and from there short master-slave chains to the network elements. The source of the PRC signal may be a terrestrial station or satellites with PRCs on board, e.g. the Global Positioning System (GPS) satellites.

Gives an example of a synchronization network, showing clock types and typical architectural structures like network nodes with intra-node synchronization distribution, subnetworks suitable for synchronization transport (rings or chains of SDH network elements).

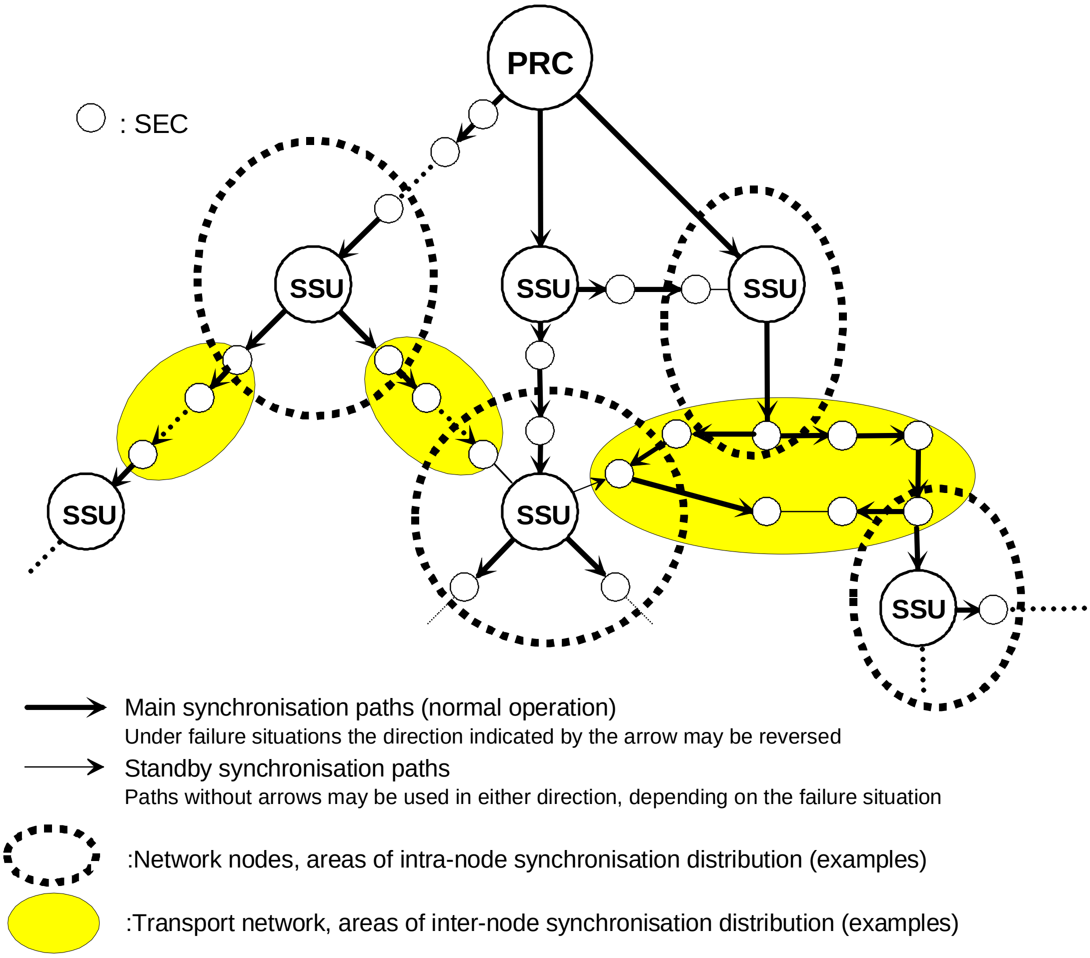



**Figure 11: Example of a synchronization network**

In the following clauses network synchronization methods and specific characteristics of inter-node synchronization distribution and intra-node synchronization distribution are treated in more detail.

## 7.2 Master-Slave Synchronization

### 7.2.1 Generic properties

Figure 12, using the representation method of (ITU-T Recommendation G.803 [19]), illustrates the architectural properties and resulting requirements of a master-slave synchronization network:

- The network consists of several levels related to the position of the clock along the synchronization chain.

A synchronization network can be decomposed into synchronization chains from a synchronization source (PRC) via suitable transport signals to synchronization sinks (SSUs or SECs).

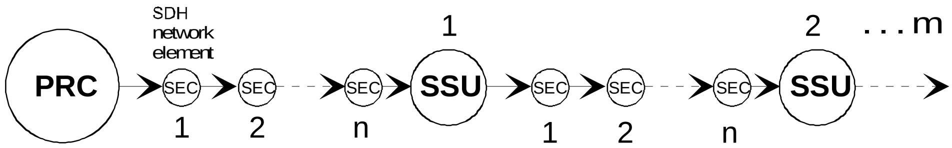



**Figure 12: Synchronization reference chain**

- The highest level contains the PRC of the network. There should be a second PRC for backup, if more than one PRC are active at the same time, see subclauses 7.4 and 7.5.

- The highest level provides distribution of the synchronization reference signal to a number of SSUs which constitutes the synchronization level 1.

- Each of those SSUs supplies timing to a subnetwork in the second synchronization level. The role of the SSU for the subnetwork is similar to the role of the PRC for the whole network. If the SSU loses all reference signals coming from the PRC, it serves as the reference source for the subnetwork. This role requires high-quality clocks according to EN 300 462-5 [5].

The following levels are like the second level.

- Synchronization transfer between hierarchy levels is unidirectional, i.e. synchronization is always transferred from a higher to a lower level, otherwise there is a risk of timing loops. If, e.g. in alternative synchronization paths, the hierarchical order is changed, additional measures must be taken to avoid timing loops.

- The SSU associated with a subnetwork (e.g. a chain or ring of SDH network elements) synchronizes the network elements in the subnetwork via transport signals.

- An SSU may and should receive reference signals from several SSUs via different paths.

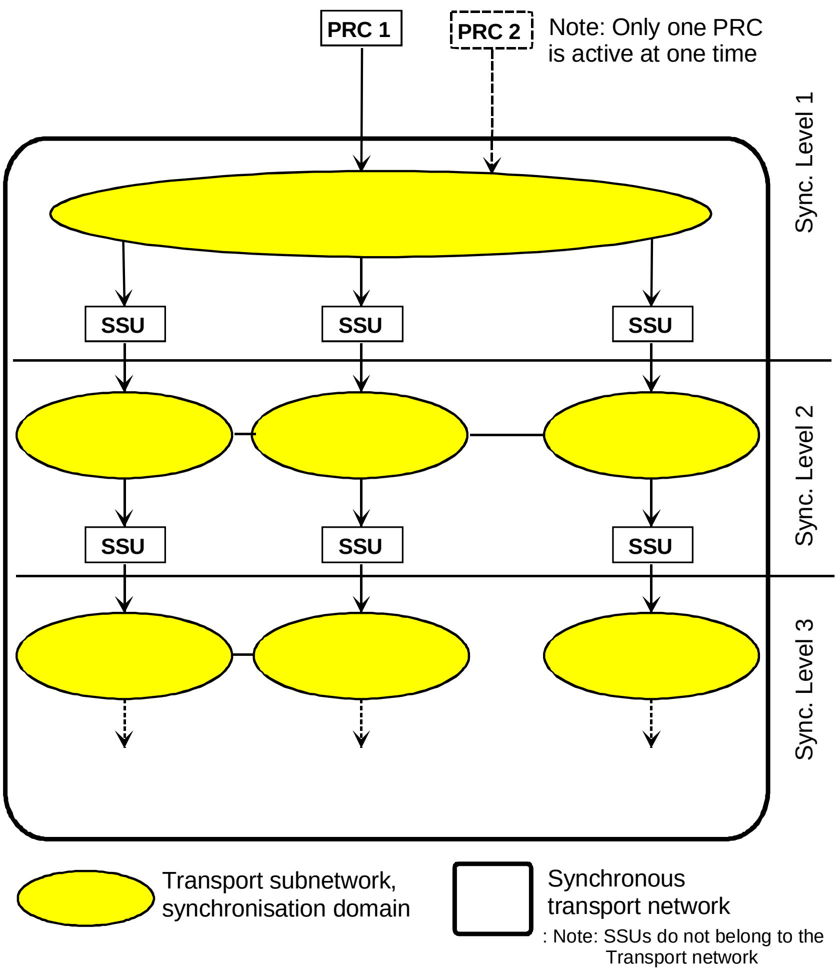



**Figure 13: Master-slave synchronization network architecture**

## 7.2.2 Architecture

### 7.2.2.1 General architecture

A more topological representation of a master-slave synchronized network was shown in Figure 11. The signal of the PRC is distributed to the SSUs directly or via a chain of SECs (SDH Equipment Clocks). The synchronization signal can be transported between network nodes via STM-N signals which is the preferable method or via other clock-transparent paths, e.g. 2 Mbit/s paths. It is important to note that 2 Mbit/s signals which were transported in SDH containers are in general not suitable as reference signals.

Basic properties of master-slave synchronization networks:

- Synchronization distribution is tree-shaped, i.e. from a single point in the network (the location of the PRC) synchronization is distributed to each network element via clock chains. In case of a failure in the network an alternative tree using transport paths normally not involved in synchronization transport must be found, if possible.
- The synchronization network can be decomposed into synchronization chains described in EN 300 462-2 [2].
- Several classes of slave clocks with different properties and different roles in the network exist. The clocks can be ordered in hierarchies with respect to their qualities or their position in the clock chain.
- It must be ensured that a slave clock of a higher quality level is never slaved to a reference signal of a lower quality. Measures for this purpose include Synchronization Status Messaging squelching to prevent use of unsuitable reference signals etc. As an example, the timing generated by an SEC in holdover must not be used as an input to an SSU.

- Each SSU supplies timing to a part of the network. If a failure in a synchronization trail occurs and no alternative trail can be found, the SSU serves as master clock for the network downstream of the failure in the synchronization tree.

The typical subnetwork structures of SDH networks, the chain and the ring, are used for the transport of traffic and synchronization. In contrast to PDH network elements SDH network elements do not only transport synchronization but should be synchronized themselves. The main requirements to inter-node synchronization are:

- Transport a synchronization signal from a node clock to another node clock, maintaining a sufficient quality in terms of jitter and wander. The quality requirements and the properties of the SECs (EN 300 462-5 [5]) result in a maximum number of 20 SECs in a chain between two SSUs.

- The need to synchronize the SDH NEs requires that an alternative synchronization trail is established when the normal synchronization trail is broken due to some failure (EN 300 462-2 [2]). In order to achieve sufficiently fast reconfiguration, automatic mechanisms based on the Synchronization Status Message have been developed. These mechanisms are described in clause 8.

Subclause 7.2.2.2 describes the synchronization properties of a chain of SDH network elements, the additional features of a ring are explained in subclause 7.2.2.3.

#### 7.2.2.2 Chain

For describing the synchronization transport in a chain of SDH network elements (NEs) it is sufficient to regard a section of the synchronization reference chain, as illustrated in Figure 14. Under normal operation the synchronization information (reference frequency and phase) is transported from SSU1 which is assumed to be synchronized to a PRC, to SSU2 via a chain of NEs containing an SEC.

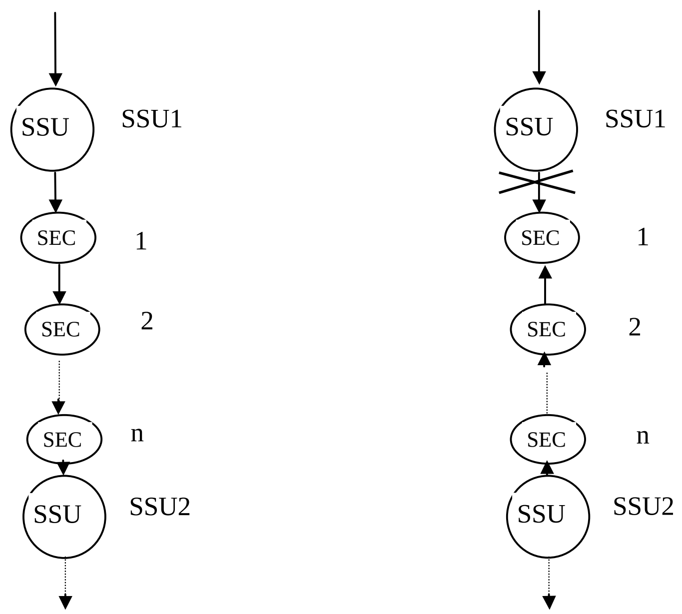



**Figure 14: Synchronization chain under normal operation and under failure condition**

Under normal operation the network elements between SSU1 and SSU2 perform the following tasks in the transport of synchronization (numbers refer to the reference chain):

**NE 1**: Generate a transport signal whose timing is derived from the upstream SSU (which in turn is synchronized to the PRC).

**NEs 2..n-1**: Recover the clock from the incoming transport SDH signal and use it as reference for the SEC. The timing of the outgoing transport signals is derived from the SETS.

**NE n**: Recover the clock from the incoming transport signal and generate a reference signal (T4) for the SSU.

The rule "a slave clock of a certain quality level must never be synchronized from a lower-quality signal" requires that the reference output signal (T4) signal is squelched (switched off) when the quality falls below the SSU level (or, in some cases, below the PRC level). For that purpose several signal criteria are supervised and the quality information in the Synchronization Status Message is evaluated, if SSM processing is supported and enabled in the NE.

Under a failure which interrupts the synchronization chain, the NEs in the chain are supplied with synchronization from the downstream SSU, reversing the direction of synchronization transport up to the point of the fault.

The role of the clocks in a section of the reference chain is illustrated in Figure 15. In this very simplified representation which omits reference selection possibilities, SSMs etc. The logical flow of synchronization is shown by the lines through the functional blocks. The lines are not physical connections but indicate only which output signals are derived from which inputs.

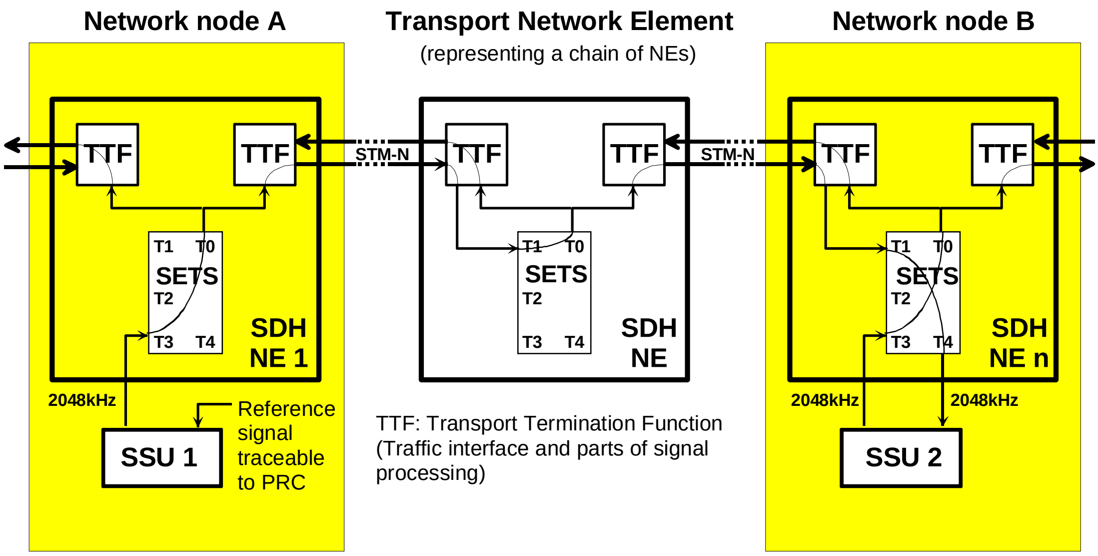



**Figure 15: Synchronization transport from SSU to SSU**

Synchronization takes the following path from the SSU in node A to the SSU in node B:

- The SSU in network node A receives a suitable reference signal traceable to the PRC in the network (assumption).
- The Timing Source SETS of the SDH Network Element in node A is synchronized from the SSU in node A via a 2 048 kHz intra-node synchronization signal.
- All outgoing SDH signals are timed by the SETS.
- The Transport Network Element in the chain extracts a reference signal from the incoming STM-N transport signal and passes it to the SETS. The outgoing STM-N signals, including the backward direction of the signal coming from node A are timed by the SETS. Potential timing loops are prevented by the SSM (Synchronization Status Message) in the STM-N signals.
- In network node B the reference signal extracted from the incoming STM-N signal is forwarded to the T4 output of the SETS, bypassing the internal oscillator of the SETS. The SSU removes jitter and partly wander (above the cutoff frequency) and gives a cleaned reference signal to the external input of the SETS.

### 7.2.2.3 Ring

With respect to synchronization, rings can be regarded as parallel chains between SSUs, as shown in Figure 16. The synchronization signal is injected into the ring at one of the NEs of the ring via the external reference input and transported through one of the SDH transport chains. At some other NE of the ring the reference signal is recovered and passed to SSU 2.

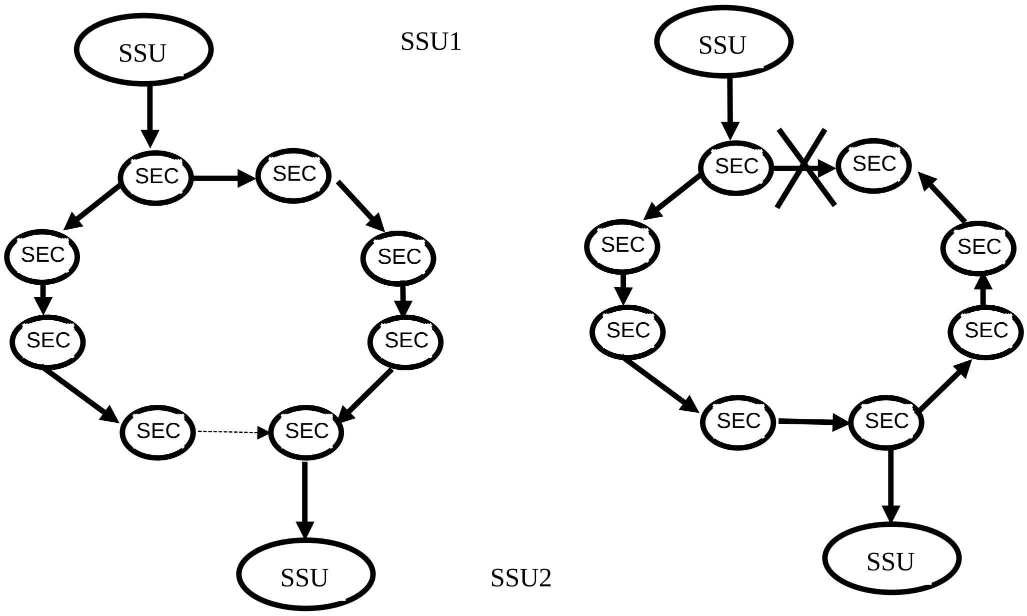



**Figure 16: Synchronization transport in a ring, normal operation and failure example**

With the parallel chains a ring offers some additional or different synchronization properties, compared to the chain:

- Using automatic reconfiguration mechanisms, each NE in the ring can be reached from the upstream SSU via two synchronization trails. Therefore it is not necessary to inject synchronization from the downstream SSU into the ring, even under many failure conditions.
- The downstream SSU can be synchronized via either of the chains, i.e. via two alternative synchronization trails. There are two single points of failure, the "gateway" NEs to the SSUs. Those can be eliminated by injecting and extracting the synchronization signal at two NEs.

Measures must be taken to avoid timing loops around the ring under certain failure conditions in connection with automatic reconfiguration. A simple method is to restrict the automatic reference selection process at two NEs in the ring. Details on automatic reconfiguration are given in clause 8.

## 7.2.3 Advantages, disadvantages, typical application

**Advantages**

- A network operator who owns the PRC has complete control of the synchronization network.
- The media for distribution is normally available and therefore the resources for synchronization distribution are already in place.

**Disadvantages**

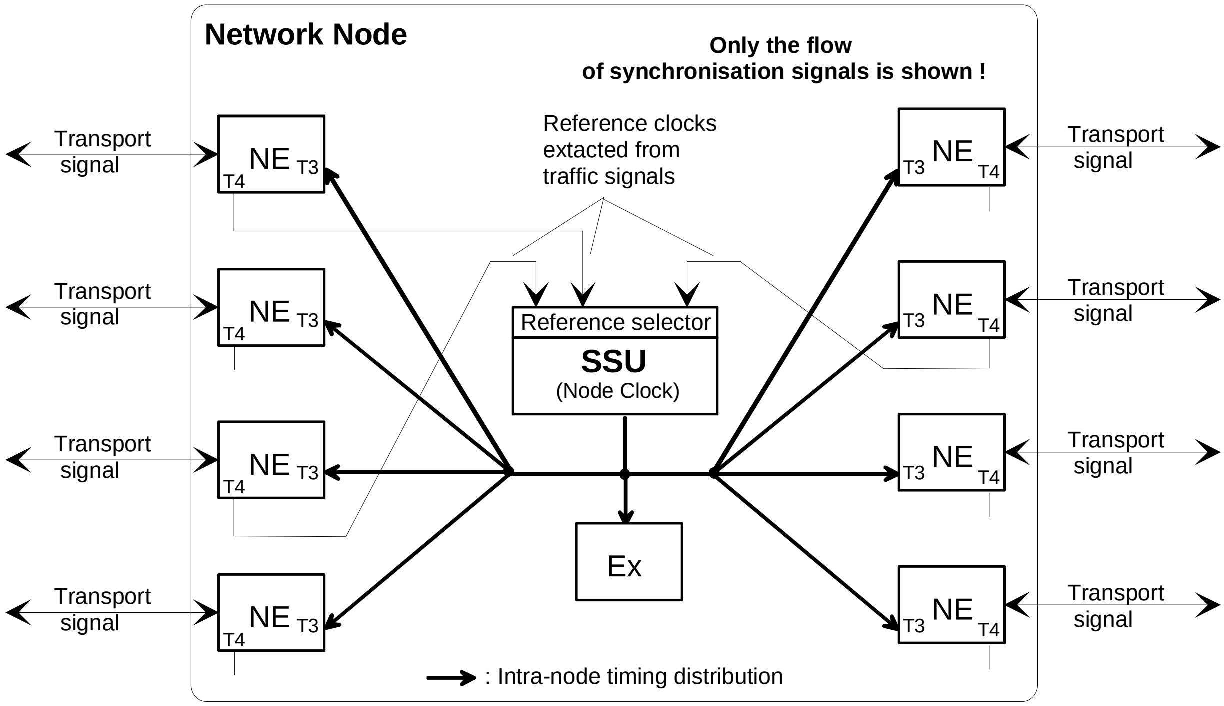
- Complex synchronization network, specifically in large networks with:
  - long master-slave chains.
- Thorough network planning by experts necessary in order to avoid timing loops.
- Transport signals suitable for the transport of synchronization are required, i.e. at the end of a trail it must be possible to recover a timing signal which meets the jitter and wander limits (e.g. EN 302 082 [11]).

**Typical application**

See Annex B.

## 7.3 Intra-node Synchronization

The purpose of intra-node synchronization is to supply a synchronization reference signal to all pieces of equipment co-located e.g. in one building. The reference signals are generated in a node clock which is usually a SASE with a quality according to EN 300 462-4 [4]. The SASE is synchronized to a reference signal coming from a PRC via inter-node synchronization transport. EN 300 462-2 [2] recommends that intra-node synchronization distribution should be in the form of a logical star. This configuration is illustrated in Figure 17.




NE: Network Element connected to a transport signal at the network node boundary, e.g. multiplexers, line terminating equipment etc.

Ex: Equipment not directly connected to transport signals e.g. exchange

NOTE: It is possible that the SSU is embedded within an NE; in this case it may receive and transmit timing through transport signals.

**Figure 17: Intra-node synchronization distribution**

Properties and functionalities of intra-node synchronization:

- Dedicated signals for synchronization transport to and from the node clock:
  - 2 048 kHz (EN 300 166 [8]);
  - 2 048 kbit/s (EN 300 166 [8]);
  - 2 048 kbit/s (EN 300 166 [8]) supporting Synchronization Status Messaging.

In currently existing networks the 2 048 kHz signal is predominantly used.

- For robustness against faults in the synchronization transport several transport signals arriving at the node are selected as potential reference sources. Which of the transport signals are suitable as potential reference sources is determined from the network view during the network synchronization planning process.
- Ensure that the reference signal at the inputs of the node clock has appropriate performance.
  This can be achieved in several ways:
  - Squelch the reference output (T4) at the NE if the quality indicated by the SSM in the incoming traffic signal is below a threshold. The threshold must not be lower than the quality of the node clock (in holdover mode),

i.e. "SSU-T"or "SSU-L".
Additionally other supervision criteria like "Loss of Signal", "Loss of Frame" etc. are used for squelching.

- Supervise the signals at the inputs of the node clock with respect to frequency deviation, phase jumps etc.
- Evaluate the SSM at the input of node clock. This requires that the SSM is conveyed to the node clock, i.e. the use of the 2 048 kbit/s signal with SSM.
- Collect the quality information of the NEs in a management system and select the best signal at the node clock by management command. This solution requires that the NEs and the node clock can be accessed from a common management system.

- Provide an SSM code for the STM-N signals leaving the node. In order to insert the correct value it is necessary to have the information about the quality of the reference signal in use at the node clock.
  - If the intra-node synchronization distribution is done via 2 048 kHz signals the only way to "transport" information is squelching the signal dependent of some supervision criteria.
  - If 2 048 kbit/s signals supporting SSM are used for intra-node synchronization, the quality information can be forwarded using the SSM. This solution requires that all involved pieces of equipment have 2 048 kbit/s reference inputs and outputs and support SSM.
  - Transport the quality information via a management system (requirements see above).
  - If none of the listed options is available, a fixed SSM value must be inserted into the STM-N signals leaving the node. The assignment of the appropriate SSM is a task of synchronization planning.

Exceptions from the star distribution:

The next figure shows an example of a network topology where equipment is physically within a network node but belongs logically to a subnetwork (a ring) synchronized from a different node clock. In order not to interfere with automatic restoration processes and the dynamic properties of the ring the node clock must not be integrated into the ring.

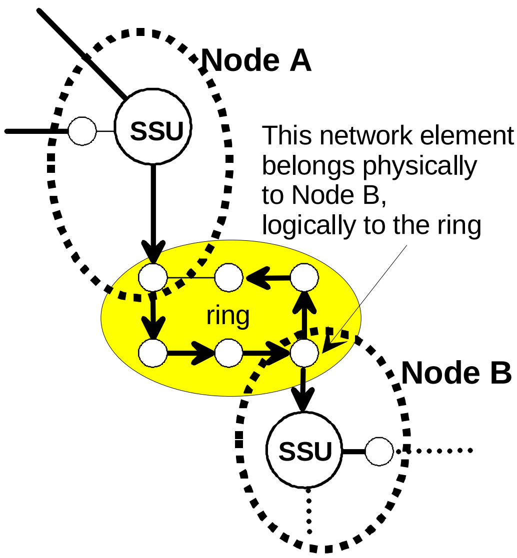



**Figure 18: Special case: Network element not synchronized from node clock (SSU)**

## 7.3.1 Interworking between SSU and Transport Network Elements

There are two main problems with the interworking between the transport network elements and the node clock (SSU) in a network node:

- It must be assured that an SSU is not synchronized by a reference signal with a quality worse than the SSU's own quality.

- For the support of Synchronization Status Messaging the transport network elements generating STM-N signals need the information about the status of the SSU (synchronized or in holdover mode) in order to insert the appropriate SSM into the outgoing signals.

Currently in most network nodes intra-node synchronization is based on 2 048 kHz signals. The transport of information on these signals is limited to a binary information: on/off. It has been proposed to use 2 048 kbit/s signals with SSM for the communication with the SSU. A 2 048 kbit/s signal with SSM has been standardized (ITU-T Recommendation G.704 [14]), but the introduction of this method requires suitable physical interfaces and evaluation processes in the SSU as well as in the transport network elements.

The next figure shows in detail the synchronization flow in a node with SSU. The detailed view is necessary because of the functionalities of the SETS.

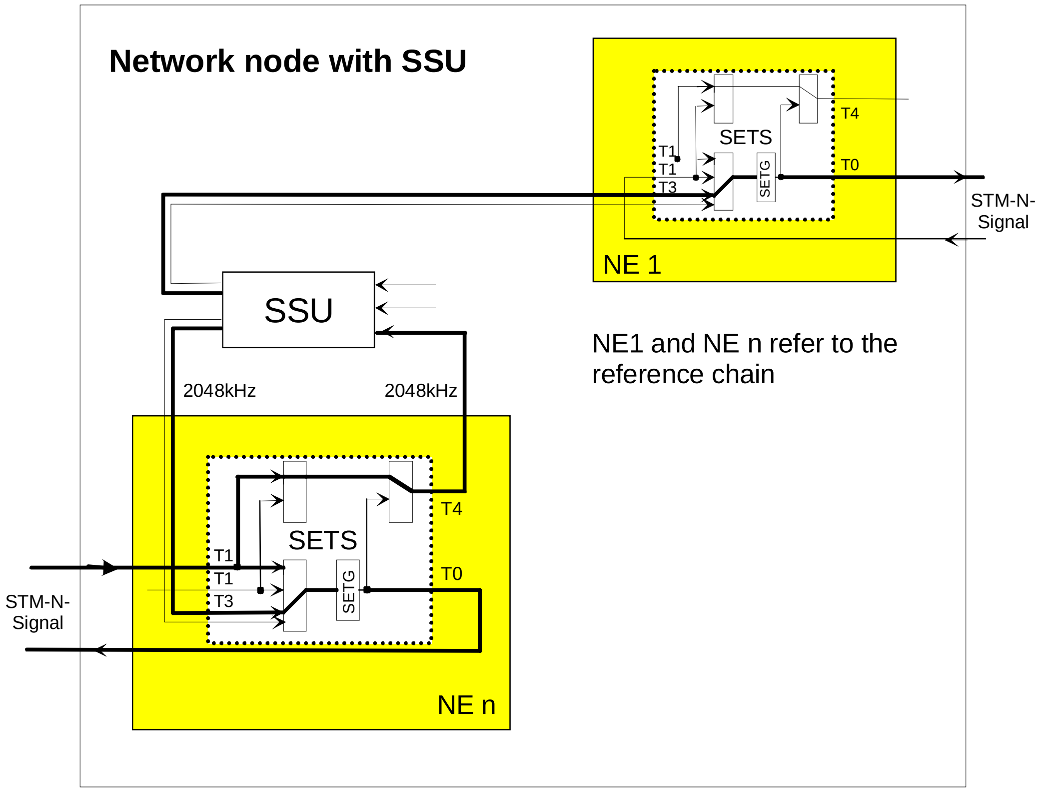



**Figure 19: Synchronization flow in a network node with SSU**

**From NE n to SSU:**

NE n extracts a reference signal out of the incoming STM-N signal and passes it to the T4 output. It is important to note that the internal clock generator of NE n (SETG) is not involved in generating the T4 signal, otherwise a timing loop between NE n and the SSU would be created.

As stated above NE n supervises the STM-N signal selected for synchronization transport on the following criteria:

- LOS: Loss Of Signal;
- LOF: Loss Of Frame;
- MS-AIS: Multiplex Section-Alarm Indication Signal;
- SSM below Minimum Acceptable Quality Level (configurable);
- The implementation of further supervision criteria like EBER (Excessive Bit Error Rate) is equipment- (manufacturer-) dependant.

If the signal fails according to the supervision criteria, the T4 output is squelched (switched off).

Since the SSU is a level-2 clock in the quality hierarchy ("SSU-T" according to the scheme in EN 300 417-6 [10]), the Minimum Acceptable Quality Level must not be lower than "SSU-T". Which of the two possible values "PRC" or "SSU-T" has to be configured, depends on the position of the clock in the synchronization network.

**From SSU to NE n:**

The SSU supplies a reference signal to all network elements in the node, including the network element that passes the reference signal to the SSU. The SETS receives the reference signal from the SSU via the T3 input and uses the reference for generating the outgoing STM-N signals (in Figure 19, only one signal is shown). A timing loop does not occur if the selection switches in the SETS are properly set. The SSM in the outgoing STM-N signals is set to a fixed value ("PRC" or "SSU-T"), see below.

**From SSU to NE 1:**

NE 1 represents all "normal" network elements in the node which are the beginning of SDH transport network chains. Those network elements receive their reference signal via a 2 048 kHz signal, usually duplicated for reliability reasons, at their T3 input.

One problem is NE 1 has no information about the synchronization status of the SSU. If the SSU is synchronized and the Minimum Acceptable Quality Level in NE n has been set to "PRC", the appropriate SSM would be PRC. If the SSU were in holdover mode, "SSU-T" would have to be inserted. Squelching the output of the SSU does not make sense because an SSU in holdover mode delivers a reference which is orders of magnitude better than the SETS' holdover mode. Currently the practice is to insert a fixed value ("PRC" or "SSU-T") into the outgoing STM-N signals. Solutions are under study.

## 7.3.2 Nodes without SSU

According to the reference chain, this is possible that some nodes, with several SDH NEs may not have an SSU. Network nodes can be configured without SSU. The reason for doing this is either to limit the number of cascaded SSU's or because of economic reasons. Several configurations of such nodes are possible as the following examples show:

**Example 1, SEC as node clock:**

The major SDH NE of the node (which implements an SEC) may be used as the node clock. A suitable large number of reference clock inputs (T1) should be available to such a node in order to ensure that the SEC node almost never loses all references to EN 300 462-4 [4] or EN 300 462-6 [6] clock sources. The output of this major SDH NE is distributed via SDH interfaces to the other SDH NE's of the node (T1) and via 2 MHz, 2 Mbit/s interface to other equipment (T4). See Figure 20.

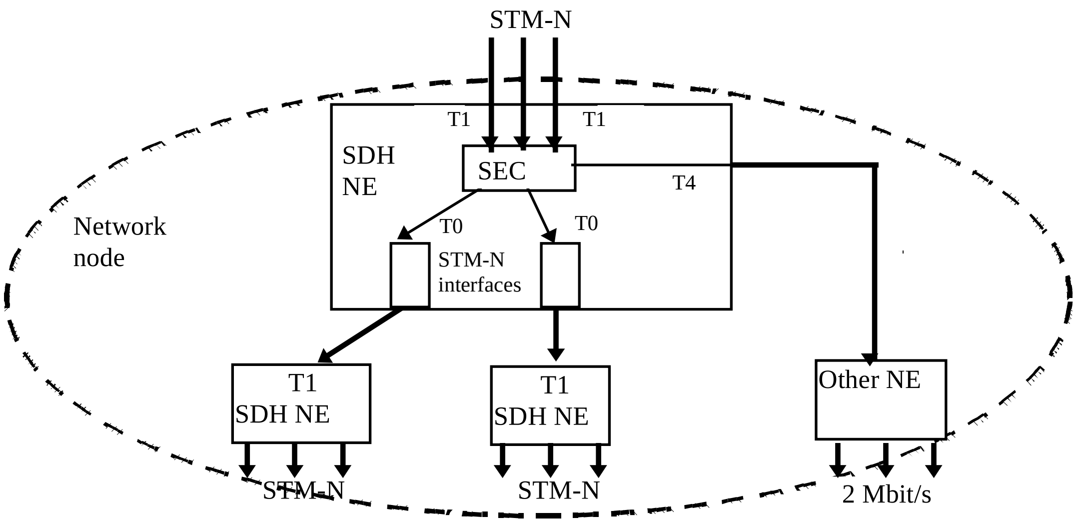



**Figure 20: SEC acting as node clock**

**Example 2, Network nodes providing ring interconnections:**

Network nodes may form a cross point for several SDH ring networks which do or do not exchange payload between them. In this case the basic entity for synchronization is the ring network and not the node itself. See Figure 21.

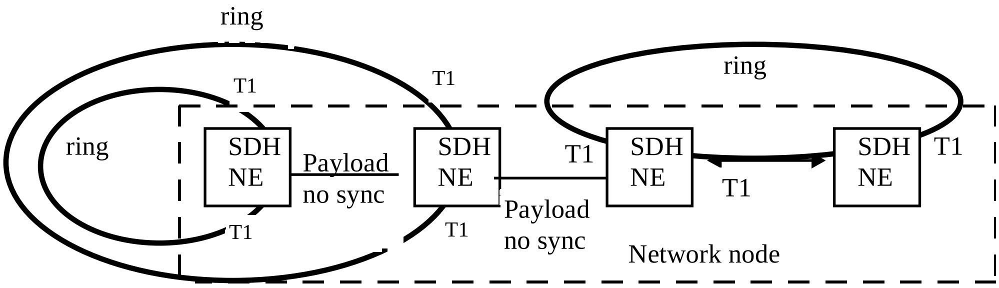



**Figure 21: Network node providing interconnection**

**Example 3, Network nodes providing synchronization interconnection between rings:**

Such network node is similarly structured to the second example. The difference is that in this case a synchronization signal is sent from one ring to an other. This signal may either be a tributary SDH link (T1) or it may be a 2 MHz interface (T4 – T3). See Figure 22. Proper network synchronization design may not allow 2 Mbit/s making such synchronization link bidirectional and controlled by the SSM because of the risk of creating a timing loop in the network.

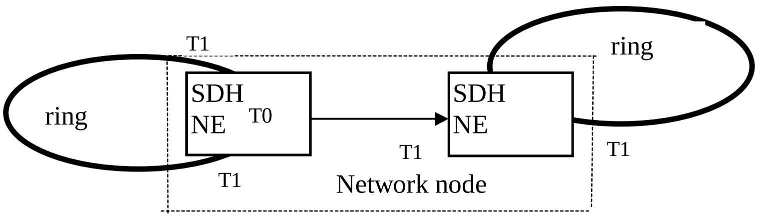



**Figure 22: Ring interconnection with timing transfer between the rings**

# 7.4 Distributed PRC Architecture

All PRC's of the network may simultaneously be active running the network in the pseudo-synchronous mode.

## 7.4.1 Generic Properties

An alternative method to the master-slave one is to distribute a synchronization signal directly to each clock in the network. This method, referred to as "Distributed Master" or "Distributed PRC" is feasible only with radio distribution because a wire-based distribution would require a complete extra network, which is by far too expensive.

As the main objective of a synchronization network is to synchronize all the SSUs, the advantages of the distributed PRC method are not affected if only the SSUs are directly GPS-synchronized and the transport network elements are master-slave-synchronized.

Figure 23 gives a generic representation of the described method, Figure 24 shows the same network as with radio- (satellite-) distributed PRC.

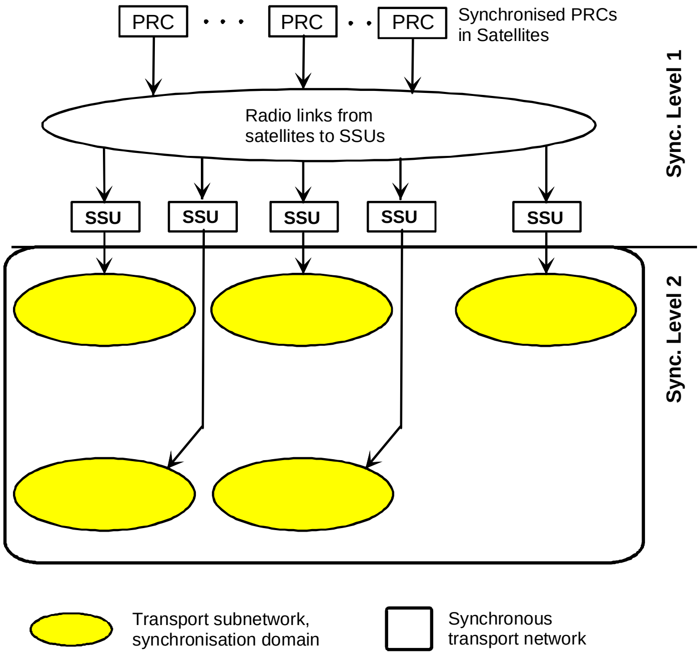



**Figure 23: Radio-distributed PRC synchronization network architecture**

## 7.4.2 Architecture

Figure 24 illustrates the GPS-based synchronization. The GPS system represents the PRC of the network, the master-slave distribution chains to the SSUs are replaced by the satellite signals. A receiver processes the GPS signal and extracts a reference signal for the SSU. Usually the synchronization distribution below the SSU level is identical to a master-slave-synchronized network.

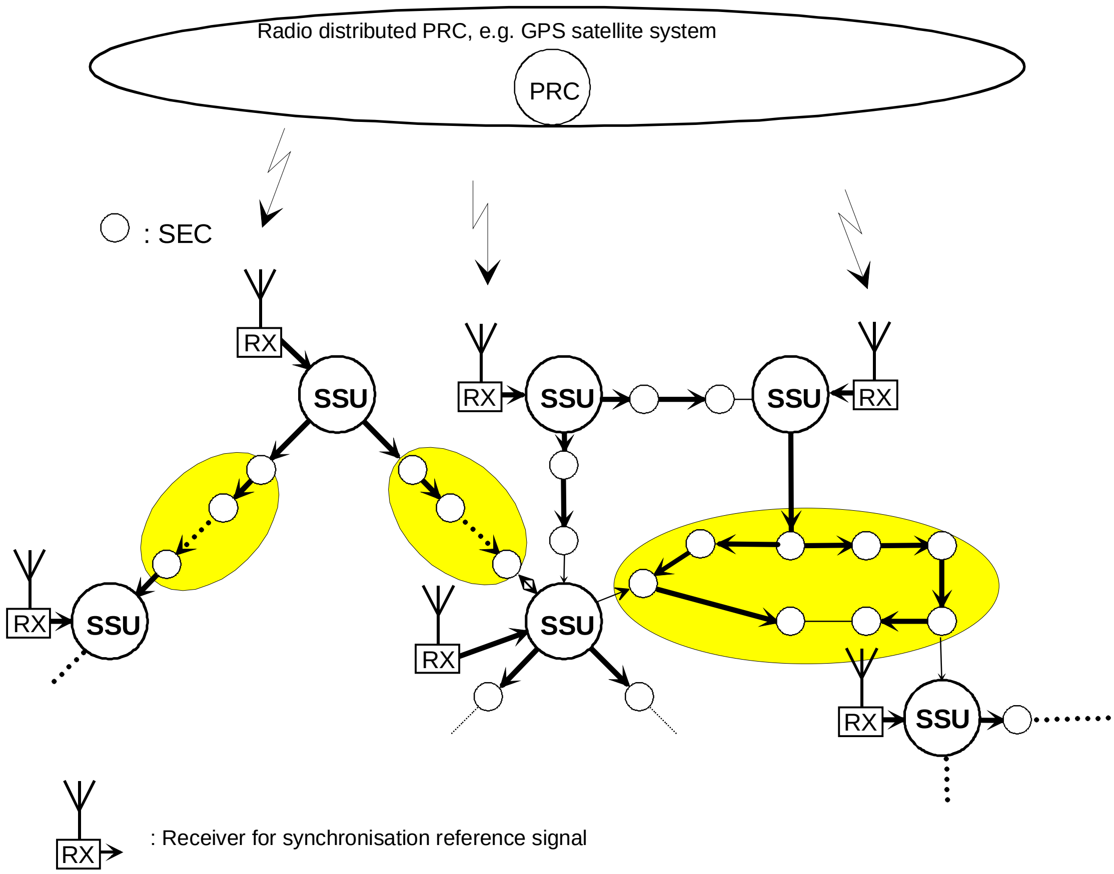



**Figure 24: Radio-distributed PRC synchronization**

### 7.4.3 Advantages, disadvantages, typical applications

**Advantages**

- Reference timing signal available world-wide.
- Flat distribution hierarchy, no risk of timing loops.
- Negligible wander, jitter can be filtered in the receiver and/or in the SSUs.
- Network planning easier.

**Disadvantages**

- Dependency on the operator of the GPS system (Defense and Transport Departments of the USA). Although there are no contracts about the use of the system, there has been an official "fact sheet" about the GPS policy of the US government which states that the GPS system will be internationally available for all users, free of direct user fees.
- Requires receivers with enhanced supervision functionalities, such as reception quality.
- Requires antenna with wide-angle view to the sky, lightning protection, cabling problems, etc.
- Risk of interference, e.g. by TV systems, saturation and jamming.

**Typical application**

See Annex C.

## 7.5 Mixed PRC Architecture

The advantages of the previous methods can be combined. Figure 25 shows an example with GPS receivers at selected locations in the network, e.g. at important network nodes with many pieces of equipment or nodes with few suitable reference signals.

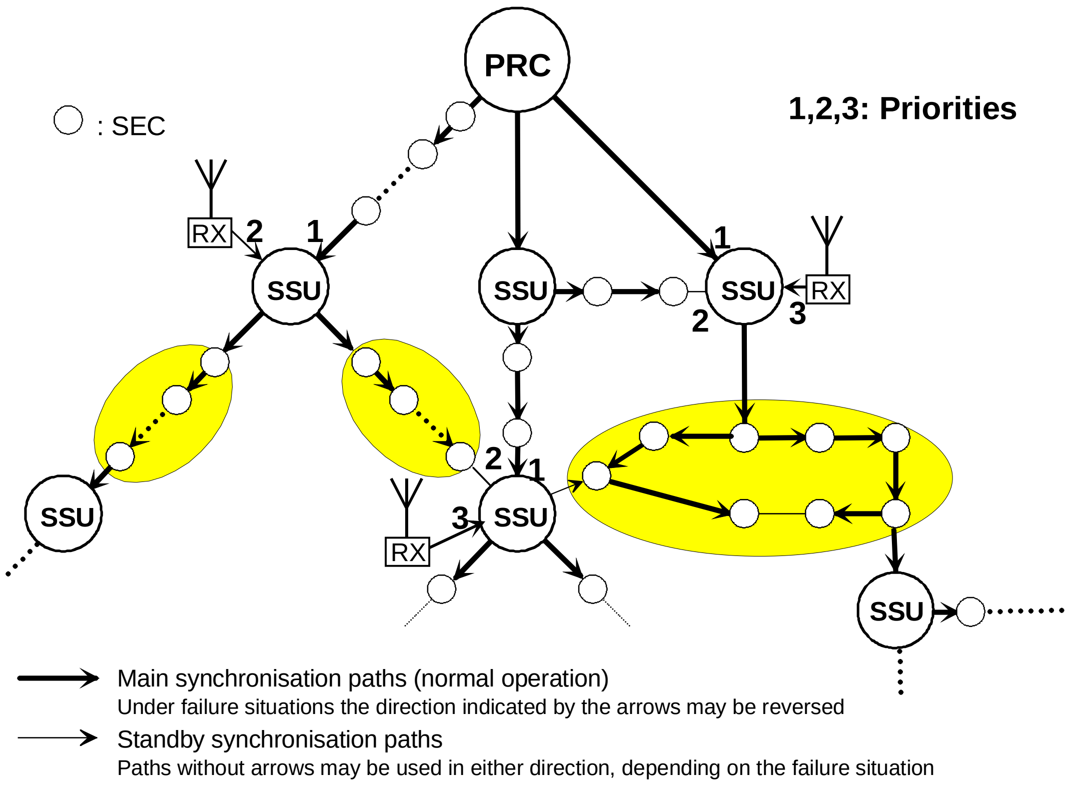



**Figure 25: Combination of master-slave and radio-distributed synchronization**

The numbers around the SSUs indicate the priorities. The assignment of the priorities determines whether the network is master-slave synchronized under normal operation with the GPS-based references as backup or vice versa. Which of the options is chosen depends on the network topology and the operator' s preferences.

**Advantages and disadvantages**

As this technique is a combination of different methods, it combines advantages and disadvantages of these methods.

**Typical application**

See Annex C.

# 7.6 Planning Rules

## 7.6.1 Definitions used in this subclause

The following definition are not located in subclause 3.1 since they are not used outside this planning rule section.

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 PRC compliant clocks in an operator domain that are the master clocks for the different synchronization areas when the synchronization network does not experience failures.

SSU-Level The collection of SSU 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.

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

NOTE: Some networks may have SDH Network Elements containing clocks other than G.813 [25] 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 sub-network A collection of SEC clocks in SDH network elements interconnected by STM-N reference carriers. When engineering the synchronization in a SEC sub-network, the directly connected SSUs need also to be considered.

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

## 7.6.2 Introduction

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

- Divide a synchronization area into an SSU-Level and SEC sub-networks.
- Group the SSUs according to their quality, defined as PRC Autonomy Period, in a number of Classes.
- Assign primary and secondary etc. references to each SSU in a manner compliant with the N(m) labelling scheme (or an equivalent alternative).
- Define the SSM protocol parameters for each SEC sub-network using the body of example networks, taking the directly interconnected SSUs into account.
- Design the intra-office synchronization for each office. This last stage is not further discussed in this subclause.

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 co-ordinator is usually nominated to maintain the synchronization plan and to co-ordinate the synchronization related activities in the synchronization areas.

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 to operate 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 of 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 done 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.

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

- 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.
- No internal loops are present.
- 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 EN 300 462-2-1 [2] is a model for a "Transmission and Multiplexing (TM); Generic requirements for synchronization networks; Part 2-1: Synchronization network architecture" synchronization link.
- A clock should never lock to a reference of 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 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.

## 7.6.3 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:

- Engineer the synchronization network considering only PRCs and SSUs (The "SSU-Level") in a synchronization area.
- Engineer the synchronization network considering only SECs (The "SEC-Level") in a synchronization area.
- Engineer the intra-office synchronization of each office. This stage is not further discussed in this subclause. See EN 300 462-2-1 [2] 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. Figure 26 and Figure 27 present an example where the SSU-Level is constructed from the complete synchronization network.

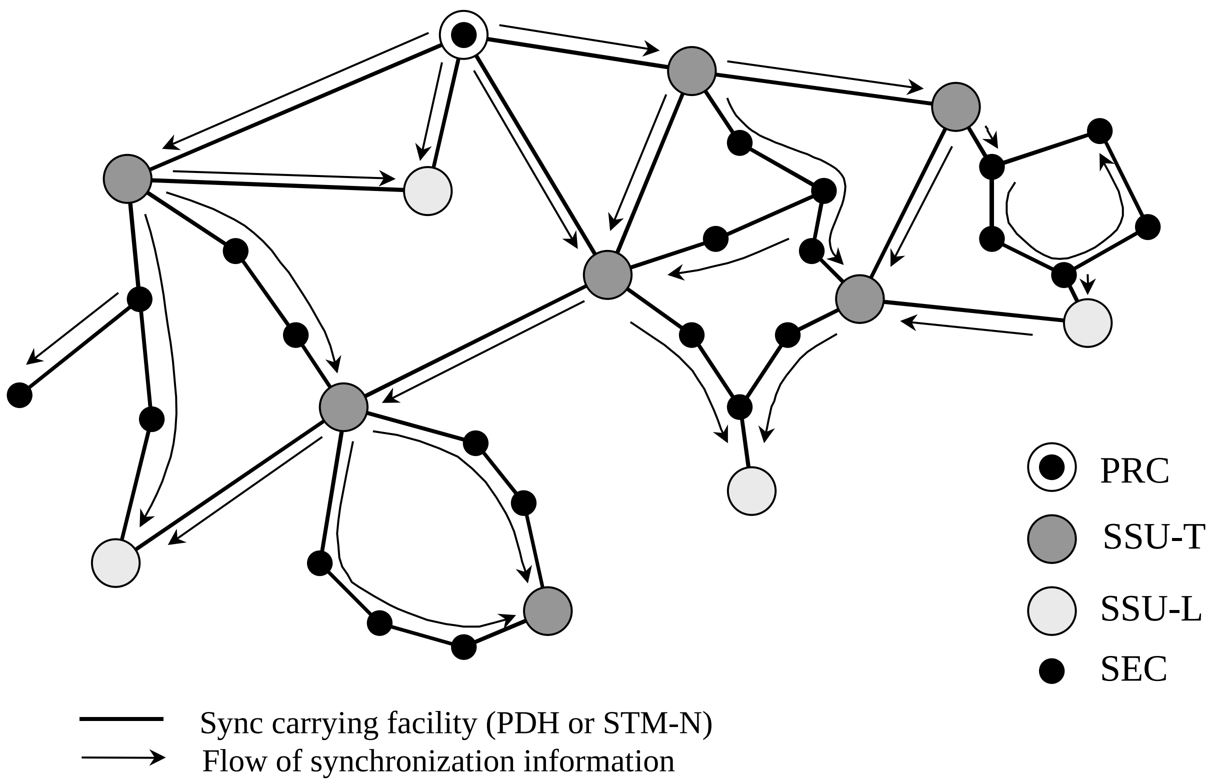



**Figure 26: Synchronization network map in a synchronization area (example)**

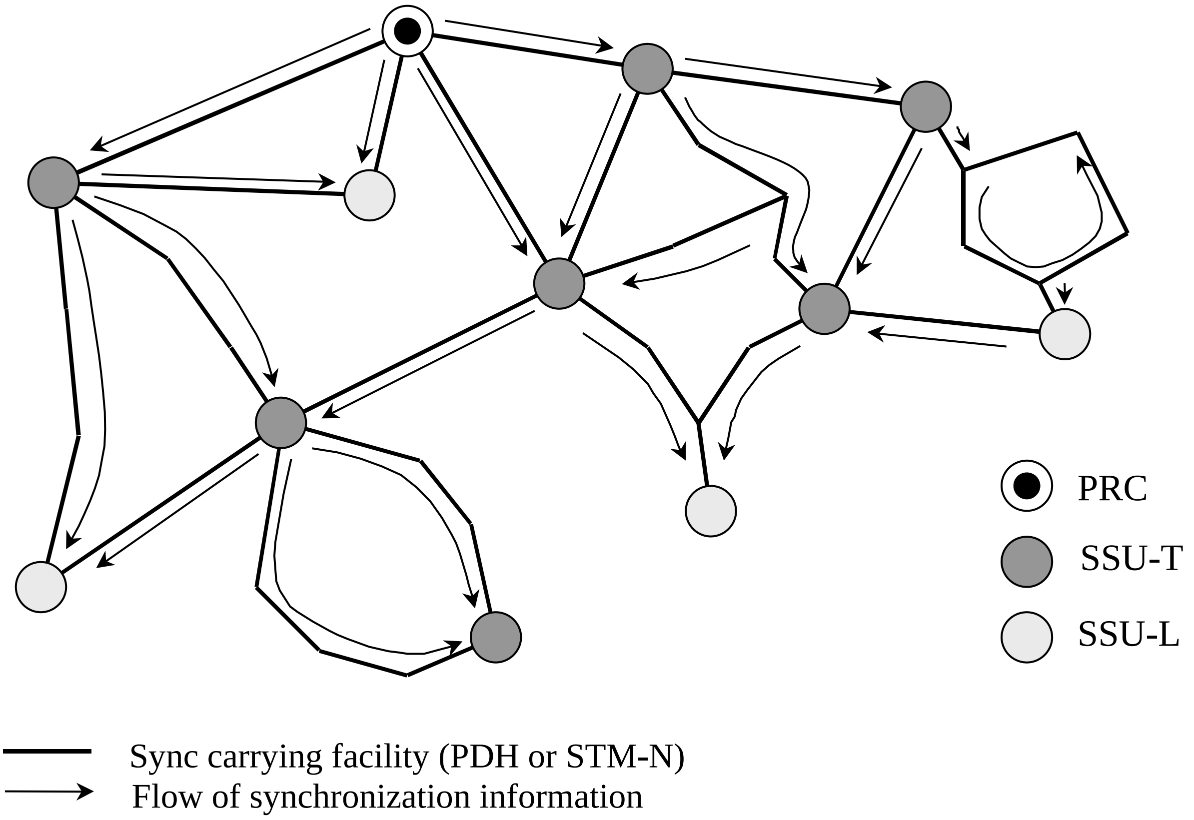



**Figure 27: SSU-Level constructed from Figure 26**

In the second stage the "SEC-Level" is considered. The SEC-Level consists of a number of unconnected "SEC sub-networks", each consisting of SECs connected by STM-N connections. These SEC sub-networks can be engineered separately. See Figure 28 for an example.

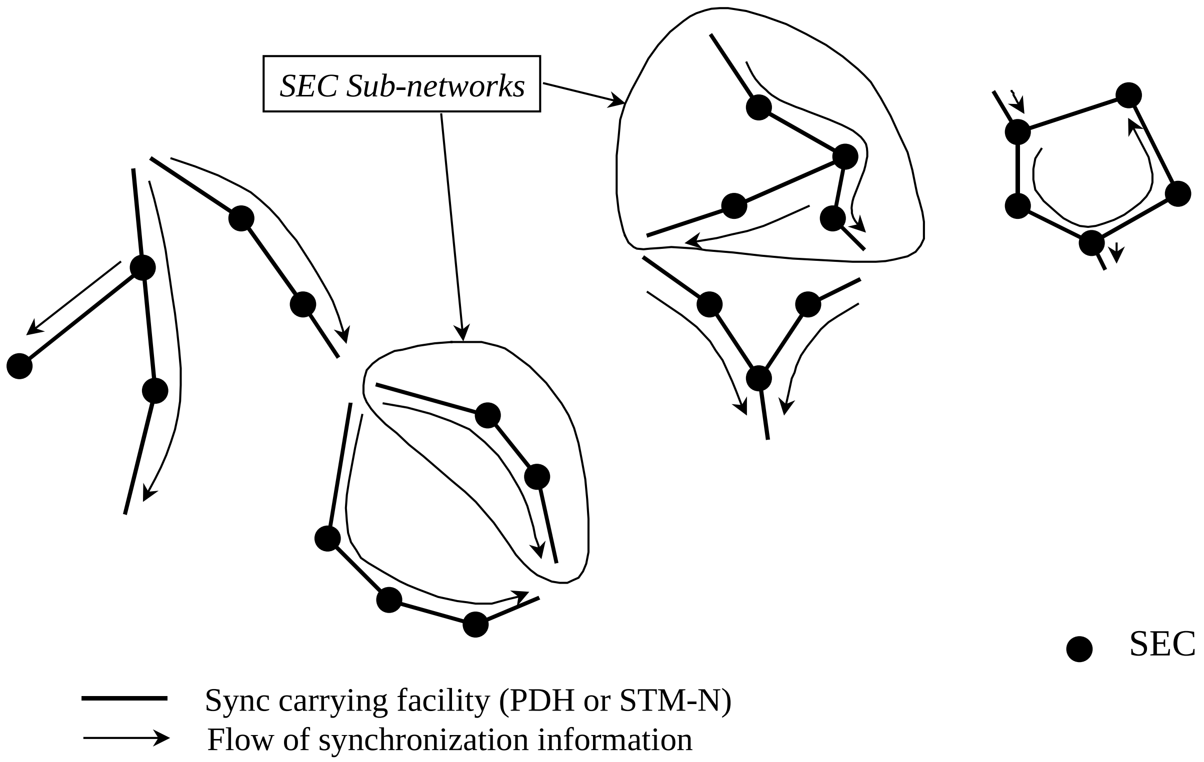



**Figure 28: SEC-Level with SEC sub-networks constructed from Figure 26**

### 7.6.4 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 into synchronization areas. In each synchronization area 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 large 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 [20]) under normal conditions is minimized. However, the synchronization network is more complex. Therefore it is harder to engineer and also 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 trails 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 pseudo-synchronous area boundary crossings in end-to-end connections and fewer installed PRC clocks.

### 7.6.5 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 EN 302 084 [26] for STM-N synchronization connections (see note). 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 29.

NOTE: Strictly speaking, EN 302 084 [26] only specifies the Jitter and Wander Network Limits for PDH and SDH networks. In practice, these same limits are often applied for other transport networks like GSM, ATM etc. as currently no alternative Recommendations exist for such networks.

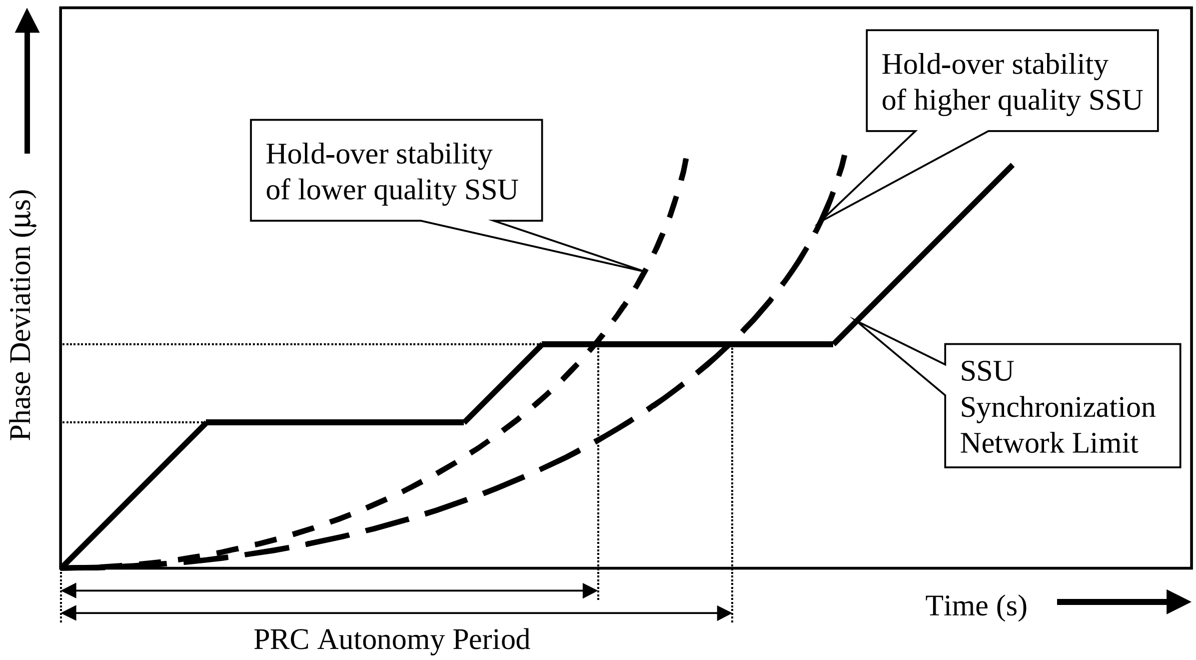



**Figure 29: Determining the PRC Autonomy Period of an SSU**

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 to the SSU necessary? If the PRC Autonomy Period is longer than the time it takes to repair a failure in the case of a single 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 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 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 using an SSU of a "lower Class of PRC Autonomy" to provide 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 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.

### 7.6.5.1 Checking reference provisionings of the SSUs

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 re-arrangements. 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. 1-st, 2-nd, etc. reference priorities). 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 between the SSUs 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 need to be present (in other words the SSUs need to be sufficiently meshed).

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

Figure 30 and Figure 31 give an examples of a network where N(m) labelling can be applied successfully and one where such is not possible.

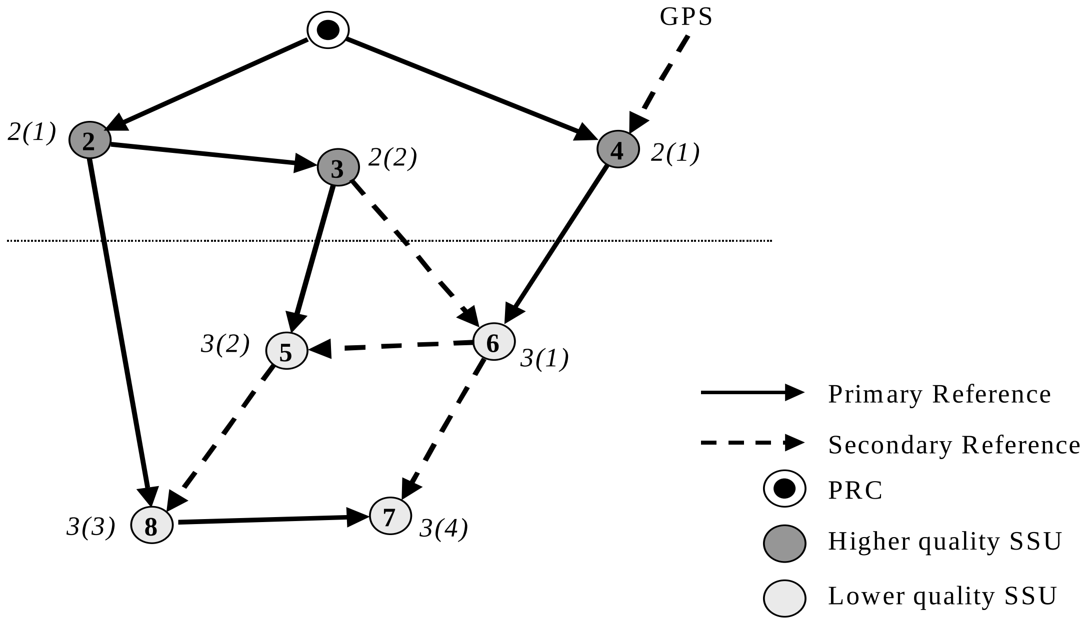



**Figure 30: Successful N(m) labelling of SSUs: No potential timing loops!**

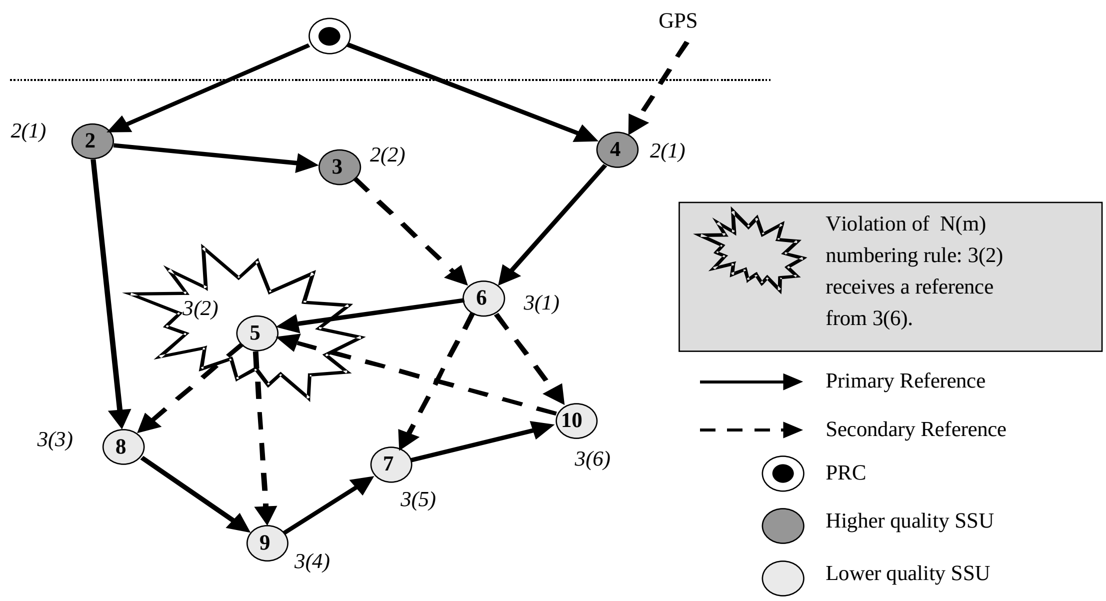



**Figure 31: N(m) labelling is not possible: Potential timing loop(s)!**

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 reprovisioned, to counter failure situations. Each re-provisioning should be checked. This whole process could be performed manually or automatically.

### 7.6.5.2 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 breaking 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. E.g. an absolute frequency guard at $1\times10^{-8}$ 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 [20].

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 EN 300 462-4-1 [4].

## 7.6.6 SEC-Level Solutions

The SEC-Level consists of many separated islands of SDH equipment with SEC clocks built in (see Figure 28). Each island is called an "SEC sub-network". Within the SEC sub-network 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. In most cases the SEC level does not provide sufficient independent references to motivate the use of the N(m) numbering scheme of the SSU-Level also in the SEC-Level. 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 EN 300 417-6-1 [10]. This protocol is proposed to be used as reference restoration control mechanism at the SEC-Level.

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

1) Providing synchronization reference signals to the SEC sub-network; or is

2) Taking a reference from the sub-network; or is

3) 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 sub-network, 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 EN 300 462-2 [2]) and for the external clock output (denoted as "T4" in EN 300 462-2 [2]) of an SDH network element. The interface between stand alone SSUs and SECs is assumed to be a 2 048 kHz interface or a non-SSM carrying dedicated 2 048 kbit/s link.

NOTE: A more detailed description of reference restoration can be found in clause 8.

The number of possible different SEC sub-network topologies is very large, but the size of the SEC sub-networks 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 sub-networks 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 sub-networks, work out the SSM parameters for those, and adapt those examples for application to real SEC sub-networks.

NOTE: Examples of SEC sub-networks are given in Annex A.

# 8 Restoration of Synchronization References

Connection failures or network element failures are serious impairments, but their occurrence is relatively infrequent. The traditional method to protect against such failures is by duplication. By providing multiple references to each network element, one can select a stand-by input in case the active input fails. So in order to construct a reliable synchronization network it is important that the trails that carry the synchronization to a central office are protected by duplicated links, which are preferably routed via different geographical paths.

The availability of multiple references implies that some kind of selection algorithm has to be applied in order to make a choice between the possibilities. Since distribution of synchronization is a function of the network as a whole and as soon as a certain node switches reference the synchronization distribution may be changed, care has to be taken that the restoration of one node does not lead to undesirable effects on the network level. Therefore, any possible selection process has to take the following boundary conditions into consideration:

1) When the timing network is restored, no timing loops may be created. This means that no clock may be synchronized to a signal which ultimately was generated by this same clock. Such loops may be unstable and may drift away in frequency.

2) When a clock goes into Hold-Over it should not be a reference for a clock of better stability than itself.

3) Each Network element should be synchronized to the highest quality available synchronization source.

4) The number of reference switches should be as small as possible. (This does not imply that non-revertive schemes are preferred over revertive, it means that "needless" reference switching and instabilities in the sync routing should be avoided).

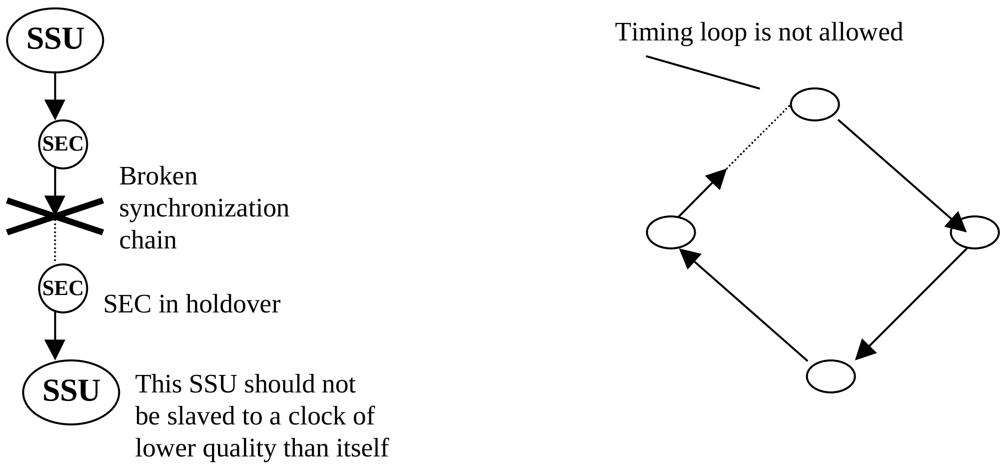



**Figure 32: Situations to avoid in synchronization restoration**

# 8.1 Types of Protection Mechanisms

Several methods of synchronization protection are possible, which all have their particular applications, advantages and disadvantages. Some methods rely on deciding on the proper restoration actions by collecting all relevant network information in a central point.

a) Manual restoration: Manual restoration of synchronization paths is only possible for network elements containing high stability clocks (at least SSU quality). The reason is that a lot of time usually elapses before a manual switch command can be given. The process requires that some kind of central point exists where all (synchronization related) alarms are collected. Each time an alarm occurs a knowledgeable person has to be called-in, in order to make the decision on which switches have to be made. In practice that restricts the application of manual switching to telecommunication centres, which contain high stability clocks. The stability of the involved clocks needs to be good enough to last for the duration of the restoration process, which may take a couple of days.

   The advantage of manual restoration is that complicated software is not necessary for the decision process. The disadvantage is that experts need to be available constantly (the level of their availability determines the necessary clock stability), and the number of clocks in the network that is controlled manually can not become too large. Moreover, a central system for collecting alarms and issuing commands should be in place.

b) Restoration based on central network management: To go one step beyond a manual restoration process, in the direction of automation, is to introduce a network management function to replace the human operator. Such a procedure reduces the maintenance costs, but it creates the problem that algorithms are needed for intelligent synchronization control. An automated central alarm collection and command issuing system is a prerequisite in order for this to function and this system has to control the synchronization functionality of all equipment in the synchronization network (including stand alone SSUs or SASEs).

The advantages are lower operations cost and a faster restoration time (minutes instead of hours) when compared to the manual restoration method, so more clocks can be controlled this way. The disadvantages are a higher investment cost and the technical problems to manage a large network centrally and designing the proper algorithms. Also interworking between different managers adds complexity. In practice this method of control is today provided only in distributed PRC systems, where two or three PRCs are present on different sites and each PRC can take over the function of any other PRC in case of failures.

Another approach is to restore based on locally available information (incoming signal failures) and some provisioned data in each node, which the user programs during installation and which is chosen in such a way that the proper restoration action is taken, given its place in the synchronization network. This type of restoration scheme reacts much faster than schemes that take the whole network in account and switching in a node may take place within 1 second. Fast restoration implies that even clocks with a relatively poor hold-over stability (like SECs) can be restored fast enough to keep the phase transients limited to 1 μs.

c) Selection based on priority tables: Priority tables give the user of an equipment the possibility to assign a certain order to the available reference signals. Normally the input with the highest priority is selected, but if it fails a switch is made to the input of second priority. More inputs and priorities are possible.

The advantage of this method is that it is simple and allows fast restoration times as only local information is needed. Network management systems are not strictly needed (it runs on its own, once installed). The disadvantage is that the priority tables do not provide sufficient degrees of freedom to engineer satisfactorily many types of networks, especially those with few access points to the synchronization network. In practice the priority tables are used in almost all PDH networks inside the synchronization equipment and switch and cross-connect equipment.

d) Selection based on synchronization status messages: The synchronization status messages can be viewed as an addition to the priority table method, because more information becomes available to each node in the form of messages which are coded in the overhead of STM-N or E1 (2 048 kbit/s) signals. These messages allow a node to react differently in different circumstances elsewhere in the network, while still, in principle, not needing a central network management system.

   The advantage over straight priority tables is that the synchronization of more types of networks can be engineered. Another advantage is that the necessary protocols are now fully specified and standardized in EN 300 417-6 [10]. Careful planning is necessary to get advantage of the SSM use.

e) Selection based on reference monitoring: Equipment can monitor the stability and frequency accuracy of the incoming references by comparing those references with each other and with the built-in oscillators. A reference can be rejected as soon as it deviates more than a certain threshold when measured against the other available signals. This method is generally used in combination with one of the others.

The methods c) and d) are worked out in more detail in the following clauses. In practical networks one can find a mixture of all these synchronization selection methods.

## 8.2 Selection based on Priority Tables

Switching based on a priority table is a very simple algorithm. The user can assign a certain priority to each incoming signal which can potentially be used as a timing reference. In principle the equipment selects the signal coming in over the input with the highest priority as its active reference. The other references are stand-by. A reference switch is made as soon as the active reference fails due to LOS (loss of signal), LOF (loss of frame) or AIS (alarm indication signal) or other transport layer defects. References may also be declared failed if unacceptably large phase or frequency offsets are detected. The presence of the latter phenomena can be established by comparing the active reference signal with the internal oscillator(s) and other input references and to use a majority vote algorithm to determine if the active input really has too high MTIE.

The exact behaviour of the priority table driven switch can differ. Some implementations are revertive in the sense that the algorithm continuously checks if a good reference of higher priority is present to which a switch is made as soon as one is found. Some systems only check the priorities if the current selection fails, which leads to non-revertive switching behaviour. Another possibility is that multiple inputs of the same priority are allowed. In this case a mixture of revertive and non-revertive behaviour results, as the system switches to another input of higher priority as soon as it becomes available (revertive behaviour), while it won't switch to good inputs of equal priority unless the current input fails (non-revertive behaviour). This latter method is specified in EN 300 417-6 [10] (in the "QL-disabled" mode).

The method of restoration based on priority tables is often used in stand alone synchronization equipment, digital switches and digital cross-connects. Such equipment is usually present in larger offices which are nodes in meshed networks, where connections are present with many different directions, so sufficient inputs are present to program the priority tables. In PDH networks this method of synchronization reference selection is the most common.

## 8.3 Restoration based on Synchronization Status Messages

With the SEC synchronization networks (i.e. the SDH subnetworks) there are two technical problems which has been solved by the introduction of the Synchronization Status Message (SSM) protocol. These are:

1) The SEC holdover stability is not defined for high frequency accuracy. This requires to rapidly re-synchronize the SEC after it has lost its synchronization reference input signal. Since the SEC's are typically arranged in a chain the re-synchronization requires to revert the direction of synchronization through a chain network.

2) The SDH sub-network may provide a reference clock output signal towards an SSU. In the case a SEC of the SDH sub-network is running in the holdover mode the reference clock output at some network element of the sub-network may be traceable to that holdover SEC. Since sound network synchronization operation requires not to slave a high quality clock (SSU in this case) to a low quality clock source (holdover SEC) it is necessary to switch off the reference clock output in such case. The function providing such controlled switch off capability is called squelch function.

For solving these problems the SSM had been introduced. The SSM is coded in the S1 byte of the STM-N section overhead and it provides the synchronization status of the equipment being the source of the STM-N signal in terms of traceability to clock sources compliant to the ITU-T specifications EN 300 462-6 [6] (Primary Reference Clock), EN 300 462-4 [4] (Transit Node Clock), EN 300 462-7 [7] (Local Node Clock), and EN 300 462-5 [5] (SEC) for their long term frequency accuracy performance. A further state (DNU = do not use for synchronization) is sent on those ports of an equipment which bear the risk of creating a timing loop if a neighbour network element would select their output signal as a synchronization reference input signal.

The problem of re-synchronization is solved by using the DNU SSM for avoiding timing loops and the QL-SEC SSM for indicating the synchronization problem in the SDH sub-network to all affected SDH network elements. Every network element transmits the DNU SSM from that port it takes its synchronization input reference from, i.e. in the "backward" direction of synchronization distribution. In the "forward" direction it transmits its actual clock quality status. Now, if the input synchronization reference signal to a network element fails the SEC of the equipment will enter the holdover mode sending out the QL-SEC SSM at all its ports. The downstream neighbour network element, which is slaved to the reference signal received from upstream keeps tracking this signal and its synchronization status will drop from the quality it had before (EN 300 462-6 [6] or 4 [4] or 7 [7]) down to EN 300 462-5 [5]. Thus the QL-SEC SSM is propagated all down the synchronization chain. If the network element at the low end of the SEC chain receives the QL-SEC SSM from upstream and it has a better quality from downstream (e. g. from an SSU) it will synchronize to that downstream reference signal. The new synchronization status (better than EN 300 462-5 [5]) is now sent upstream and the next upstream network element can synchronize to the downstream. Thus the SEC's of the chain switch one after the other to the synchronization reference signal received from downstream.

The second problem, i.e. the need to squelch a low quality reference clock output signal, is also solved by using the SSM. The SDH network elements providing the squelch function allow to program a quality threshold below which the clock output signal is squelched. If instead of an output reference clock signal a 2 Mbit/s reference signal is used, then there are two options: If the interface does not support SSM then an AIS is sent if the clock quality is below the squelch threshold; and if the interface supports the SSM it is up to the synchronization client (i.e. the SSU) to deselect any too low quality reference signals.

Further features associated with the SSM protocol are as follows.

In order to prevent any third party from using an SDH signal as synchronization reference source the transmit SSM can be forced to DNU at any port of the SDH equipment.

The SSM based input selection algorithm can be supplemented by allocating priorities to the input ports which determine the selection among several input signals of the same (highest) quality.

NOTE: In order to keep the SSM based restoration mechanisms efficient and meaningful, it is important that the value carried by the SSM of STM-N signals in a network always reflect the actual quality of the timing carried by these signals. Forcing the QL, transmitted as well as received by an equipment, must be avoided with the exception of three cases:

- attribution of a QL to an external 2 MHz source;
- interworking with equipment not supporting SSM processing or operating in QL-disabled mode (cases listed in subclause 4.4.3 of EN 300 417-6-1 [10]);
- prevention of a third party from using a SDH signal as timing source and in the case of interworking between two operators (in the case cited previously in this clause as well as in subclause 12.3.2).

## 8.3.1 Rules for the Synchronization Message Algorithm

The full algorithm describing the operation of the synchronization messages is described in EN 300 417-6 [10] , the following explanation summarizes this description.

An SDH network element uses several criteria to select its active reference. First, the Quality Level of the signal is considered. All references that have the highest available Quality Level are singled out. The Quality Level of a particular reference is either retrieved from the incoming signal overhead or it is programmed by the user. If an incoming reference exhibits signal fail (SF) due to loss of signal, loss of frame or other causes, such a reference can be treated as if it has the quality level DNU.

After this procedure, the references that were singled out are ordered according to the priority that the user assigned to their respective inputs. From this result the reference with the highest priority (within this group of references with the highest quality level) is selected. In case some inputs have equal priorities assigned to them, the result may still be ambiguous. In case multiple references satisfy these criteria, a reference switch is made to an arbitrary input, except when the current reference is among this group, in that case no switch is made.

An alternative, but equivalent, method of description is that, given the priority and Quality Level of the current reference, all other possible reference sources are continuously polled to check for one that has either a higher Quality Level or a higher priority than the current selection. As soon as such a reference is found a reference switch is made to this new input, otherwise the selection remains as is.

Since each network element has to select a reference not only for its internal clock, but also for its external synchronization outputs, there are two independent processes of the above described type active to select the appropriate reference for both purposes.

The reference that is eventually selected is forwarded to the internal clock or the external synchronization output circuitry. These circuits may still reject the reference if the associated Quality Level is insufficient. The internal clock will reject the reference if the Quality Level is lower than the Quality Level associated with its internal oscillator, while the reference for the external synchronization output will be rejected if its Quality Level is lower than a provisioned threshold. In the first case the internal clock will go to hold-over, in the latter case the external station clock output will be squelched, replaced by AIS or a DNU message is inserted (depending on the format of the output signal).

Selection of a reference can be done by the above described automatic selection process, but it is also possible to force a certain selection by means of special commands or lock-out certain references from the selection process. Such commands can be issued by the user through the management system.

Figure 33 shows an example of the reference selector picking the input with the highest priority (input A has Priority 3, which is better than input B with priority 4) between two inputs that both receive the highest quality level (A and B both receive QL = PRC). Although inputs C and D have higher priorities, they will not be selected, because the incoming references via those inputs have lower quality level.

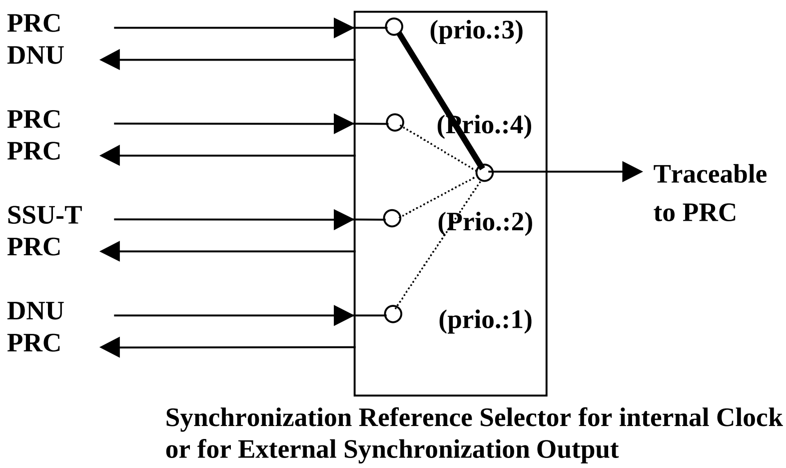



**Figure 33: Quality Levels and port priorities control the synchronization reference selection process**

NOTE: It should be noted that traffic protection and synchronization protection are independent processes, even if they are carried on the same media.

### 8.3.2 Basic rules for Synchronization Message Generation

The messages on the outgoing STM-N signals are rather straightforward to determine. The quality of the selected reference for the internal clock is re-transmitted on all outputs. The exception is the output in the return direction of the input that provides the active reference will have the message "DNU". This is to avoid a timing loop between the first upstream network element and the network element under consideration. If no reference of sufficient quality is available, the network element will proceed using its internal oscillator, i.e. it enters the hold-over state. In that case the outgoing message will be the Quality Level associated with the internal oscillator.

In Figure 33 the outgoing Quality Levels are shown that correspond to the current state of the input Quality Levels, all outputs carry "PRC" since that is the QL of the selected input signal (input A). Output A however transmits "DNU", because this signal is in the return direction of the selected input.

The message that is forwarded over the external synchronization output, provided the output supports synchronization messaging, is the QL of the selected input. If no reference is available with a QL of at least the squelch threshold, the external synchronization output is squelched. This may be implemented as transmitting AIS or DNU in 2 048 kbit/s or by turning the 2 048 kHz signal off.

### 8.3.3 Provisionable parameters in SSM controlled reference selections

The network operator can control the way the synchronization paths are routed and how they restore under different failure conditions by means of a number of basic provisionable parameters in each network element are given in Table 2.

**Table 2: List of basic provisionable parameters for the SSM algorithm**

| Parameter | Possible Values |
|---|---|
| QL mode | enabled, disabled (per NE) |
| Timing source priority | not assigned, 1, 2, 3, etc. (per possible reference) |
| Assigned QL | AUTO, PRC, SSU-T, SSU-L, SEC (per possible reference) |
| Squelch threshold for T4 | PRC, SSU-T, SSU-L, SEC |
| Force DNU | off, on (per STM-N output) |
| Synchronization output enabling | on, off (per synchronization output) |
| Synchronization output source selector | independent, slaved to internal (per NE) |

The provisioning of the SSM parameters is an integral part of any network synchronization design and network synchronization planning. In fact, proper provisioning of these parameters is needed in order to achieve restoration of synchronization under all realistic failure scenarios, while meeting the general objectives for synchronization restoration as stated in the beginning of this clause.

## 8.4 Applications of Synchronization Status Messages

The Synchronization Status Message (SSM) is used for the following purposes:

- To allow synchronization reconfiguration after a failure without creating a timing loop.
- To prevent synchronization reconfiguration of an SSU by a lower quality (SEC quality) derived clock reference.
- To provide information of the long term frequency accuracy of the timing source.

The SSM protocol is supported by a suitable synchronization architecture, i.e. limitation of configured timing references. Within such specific synchronization architecture the SSM protocol can assure the functions quoted above.

The subclauses below describe the configuration and architecture limitations required for supporting SSM's in ring networks and in network nodes employing a SASE.

In this clause, the following SEC representation, shown in Figure 34 will be used.

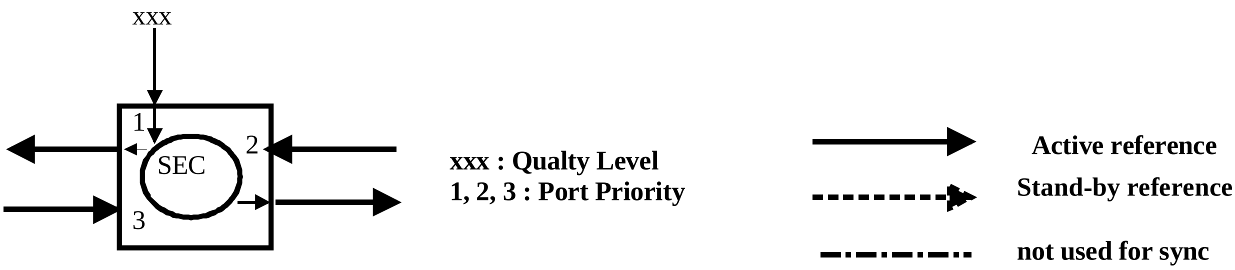



**Figure 34: SEC representation**

## 8.4.1 Application of Synchronization Status Messages in Ring Networks

### 8.4.1.1 Ring with reference in a single NE

To illustrate the mechanism of synchronization restoration by means of Synchronization Status Messages, in this clause the example of a ring network is detailed.

Figure 35 shows a simple 2-fibre ring network which is connected in one location (the hub-node, i.e. the topmost node of the ring) to the synchronization of the main network. The ring itself contains add/drop multiplexers (ADMs). Synchronization is distributed via the hub-node to the other nodes on the ring. The synchronization signal obtained from the main network is in this example supposed to be traceable to the PRC. This message is sent around the ring in both directions by the hub node. Other nodes re-transmit this message and return DNU (Do Not Use for synchronization) upstream. The provisioned port priorities determine how the timing flows in the ring when no failures are present. In the example in Figure 35 the normal flow of timing is clockwise through the ring, but it is also possible to time the ring partially clockwise and partially counter-clockwise by reversing the port priorities on a part of the nodes.

In case of a defect in one of the links that form the ring, the first downstream node goes into Hold-Over, since no other option is available. (The STM-N from the other direction is labelled "don’t use" and may not be selected. A timing loop would be created if it was.) This node changes its sync message to "SEC". All downstream network elements remain locked to the node in hold-over. So, one by one all downstream nodes replace their outgoing message by "SEC".

The final node before the hub-node however will not remain locked to the chain, since it receives on the other STM-N input a signal of higher quality, conveyed by the message "PRC". This node will perform a reference switch and adapt its outgoing SSMs accordingly. Figure 36 shows the situation at this moment.

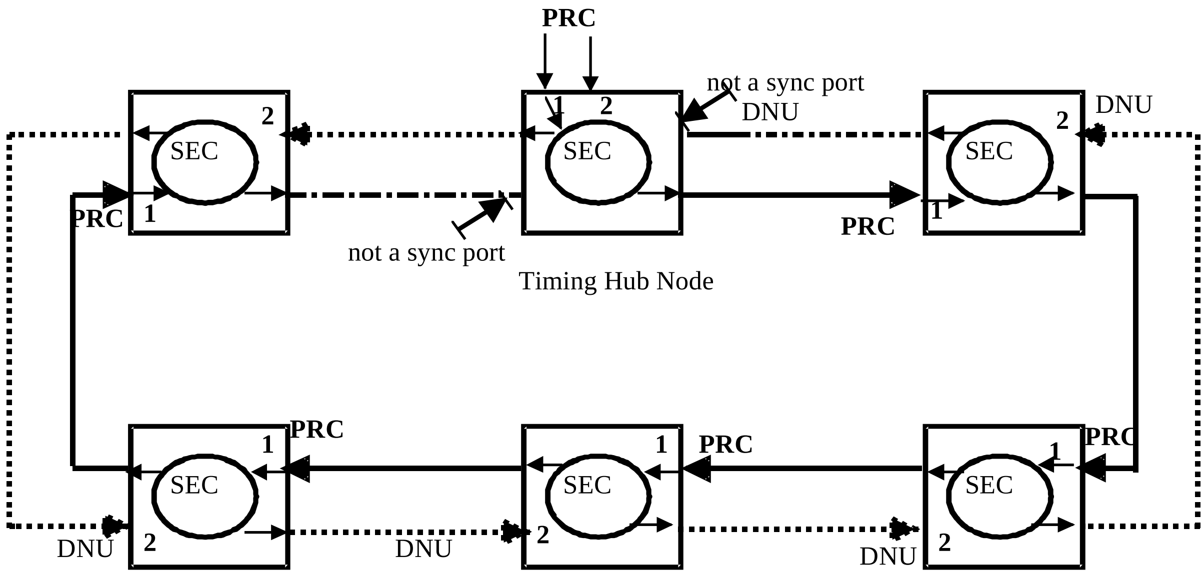



**Figure 35: Ring network with SSMs and Port priorities-normal situation**

Next, the node before the last node makes the same reference switch, since it can now choose between a reference with quality level "SEC" from the original direction and one with quality level "PRC" from the other direction (changed from "DNU"). This process repeats until the node that originally switched to Hold-Over is locked to the timing signal from the other side of the ring. The final situation is depicted in Figure 37.

The whole process of restoration, for rings of at most 20 nodes, must be finished within 15 seconds. This ensures that the phase transient in the timing of the node in hold-over is less than 1 µs. As soon as the cable break has been repaired, the original situation will be restored, due to the higher port priorities for references in the original direction of synchronization.

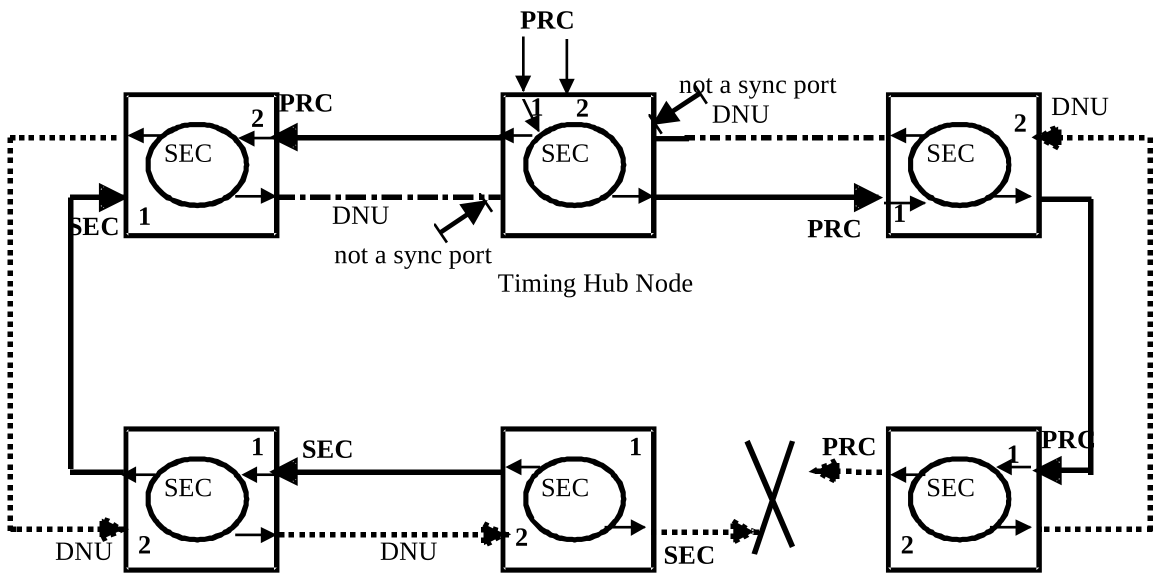



**Figure 36: Ring Network in restoration Process- last node switched reference**

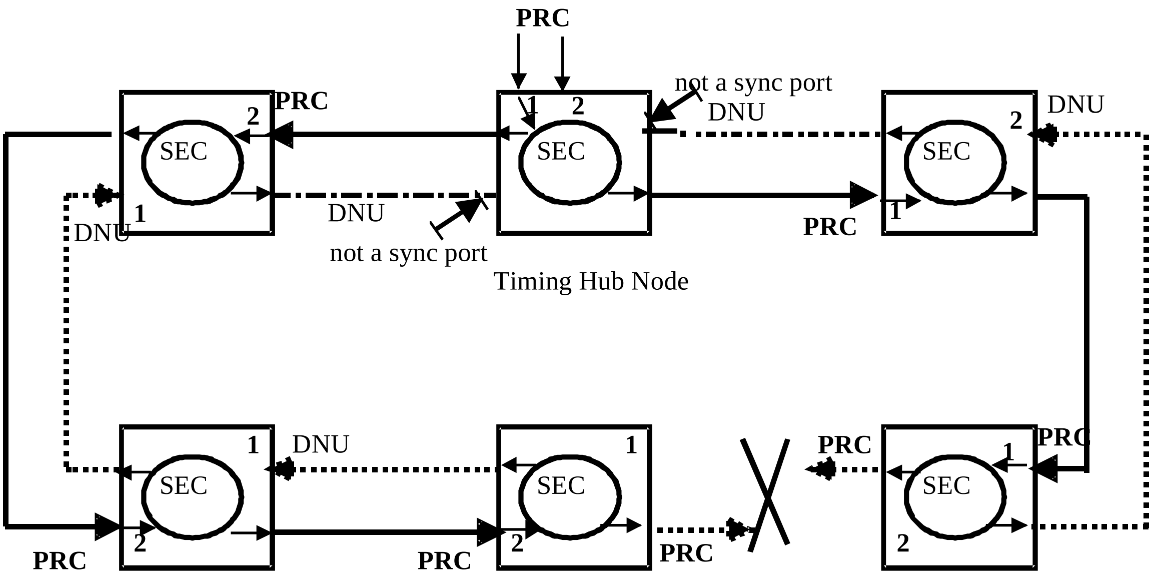



**Figure 37: Ring Network in Restoration Process: Final Situation**

### 8.4.1.2 Ring with reference in different NE's

In the case of external clock supply to a ring network at a single node only, there is no need to synchronize the NE receiving the external clock with a second timing coming from the ring; this prevent any possibility of generation of a timing loop during protection events. But this simple configuration is not protected against failure of the single NE of the ring providing timing from an external reference.

To provide protection against all single failures of the synchronization distribution network then at least two independent timing sources should be available to each sub-network. However careful planning must be done to ensure that timing loops cannot be generated.

Taking the case of a simple ring with external timing sources at two network elements subclause 8.4.1.2.1 shows how easily a timing loop can be created without careful planning. Subclause 8.4.1.2.2 gives an example of how correct planning can prevent such problems.

#### 8.4.1.2.1 Example of timing loop generation

In the next figure, each of the two external timingnodes (node with external timing) can be synchronized, either by is external clock or via any of the 2 lines. In case of failure of the active external clock in timing node 1, this node selects its fourth priority, which carries the timing generated by itself. This is a timing loop situation.

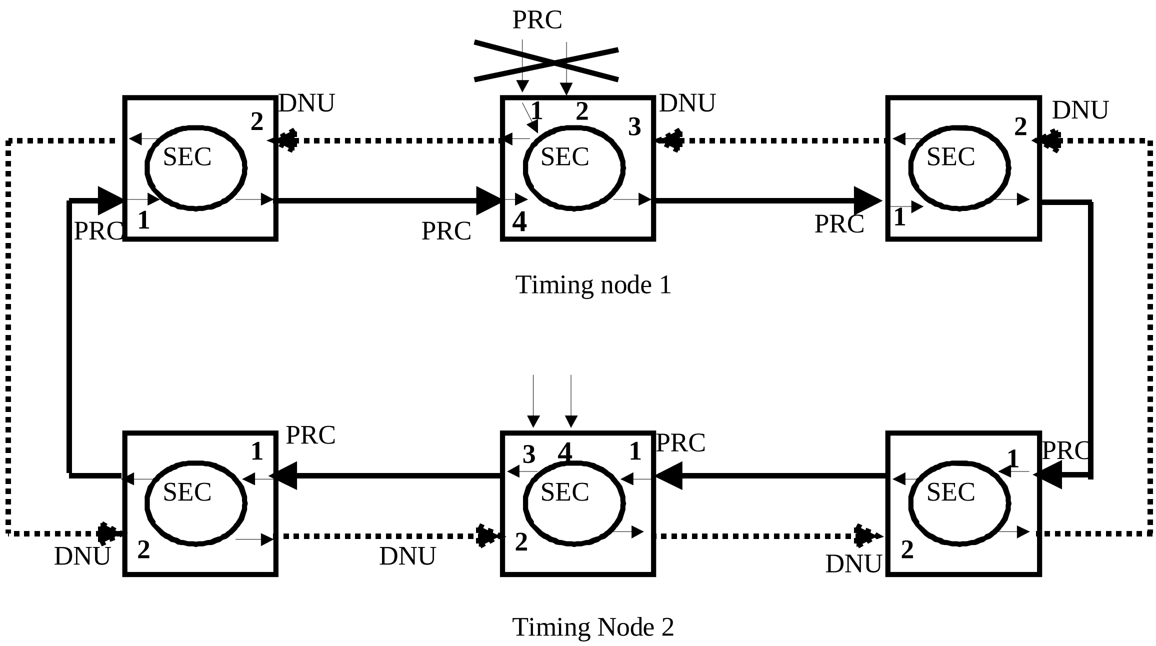



**Figure 38: Example of timing loop**

#### 8.4.1.2.2 Configuration with a single active external reference

In this configuration, only one external reference is active on the ring in nominal condition.. This allows the use of single synchronization reference to synchronize the whole ring.

In nominal condition, timing node 1 delivers timing to all nodes of the ring, including timing node 2.

Note that each timing node is not allowed to be synchronized on its west (east) line port when it normally transmit synchronization to its east (west) line port so that it is impossible to generate a timing loop.

In this example, the 2 Quality levels of the signals provided to the 2 external timing nodes are QL and QL*. They can be provisioned in the case of 2 MHz external timing signals or read on the S1 byte in case of timing provided by a STM-N tributary. These 2 quality levels can be different.

In Figure 39 QL is higher or equal quality than QL*; if not, the timing node 2 would deliver the timing to the ring as it is the case in Figure 40.

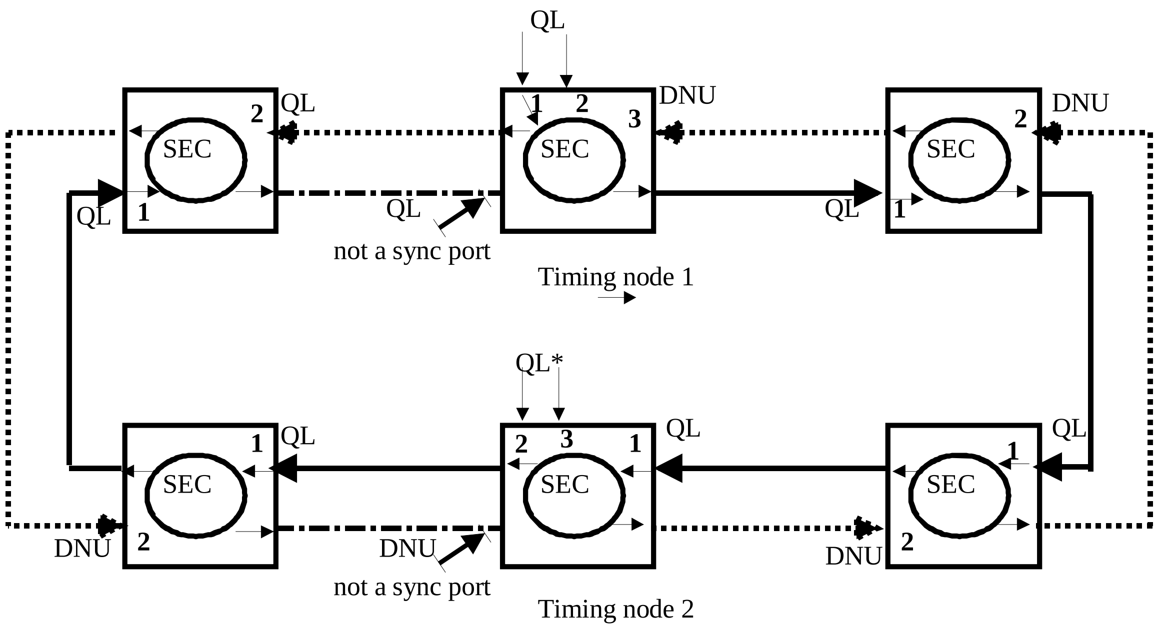



**Figure 39: Ring synchronized to one of the 2 references**

On Figure 40, the external reference of timing node 1 fails; bold lines show how synchronization is rearranged from timing node 2.

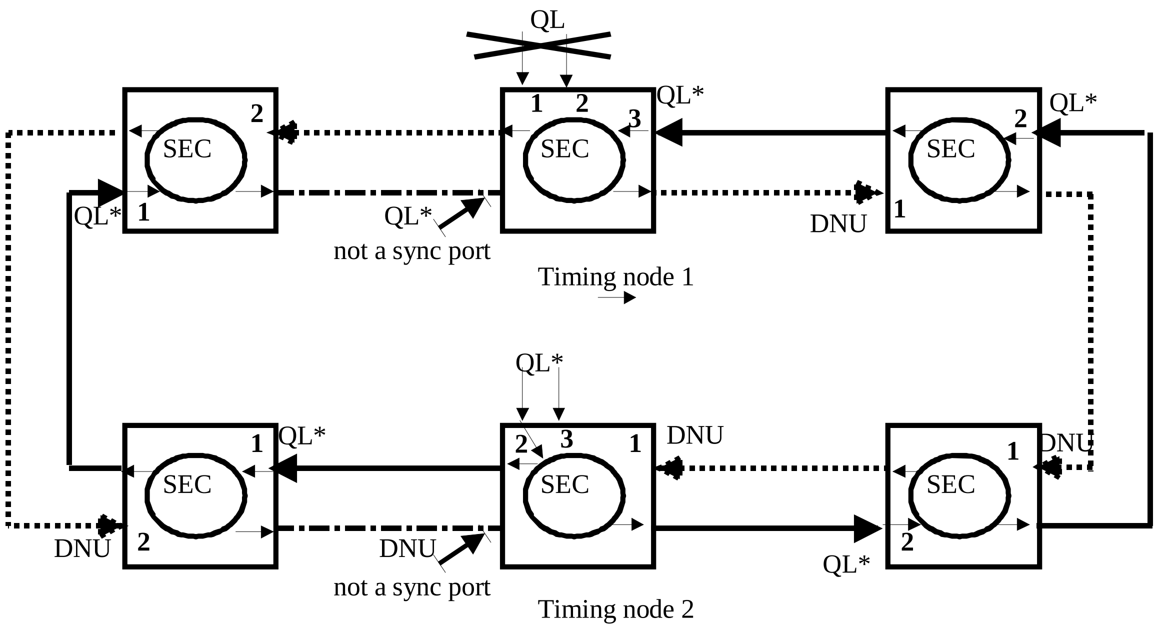



**Figure 40: Ring synchronized on a single reference in reference LOS condition**

As an alternative, another configuration can be realized by changing the priorities of timing node2. It is possible to configure the 2 external timing nodes 1 & 2 of timing node 2 with priority 1 allocated to the external source. In this case, this means that when QL and QL* are equal value, 2 external timings will be used simultaneously in the ring.

## 8.4.2 Integration of SASE into Synchronization Status Message Protocol

### 8.4.2.1 With 2 Mbit/s signal reference interface

The SSM received in the SDH network element by an STM-N input is transferred to the 2 Mbit/s signal reference output derived from that input and connected to the SASE. The SASE is configured to select its input according to the received SSM quality indications.

The filtered output reference of the SASE is provided by 2 Mbit/s signals with SSM to the network elements. They derive their transmit SSM from the received SSM on the 2 Mbit/s reference signal they are synchronized to.

For prevention of timing loops three configurations are available:

- Allocate a fixed SSM= "DNU " to all T1 interfaces, in backward direction, that have been selected as source for T4. Adopting this solution will prevent NE's to revert synchronization in the backward direction.
- Allocate dynamically SSM= "DNU" to the T1 interfaces that have been selected as source for T4.
- Allocate dynamically SSM= "DNU" to the T1 interfaces that have been selected as source for T4 and which have the same quality level as received from the SASE.

NOTE: These configurations will not prevent any risk of timing loops in the network; a correct configuration of SEC's is still required to prevent timing loops in the network. Figure 41 shows an example of network where the above rules cannot prevent a timing loop between an SEC and an SSU.

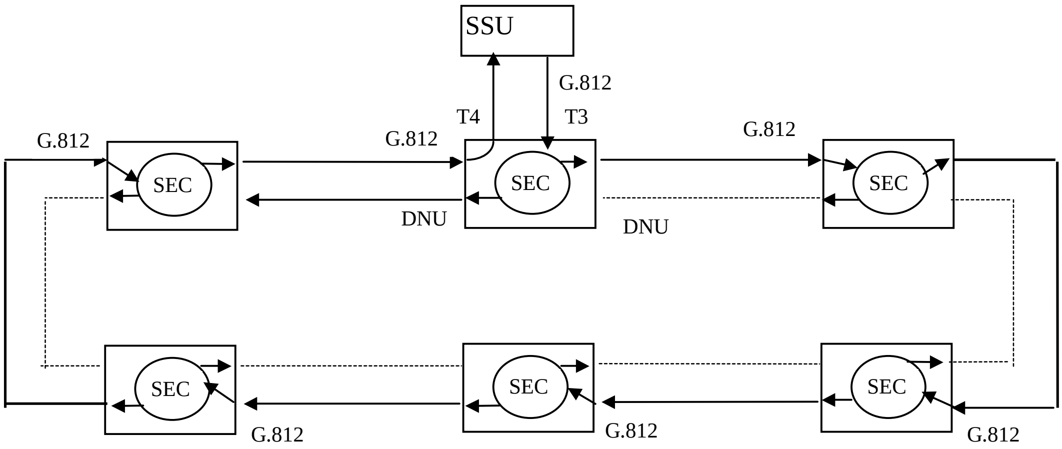



**Figure 41: Example of timing loop between SSU and SEC**

### 8.4.2.2 With 2 MHz clock reference interface

The integration of SASE into the SSM process with 2 MHz reference interfaces is realized with the squelch function of the T4 output of the SEC.

- T4 Squelching

As an SSU of a certain QL should lock on the signal sourced by an SSU of the same QL and must not lock on a signal generated by a lower QL than its own QL, the squelch threshold of the T4 should be set to this QL value. Accordingly, it is not possible to distinguish between a received T1 with a SSM QL-PRC or QL-SSU.

- Set of QL at the SEC output

The 2 MHz input port T3 is allocated a fixed QL value, PRC or SSU.

- Prevention of timing loops

For prevention of timing loops two configurations are available:

- Allocate a fixed SSM= "DNU" to all T1 interfaces, in backward direction, that have been configured as candidate for source to T4. Adopting this solution will prevent NE's to revert synchronization in the backward direction.

- Allocate dynamically SSM= "DNU" to the T1 interfaces that have been selected as source for T4.

NOTE: These configurations will not prevent timing loops in the network; a correct configuration of SECs is still required to prevent timing loop in the network.

# 9 Maintenance Strategies

The ITU-T Recommendation M.2130 [21] "Operational procedures for the maintenance of the transport networks" is a basis for maintenance strategies. The Annex A "Synchronization faults" of this recommendation concerns the maintenance of synchronization.

According to this recommendation synchronization faults are detected in SSU's, but the SEC's with their associated SDH functions of reference clock selection and squelching give even more important fault information, especially on more severe effects such as SEC holdover which causes a much larger frequency offset than SSU holdover.

Maintenance should be done in order to keep the performance within G.822 [20] limits.

The following flow diagram is derived from the maintenance procedure as described in ITU-T Recommendation M.2130 [21]. While the ITU-T Recommendation gives rather generic terms such as "synchronization fault", "severe degradation" or "information regarding the event" we do here a mapping on alarms and well defined events described in EN 300 417-6-1 [10] and in EN 300 462 [1] to [7] (all parts).

In the **first stage** the synchronization fault is detected by:

- loss of reference signal input to a clock (SEC, SSU);
- holdover operation of a clock (SEC, SSU);
- frequency offset detection on a selected or on a non selected input (SSU only);
- excessive wander detected on an input (SSU only).

In the **second stage** the failure cause shall be checked. This can be done remotely by checking the relevant SDH synchronization distribution functions using the SDH management system or a dedicated management system for synchronization network management which looks on both, the SDH NE's and the SASE's:

- received AIS or LOS on STM-N or 2 Mbit/s reference inputs;
- squelched T4 outputs;
- received quality level below the clock's intrinsic quality.

If the remote checking is not successful providing the reason of the fault then local checking for cable cuts or other physical faults is required.

**Third stage:** Recording the event information. This is the normal procedure performed by management systems.

**Fourth stage:** If it is a severe degradation, i.e. an SEC of the synchronization distribution chain is in holdover mode, then the downstream synchronization node shall be informed about the event. This is normally done via the SSM, but it can also be done via the management system if the SSM protocol is not available on the link. This information allows the downstream SSU to deselect the degraded reference signal.

If the degradation is not a severe one, e. g. an SEC has lost all but one of its reference input signals, the restoration maintenance action may provide a second reference signal in order to re-establish the required synchronization redundancy.

**Fifth stage:** The synchronization fault is repaired by repairing the failed transmission link or by changing failed equipment parts.

**Final stage:** The integrity of the synchronization may be checked by monitoring the MTIE and / or TDEV parameters using the built in measurement capabilities of SASE's or by using portable test sets and with or without comparing the test signal to a suitable timing reference signal such as a GPS derived signal or to the local Caesium reference of the test set. Finding the measurement result to be within the relevant network wander limits forms the basis to declare the synchronization fault to be removed successfully.

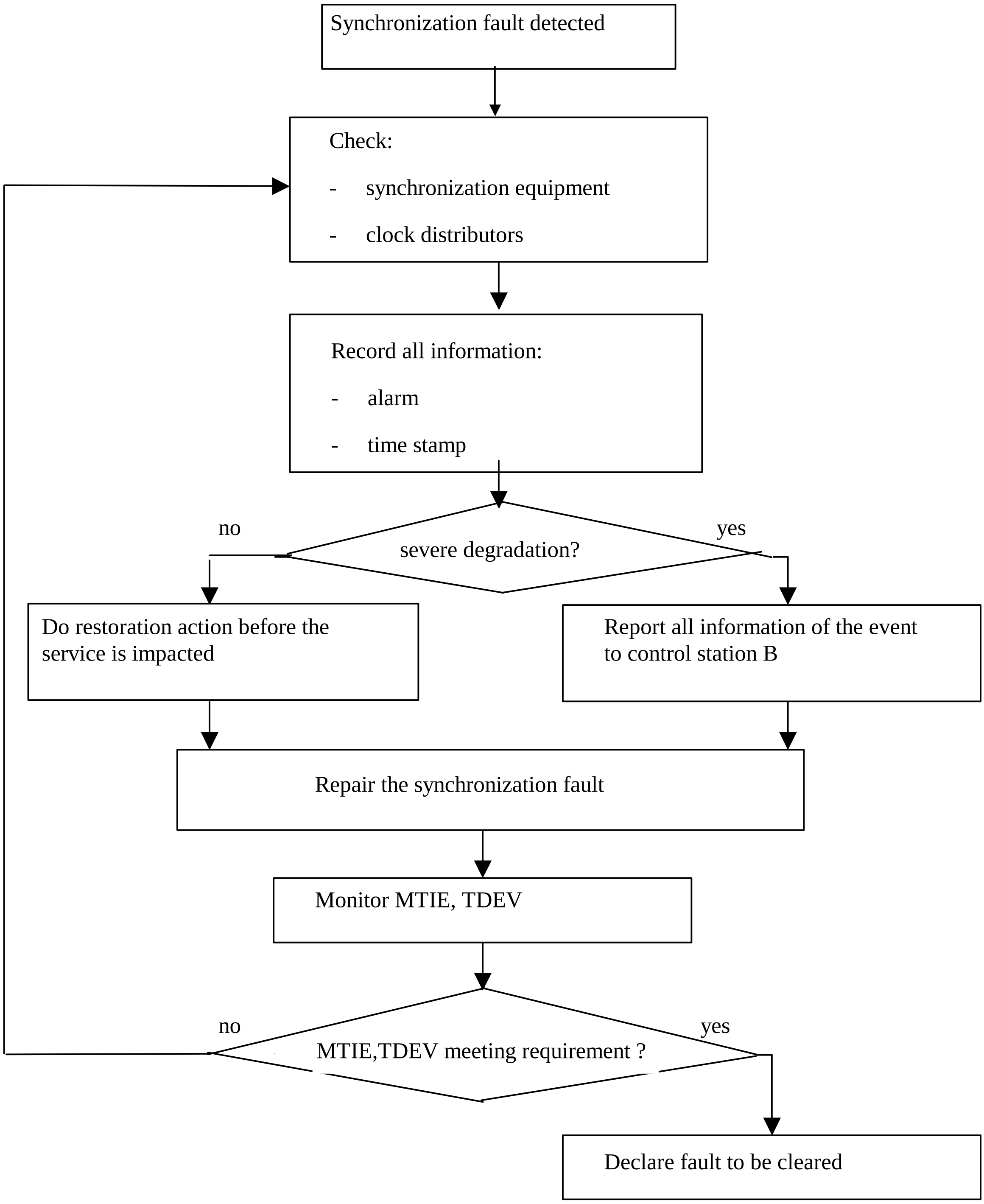



**Figure 42: Flow diagram for synchronization network maintenance response on failures**

# 10 2 Mbit/s retiming applications

By using retiming methods, it is possible to alter the ownership of the synchronization network. This can be of significant especially in the case of leased lines. Where the leased line client expects timing transparency but because of a retiming function in the server network will not be getting timing transparency.

NOTE: There is no ETSI document that specifies the retiming feature. However, it is commonly understood under the term "retiming" a function of force clocking a 2 Mbit/s signal by an external reference clock (i.e. not the clock derived from the 2 Mbit/s signal itself). The performance of such function is not specified by any ETSI deliverable.

## 10.1 Definition

Retiming data means that this data is timed by another clock rather than by its own clock source. This function can be implemented by writing a recovered signal into an elastic store (buffer) and time the output of that elastic store with another clock source, e.g., an SEC (if implemented in an SEC).

Normally, in the absence of retiming, the rate of the outgoing signal is equal (when measure over a long enough time) to the rate of the 2 incoming signal; in case of retiming this relationship disappears. This means that data will be lost each time the phase difference between the 2 Mbit/s where it is mapped into a VC12 and the NE clock of the desynchronizing node is larger than the buffer space of the retiming buffer. In case of frequency offset, this will lead to continuous buffer slips. This function is described in Figure 43.

The control of the slippage can be realized in several different ways:

- By methods causing Signal Fail (SF) in downstream equipment.

When slips are of a nature such that they cause a loss of basic frame alignment in downstream equipment, then an SF and subsequent rejection of the signal as a reference will follow. The effect on the synchronization will normally be small, as it is only a temporary rejection of the reference. It will be requalified again after a reframing cycle, usually restricted to one severely errored second (SES).

**A1**: bit slip method

Whenever the buffer is full or empty it is recentered, without regard for byte or frame boundaries in the involved 2 Mbit/s bit-stream. After each recenter operation, downstream equipment will certainly suffer loss of frame and go through a reframe process. This method does not require a G.704 [14] frame structure to be present.

**A2**: byte slip method

Whenever the buffer is full or empty, a whole number of time slots in the data signal is repeated or deleted. After each slip operation, downstream equipment will certainly suffer loss of frame and go through a reframe process.

**A3**: simple frame slip method

Whenever the buffer is full or empty, exactly one whole frame is deleted or repeated. This requires a slip-buffer of at least 125 µs and a G.704 [14] structure in the 2 Mbit/s signal. After each frame slip, downstream equipment will certainly suffer a loss of basic frame alignment, as the odd-even sequence is interrupted, and go through a reframe process.

- By a method that avoids Signal Fail (SF) in downstream equipment

**B1**: Double frame slip

Whenever the buffer is full or empty, two whole frames are deleted or repeated. This requires a slip-buffer of at least 250 µs and a G.704 [14] structure in the data signal. A slip event of this type should not cause loss of basic frame alignment, but only a loss of multi-frame alignment. The latter should not cause an SF and hence no temporary rejection of the reference. Unfortunately, many equipment in the field will declare loss of basic frame alignment after sustained CRC-4 errors. The applicable standard (ITU-T Recommendation G.706 [15]) is only been updated recently: therefore the "double-frame slip" method must in practice often be placed in the category of methods causing SF.

A general problem for any retiming scheme is that if the local clock of the retiming node looses its reference, the 2 Mbit/s signal must be replaced by AIS, analogous to the squelching of a 2 048 kHz synchronization output. This destroys the data content, but is necessary to signal the downstream switch that it has to select another reference or go into holdover.

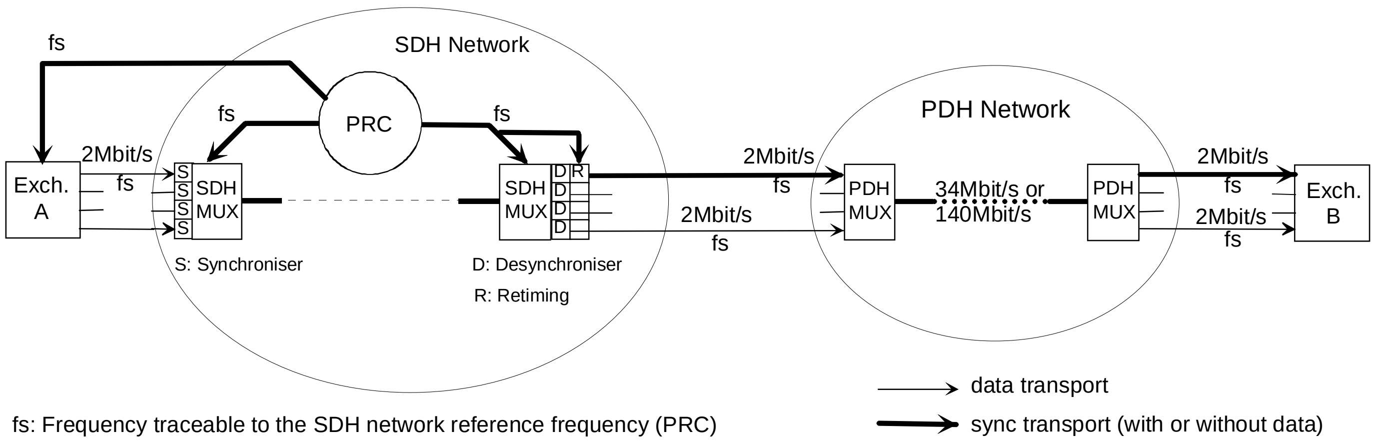



**Figure 43: Retiming of synchronous 2 Mbit/s**

# 10.2 Network applications for 2 Mbit/s retiming

## 10.2.1 Transport of synchronization between Digital Switches

When timing is to be transported between, for example, two digital switches, it is recommended to use the STM-N as a carrier. If however the latter part of the distance between adjacent switches does not deploy SDH, then such method is not possible if no dedicated synchronization signal is present at the input of the switch as shown in Figure 44. Retiming one 2 Mbit/s signal could solve this problem, as shown in Figure 46.

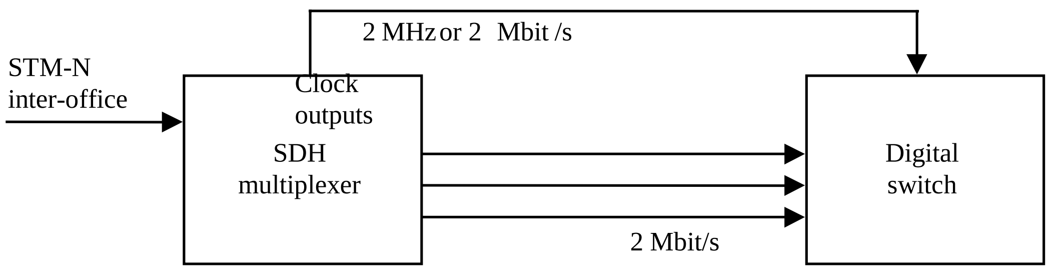



**Figure 44: Synchronization of a switch via a dedicated synchronization signal**

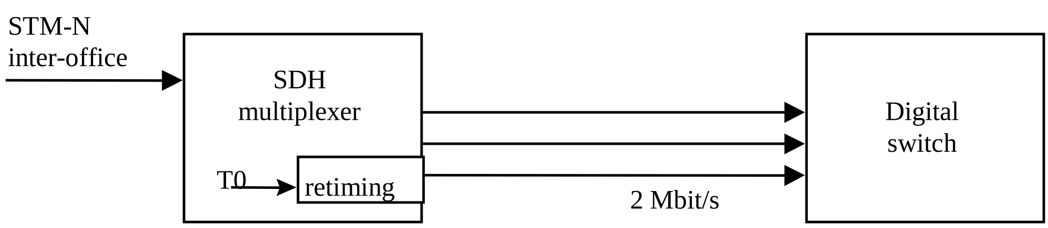



**Figure 45: Synchronization of a switch via a retimed 2 Mbit/s**

## 10.2.2 Transport of synchronization between a Digital Switch and customer Premises equipment

Customer premises Equipment (CPE) will not often be co-located with the SDH multiplexer that desynchronizes the 2 Mbit/s which has that customer as its destination. As soon as the distance is larger than a couple of 100 meters, the 2 048 kHz interface is not adequate to provide timing to the CPE. Moreover, many CPE do not have 2 048 kHz dedicated inputs for timing, while also the number of 2 048 kHz outputs of an SDH multiplexer is usually limited. In all such cases, the only practical way to time the CPE is to use the 2 048 Mbits data link, contrary to EN 300 462-2 [2].

In the case described above, retiming the 2 Mbit/s going to the customer avoids the problem of phase hits generated by TU 12 pointer adjustments in the SDH exit node. This is an advantage, as it would eliminate possible alarms in CPE equipped with a very narrow-band (<<1 Hz) internal clock.

On the other hand, the distances between the final switch and the customer are usually small, so that only a single SDH island is present. The probability of TU 12 pointer adjustments is very low in such networks, certainly if fast restoration mechanisms are used to heal cable cuts or equipment failures in the SDH access network. The SSM algorithm, specified in EN 300 417-6-1 [10], is fast enough to keep phase transients associated with failure events within 1 µs, hence in most cases a pointer adjustment is avoided even under such conditions. It is not clear that retiming would result in better network performance than if pointer adjustments are just accepted and no retiming is applied; the performance depends on retiming implementation and on the application.

If retiming is applied in switch-CPE traffic and the SDH exit node goes into holdover, two options exist:

- AIS insertion with loss of all data traffic;
- Data service continues with poor timing transportation and potential poor slip performance.

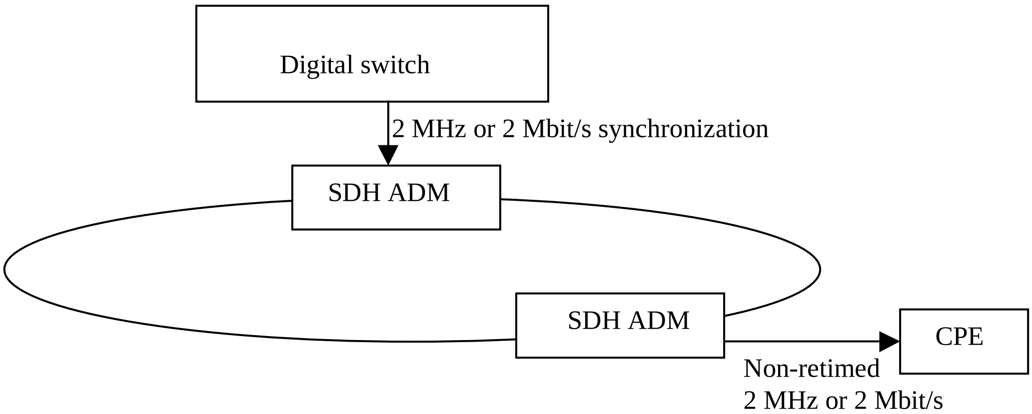



**Figure 46: Timing flow in an SDH access ring from switch to CPE**

## 10.2.3 Transport of Synchronization between multiple CPE

In this application, 2 Mbit/s retiming can only be used if the private network is synchronized from the public network, otherwise continuous slippage will occur. Even the occasional slips will occur if the connections between the customer sites become so long that accumulated wander occasionally exceeds the size of the retiming slip buffer. Additionally, all problems mentioned for the case of traffic between the switch and the CPE also can occur in this case.

Retiming 2 Mbit/s is not a solution for problems associated with, third party timing.

# 11 Managing the Synchronization Network

## 11.1 Need for Managing the Sync Network

Management of synchronization networks is required to provide a network view to the operator.

## 11.2 Requirements for a Synchronization Network Management System

The following requirements to the synchronization management system allow the network operator to minimize the cost for operating the network by remote initiation of required maintenance actions, if possible, or by physically accessing only the very node which needs physical maintenance work to be done.

These requirements are:

1. Display the current configurations of equipment within the network:
   The manager should be able to retrieve the synchronization relevant configuration from all equipment part of the synchronization network (SASE's and SDH-NE's), e. g. input priority, SSM quality allocations, existing manual or forced switch states.

2. Display the network synchronization topology:
   This function should allow to display the currently active synchronization trails starting at the PRC and running through a sequence of SDH subnetworks and SASE's. Also the inactive redundant synchronization paths should be shown.

3. Fault management

   - Monitor for faults

   The management system should monitor the loss of signal and degraded signal alarms issued by the equipment (SASE and SDH equipment incorporating an SSU may monitor the absolute frequency offset of the input signal. With this feature a degraded signal alarm will be issued if a certain threshold is crossed). Also any equipment alarm and any input signal loss alarm should be monitored.

   - Trouble shooting

   The management system should allow any manual interaction in order to alleviate existing problems. Such actions include the manual and the forced selection of an input signal and disabling of an input port. Forced squelching may also be used.

4. Allow to change the current configurations of equipment within the network: Although the synchronization configuration is rather static and not subject to frequent changes the management system should allow to modify the configuration remotely in all the equipment of the network (SDH and SASE).

The requirements listed below are used to improve the performance of the synchronization network:

1. Collect performance measurement data from the equipment within the synchronization network:
   Some types of synchronization equipments allow to online measure the wander of their input signals. The measurement results (either threshold crossing events or complete measurement data files) from various network nodes may be collected by the management system.

2. Support of SSM's between SDH-NE's and SASE:
   The management system may also be used to determine the correct SSM to be sent out at STM-N ports of the SDH-NE's. The management system may change this allocation to PRC if it finds from its over all network view that the SASE is tracking an input reference signal which is traceable to PRC. As an example, if an operator normally allocates the SSU code to the input coming from a SASE as this is the highest guaranteed quality, then the management system could change this allocation to PRC if he knows this is the current source for this signal.

Furthermore some support to the engineering of the synchronization network may be given by the synchronization management system. Especially for designing extensions to the existing telecom network the management system may support the synchronization configuration of the added equipment by giving synchronization network topology proposals for the new parts in relationship to the already existing network. Any modification made to the synchronization network configuration should be checked for potential timing loops under failure conditions. Furthermore the system may check whether isolations from PRC traceable signals may be caused by failures and whether such isolations would be clocked by a SSU or a SEC.

NOTE: It is not always possible to isolate the synchronization functionality of NE's (e.g. SASE and SDH) for specific monitoring by a dedicated synchronization management system. Nor is it possible in a larger network to display in detail the synchronization trails. So, in these circumstances, synchronization management could be performed at two levels. The first level would deal with PRC and SSU (SASE) in a specific system; the second level would be a subset of the transmission management system limited to the synchronization functionalities of NE's.

As an extra to the various requirements and actions described above, the operator will have to correlate troubles and faults appearing on a level with events on the other level, and to take necessary actions to remedy them.

# 12 Synchronization Interworking between Operators

## 12.1 General

The concept of telecommunication networks operating fully synchronously is derived from the synchronization needs of the synchronous switching technique, and it requires all networks to operate synchronously or at least pseudo-synchronously in the long term. Synchronous operation of the networks of several operators needs either to synchronize one operator domain to another operator's domain or to jointly synchronize the networks to a common PRC. Exchanging synchronization between networks is limited by performance degradation due to wander accumulation and finally it is difficult because of administrative issues. Thus the first digital telecommunication networks have been operated pseudo-synchronously. With the GPS technique a common PRC becomes available all over the world at reasonable cost per unit. This allows running the networks synchronously but individually synchronized to a common PRC reference.

The decision on which solution (synchronizing to another network, use of Caesium PRC or use of GPS PRC) is the most suitable and most economic one depends on the network type and size.

## 12.2 Independent Synchronization

### 12.2.1 National Operator Aspects

For large national or international network operators it is important to have an autonomous and independent network solution. Such operators normally use a Cs-PRC. This makes them independent even from the administration running the GPS. Although the cost of a Cs-PRC exceeds that of a GPS-PRC it is still a marginal fraction of the overall network investment.

Performance objectives (e.g. controlled slip rate objectives on international connections as specified in ITU-T Recommendation G.822 [20]) are met with proper design of the synchronization network within each operator domain.

### 12.2.2 Competitive Operator Environment

Network operators who want to be independent from their competitors may use GPS-PRC's. As a backup they may use reference signals from other network operators the configuration limitation of which is discussed below.

Furthermore the flexibility in terms of changing business relationship between network operators is supported by autonomous synchronization. If an operator domain "A" is synchronized to reference signals received from other operators domain "B" and if that relationship is changed such that a third operator "C" replaces the role of operator "B" it is very likely that the operator "A" needs to modify the structure of his synchronization network because the physical locations of the reference signal interfaces may be at different places. Such impact which may cause service degradation due to the synchronization reconfiguration work is avoided by using autonomous synchronization.

## 12.3 Exchange of Synchronization Reference Signals

Not all network operators are able to distribute synchronization references via own network facilities, e.g. operators using leased lines for transmission. GPS based PRCs can solve the distribution problem for some operators, but not for all. For economical reasons, it is not realistic to place a GPS based PRC at every minor point of interconnect. Furthermore, it is not possible to mount a GPS antenna at all locations due to either physical or contractual constraints (e.g. in situations where co-location is used).

If synchronization reference signals are exchanged between two network operator domains these network operators run a common synchronization network which normally requires an unique planning and configuration authority in order to avoid creation of timing loops. Such unique handling of synchronization is normally prohibited by the administrative boundaries of the involved network operators.

However, if one operator domain works as a synchronization distribution network while the other operator domains are slaved to such synchronization master domain there is no risk of creating a timing loop between different operator domains.

An operator using synchronization references from one or more synchronization providers still needs careful planning of his synchronization network. The planning should take into account the performance requirements, available references, distribution facilities, network elements and the size of the network to be synchronized (cf. paragraph 7.10). The use of several synchronization providers further complicates a coherent synchronization network planning.

Depending on the actual situation, further detailed information or less detailed information on the synchronization references is needed. There are a number of issues which can be relevant, such as:

- Quality of the synchronization reference signals under normal operation. This could be related to the network limits in EN 300 462-3-1 [3] and the frequency accuracy in EN 300 462-6-1 [6].
- Quality under failure conditions (holdover accuracy, e.g. related to EN 300 462-4-1 [4]).
- Performance under transition from normal to failure condition and vice versa (e.g. related to relevant requirements in EN 300 462-4-1 [4] and EN 300 462-5-1 [5]).
- Availability of the reference signal (this may differ from the availability of a related traffic service).
- How is the operator informed in case of failures or degradation of the reference signal (e.g. via squelching of synchronization signals, via SSM or via management information).
- The use of SSM (if supported by the synchronization interface) and which code is transmitted if SSM is not used.
- In situations where retiming is provided, the slip method applied may be important (see Clause 10).

### 12.3.1 Long Distance Operator – Regional Operators

Some operators co-operate in the way that one of them provides a long distance national or international backbone network and the others run regional networks providing access to the backbone. In such case the backbone network can take over the role of synchronization distribution to the regional networks.

The synchronization signal distributed by the long distance operator will be degraded by wander accumulation and by faults in the synchronization distribution network and consequent SSU holdover operation. In order to improve the synchronization quality the regional operator may run a PRC (e. g. implemented by GPS) as backup redundancy. Synchronizing to the reference signal of the long distance operator in the first priority ensures synchronous operation of all the network. Having a PRC as backup guarantees the best possible synchronization performance in the regional network. The commercial SASE's provide facilities for comparing reference clock inputs and for configuring performance thresholds for rejecting degraded input signals. However, these features are not specified within ETSI documents.

### 12.3.2 Transmission Carrier – Service Providers

A service provider may synchronize its service switches to a clock reference from the carrier he is connected to. This is perfect if only a single carrier is used. If several carriers are used the service network may run pseudo-synchronously instead on synchronously, e. g. if the carries are synchronized to different PRC’s. Although the pseudo-synchronous network experience some slips, the rate of such slips is sufficiently low not to impact the service quality because of the very high PRC clock accuracy defined in EN 300 462-6-1 [6].

However, if the service provider needs to use retiming function in the carrier network or he runs retiming function on his own equipment which is clocked by different carrier clock reference signals at different locations in the network then the performance of the service may be impacted because the slip event caused by retiming equipment is worst than a frame slip created by the frame aligner of a service switch.

Any network operator can hide his actual synchronization quality for his clients even at STM-N interfaces by forcing the SSM quality to "Do Not Use". This indicates that the operator does not want to give synchronization to the client.

## 12.4 Performance Issues

The payload performance of SDH based transport networks is not directly impacted by impairment of synchronization such as wander or frequency offset, but the performance of the synchronization reference output signals towards the service switches may be degraded. Such impact can actually be detected indirectly by the performance of the service signal (jitter, wander, frame slips or even bit slips). Direct detection of synchronization degradation is possible if there is an alternative sufficiently accurate and stable clock reference available, e.g. from GPS.

The performance of synchronization reference signals between networks may be guaranteed on contractual basis. Such contracts may address the availability of the interface signal, the availability of PRC quality signals, and the maximum frequency offset if not at PRC quality. The synchronization offering network operator may need to provide a SASE close to the interconnecting point in order to improve the holdover quality, he may need to duplicate the synchronization links towards the SASE and he may need to provide duplicate interface signals in order to meet the contract.

# Annex A (informative): Examples of Subnetworks employing SSM controlled restoration

## A.1 Introduction

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

In Figure A.2 through Figure A.8 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 A.1. 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 A.1). The arrows arriving at and leaving from the network element denote the synchronization carrying in- and outputs (either STM-N, 2 048 kHz or non-SSM-carrying 2 048 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 down-stream 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-T", "SSU-L" or "SEC".

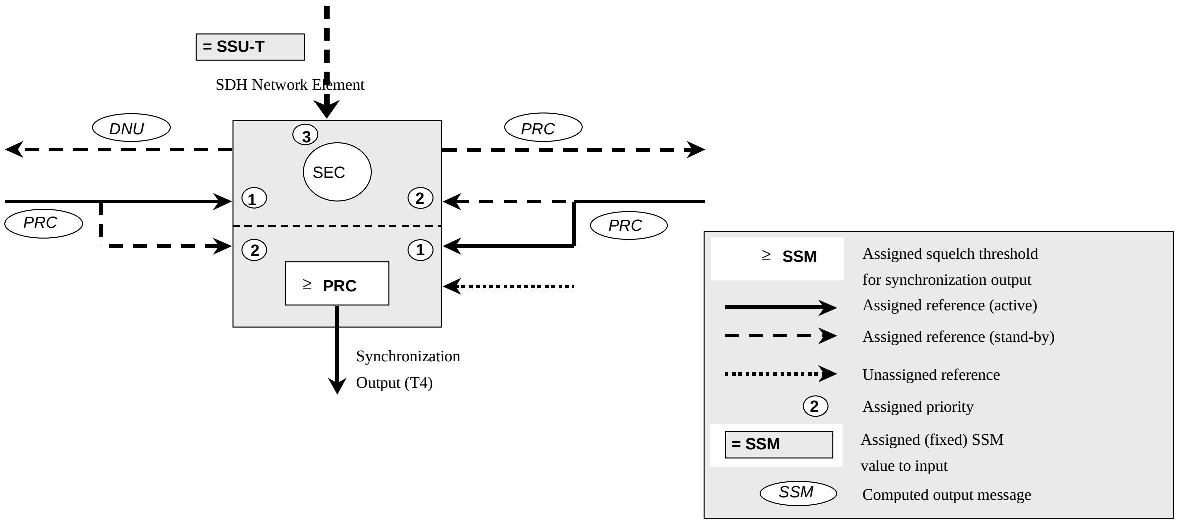



**Figure A.1: Conventions used in SEC sub-network drawings**

NOTE: The upper part of the grey box, with the disk labelled SEC, includes the selector B as specified in EN 300 462-2 [2]; the lower part includes the selector A as specified in EN 300 462-2 [2].

# A.2 Network example n°1

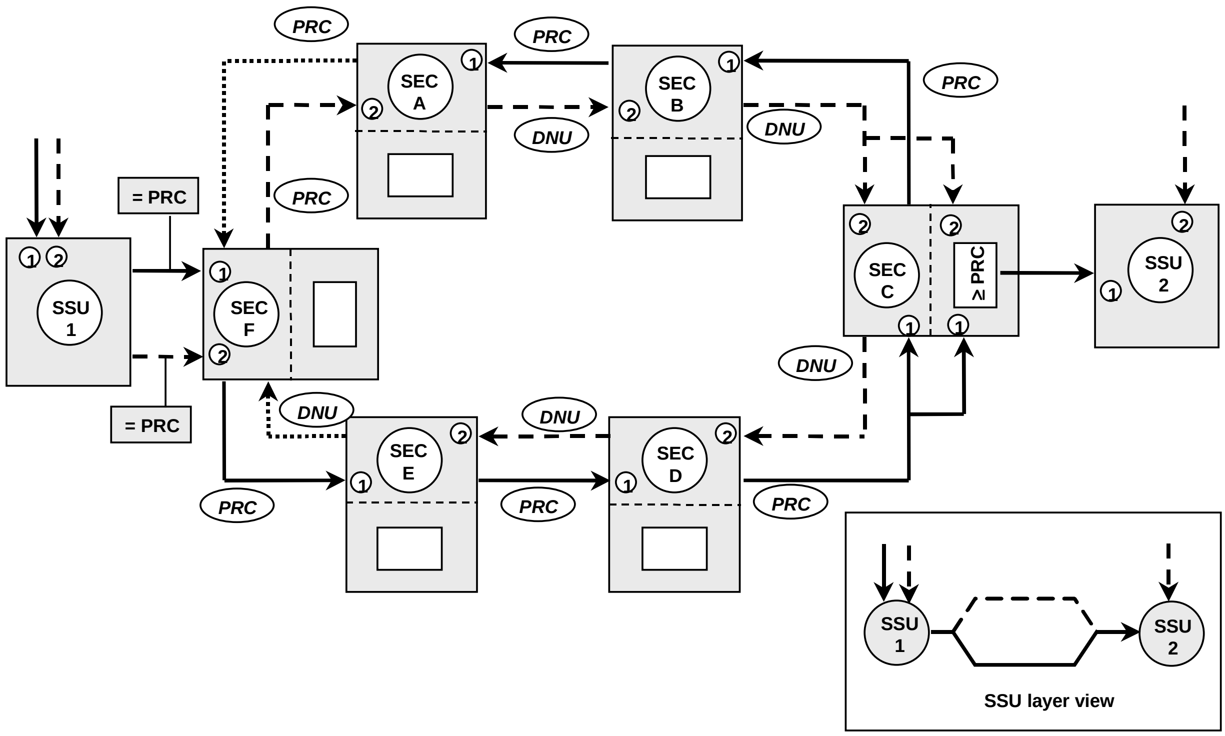



**Figure A.2: SDH ring network with one source SSU source and one sink SSU**

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-sub-network, as well as the references of SSU-1.

# A.3 Network example n°2

In this network example, 3 slightly different NE configurations are presented to show the impact of NE configuration on the network behaviour.

## A.3.1 first configuration

In this configuration, the two external references are not configured with the same Quality Level. SSU3 is locked to SSU1 as long as one of the synchronization signal is present on the 2 external ports of SEC F.

In case of a failure of a section in the ring, the ring will take care of the protection; depending on the location of the failure and on the number of ADM's in the ring, it is possible that SSU3 is locked to SSU2 during a transient period not longer than a few seconds.

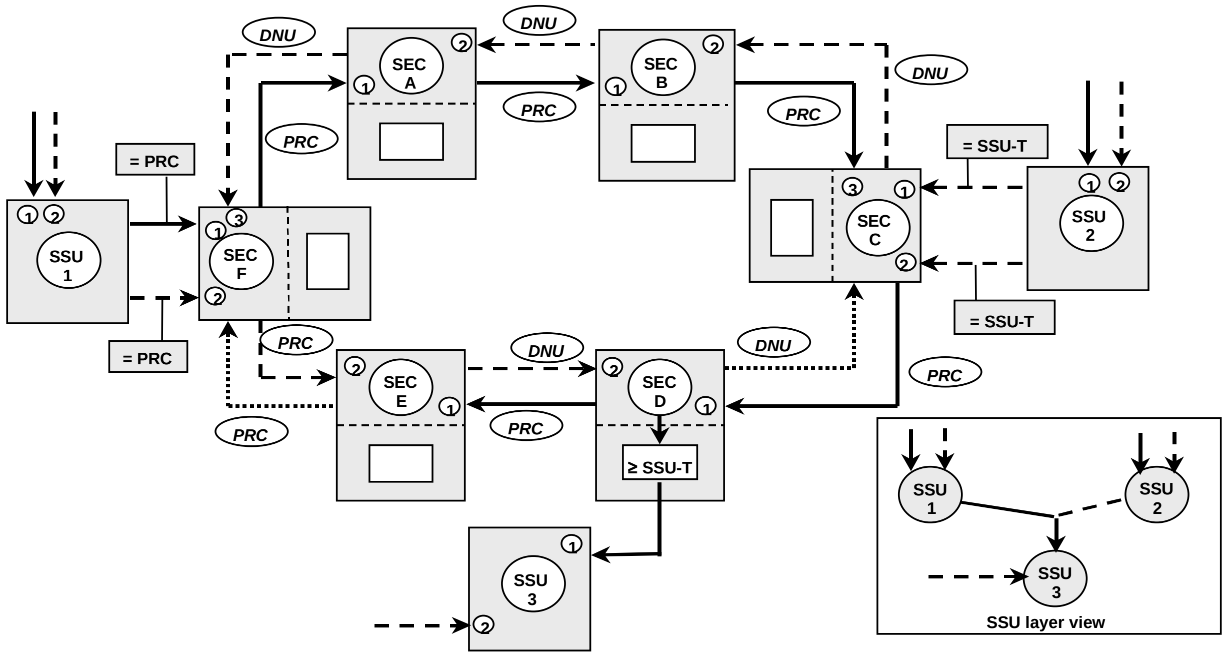



**Figure A.3: SDH ring network with two source SSUs and one sink SSU**

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.

# A.3.2 second configuration

In this configuration SEC C selects its external reference rather than the line timing coming from SEC B and SSU1.

SSU3 is locked to SSU2 and 2 different timings feed the ring.

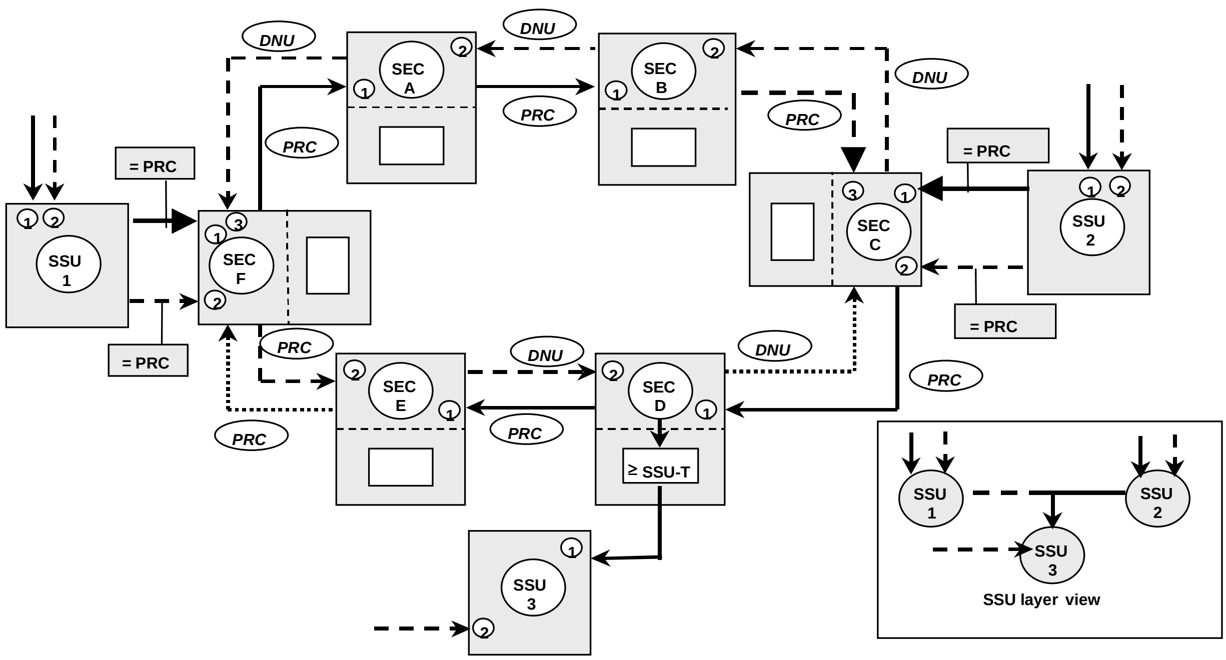



**Figure A.4: Second configuration**

### A.3.3 third configuration

By changing the priorities of SEC C, the nominal situation is identical to the first configuration and all NE's and SSU3 are locked to SSU1.

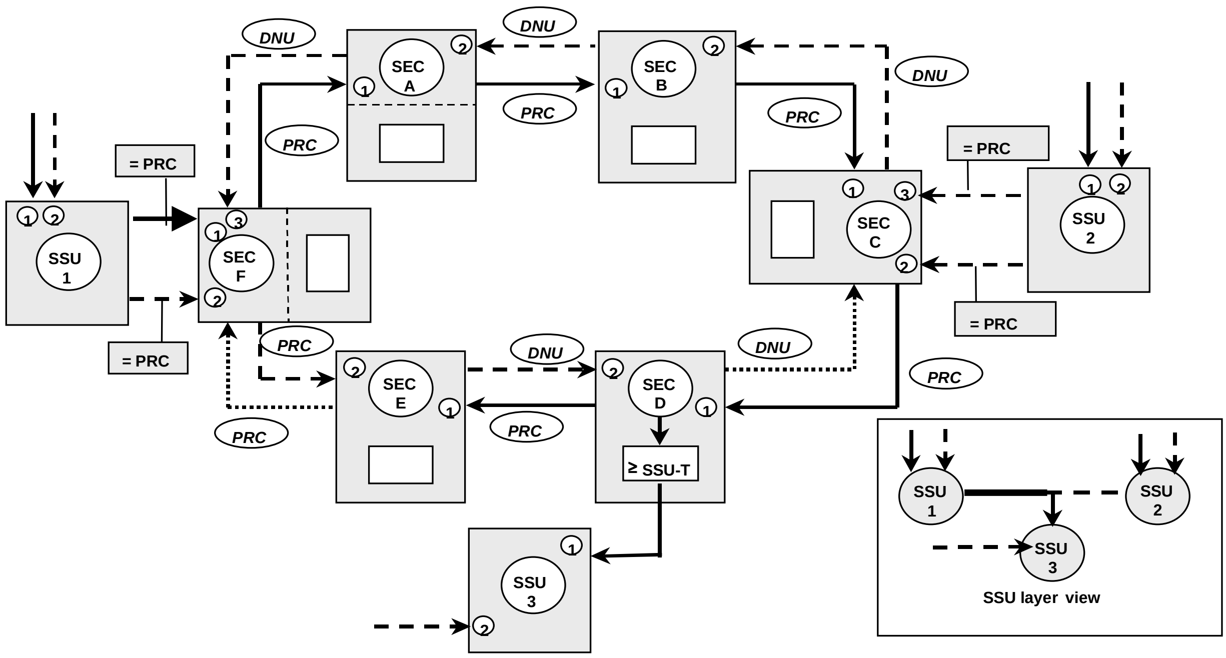



**Figure A.5: Third configuration**

## A.4 Network example n°3

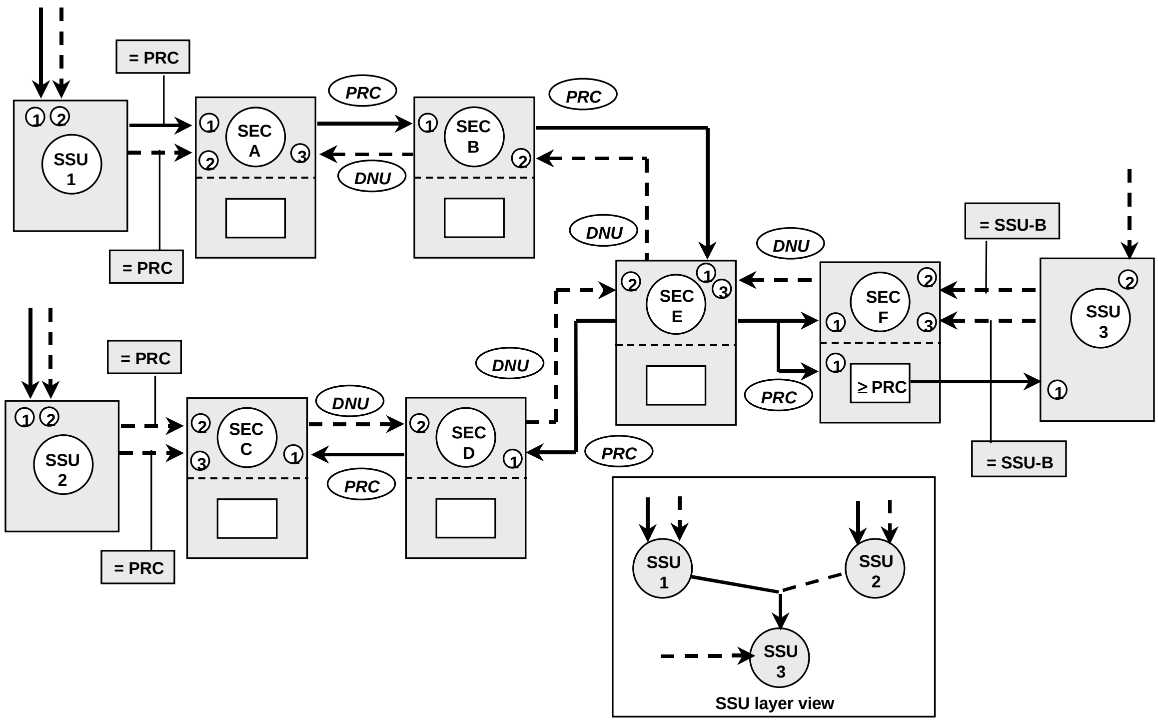



**Figure A.6: SDH Y-network with two source SSUs and one sink SSU**

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.

# A.5 Network example n°4

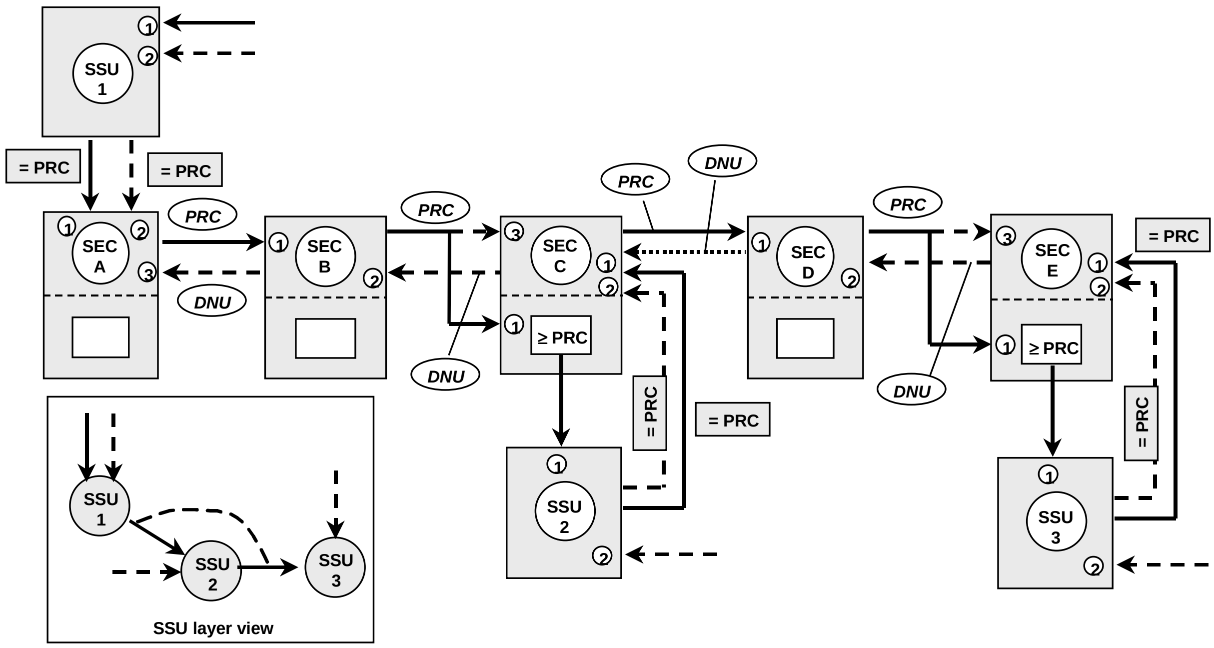



**Figure A.7: SDH linear network with filtering SSUs**

NOTE: The bypass of SSU2, as shown on the SSU layer view, should not be implemented if this results in a chain of more than 20 SEC's between SSU1 and SSU3.

# A.6 Network example n°5

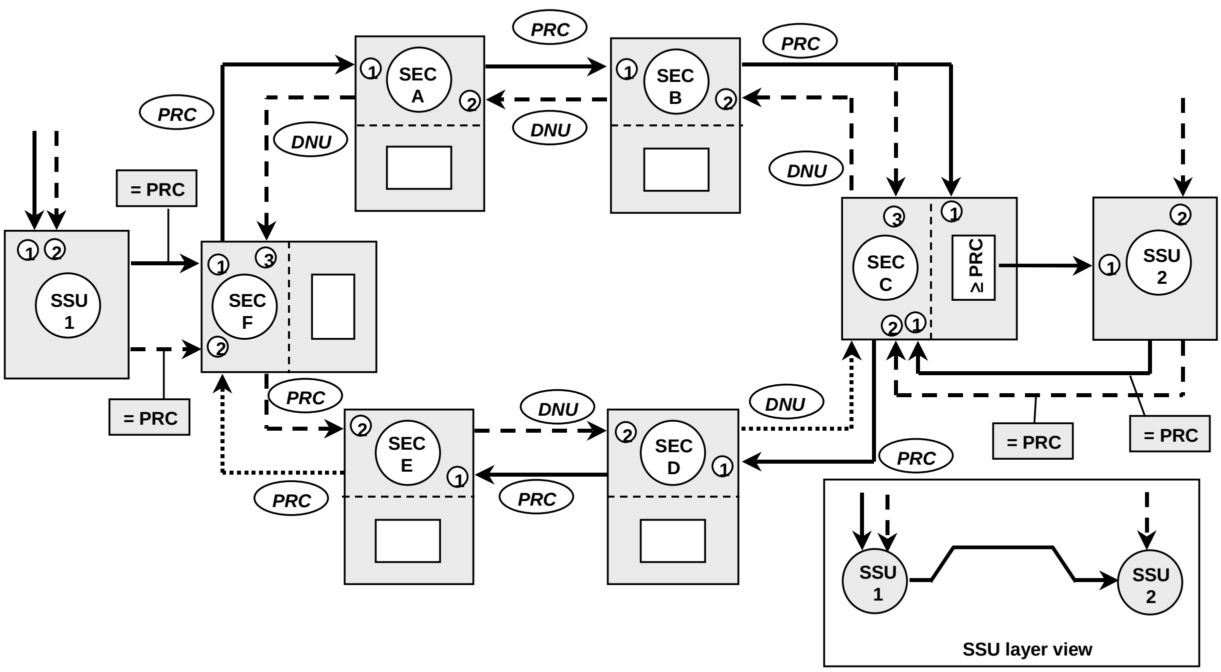



**Figure A.8: SDH ring network with filtering SSU**

# Annex B (informative): Interworking between SASE's and SDH NE's

# B.1 Introduction

This Annex presents a methodology to engineer synchronization networks without network wide use of SSM. The use of networkwide SSM can be prevented by defining a number of independent and self-supporting "synchronization sub-networks". Each overall synchronization network has to be made up of these defined "modules". This systematic way of engineering will result in very stable synchronization networks and will ensure that all potential problems in all imaginable network configurations can be found. Examples of sub-networks, which can be used with the methodology presented, are given in clause B.3. and they show that:

- The usage of SSMs on a network-wide scale (i.e., on the scale of an entire operator network) is ***not*** needed and don't really enhance the overall network synchronization performance under the conditions that:
    - the synchronization network is designed so that, even under fault conditions, all SSU's in this network receive only synchronization references from SSU's of higher hierarchical (sub)level;
    - the entire network is made up of well defined synchronization sub-networks.
- Within synchronization sub-networks, the use of SSM, i.e. SSM between SSU's and SDH-NE's, is ***not*** needed and don't really enhance the overall network synchronization performance under the condition that the synchronization network meet EN 300 462-2 [2] (i.e., each SSU has at least two independent references).
- When the synchronization sub-network doesn't meet EN 300 462-2 [2], an SSU in holdover takes over the control of (part of) the subnetwork as long as an alternative method has not been proven itself for all imaginable (sub-) network configurations.
- In EN 300 417-6-1 [10] (subclause 4.13), some mechanisms are defined to prevent timing loops in synchronization (sub-)networks by inserting DNU at the traffic output port of an SDH-NE in the direction of the NE which is used or can be used as actual synchronization source. The mechanisms that are used for the case that an SSU is interconnected with an SDH-NE give, in some situations, rise to an unnecessary DNU insertion. These mechanisms were not applied in the presented sub-networks.

# B.2 Network analysis

In SDH networks, the SEC can be considered transparent for:

1) the clock information to the SSU's in the synchronization network;

2) the wander components contributing to the overall network slip performance.

Therefore, starting-point in this design methodology is that the SEC is of minor importance in the overall synchronization network, i.e., the main synchronization network is an SSU network controlled by one or more PRC's. Recommendations and specifications in EN 300 462-2 [2] and ITU-T Recommendation G.803 [19] /§8, such as the hierarchical relationship between clocks, as well as the general method of avoiding timing loops are intended for synchronization networks as described above.

The potential for timing loops exists only when either the primary or secondary synchronization reference is passed between offices of the same level. A method of avoiding timing loops involves assigning a quality (sub-)level to each station. Any time a station receives its synchronization reference from another station of the same level, the receiving station is assigned a quality code one level below the source station. Thus each station receives its synchronization from a higher level (or higher sublevel) station. This method is described in more detail in subclause 7.6.5.

The design methodology, presented in this Annex, is further based on:

- The synchronization network can be split up in "synchronization sub-networks" (this is *not* a standardized concept).
- Each "synchronization sub-networks" consists of an SSU and one or more (typical 2) synchronization reference links from SSU('s) of higher (sub)level and/or PRC('s).

NOTE 1: This is in conformity with the general method of avoiding timing loops.

NOTE 2: A high quality alternative reference for an SSU is available from the GPS satellite system, which can be considered as a level 1 reference.

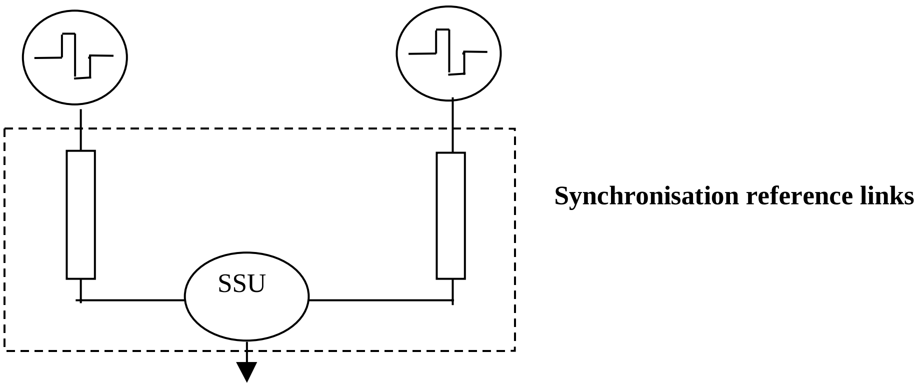



**Figure B.1: Typical synchronization subnetworks**

- Each problem area within a "synchronization sub-network" has to be solved within that "synchronization sub-network" (if necessary with the help of the network management), i.e. timing rearrangements (reference switching) should only take place within the "synchronization sub-network" concerned and not based on or being the result of events and decisions in other "synchronization sub-networks".

In the design methodology described in this Annex, only synchronization reference links containing SDH networks (rings, point to point, meshed) and GPS receivers are considered in the subnetwork investigations. Synchronization references links containing PDH facilities and radio links are not further considered. All what has to be done in these sub-networks, is assigning (sub-)levels to the SSU's. No further investigation is needed.

NOTE: The synchronization sub-network as described in the above and which contains SEC's in the synchronization reference links, is almost identical to the SEC sub-network as defined in subclause 7.6.1.

# B.3 SDH sub-network Examples

In the following examples, it is assumed that:

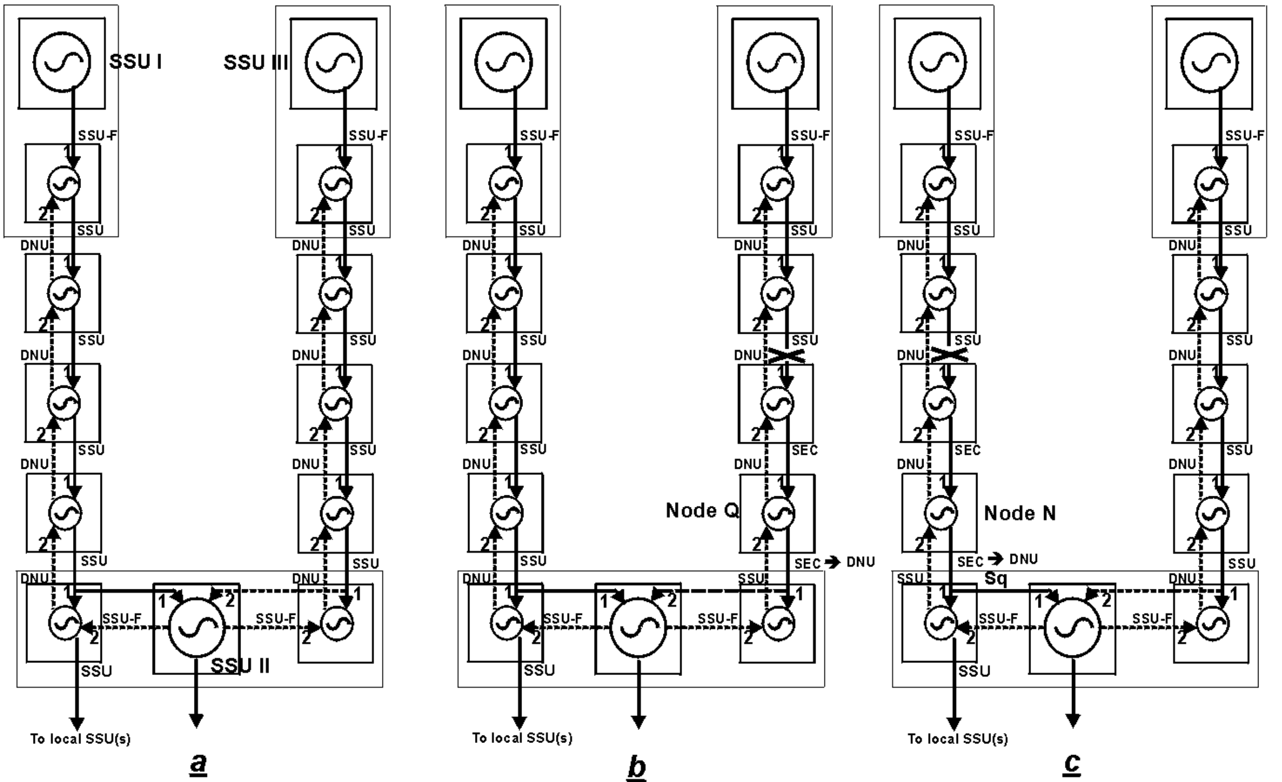
1) SSM is used in SDH sub-networks in conformity with the synchronization principles described in EN 300 417-6-1 [10].
2) SSM is *not* used network wide, i.e. SSM is not supported by SSU's.

In all the figures, the following is shown:

- QL's, such as SSU, SEC and DNU (Note that SSU-F stands for SSU-forced, i.e. the QL is provisioned at the input of the SEC);
- Port priorities (i.e. 1, 2, …);
- Squelched signal at station output of SEC **(Sq)** when QL at station output has been configured to be squelched if QL is lower than SSU-T).

In SDH meshed networks, transmission links have to be selected to be used as designated synchronization reference links.

The sub-networks, shown in Figure B.2 to Figure B.6, are standard sub-networks, i.e. these networks meet the recommendations in the current standards. In these figures, the SDH ring-network and SSU II are, in normal situations, controlled by SSU I. In Figure B.6, a second reference is realized by a GPS satellite system. It is demonstrated that for all these networks automatic restoration, in case of a failure condition, is feasible without any additional tool, such as SSM or other timing marker scheme.




(Timing signals and SSM's in sub-networks under normal network conditions, i.e. No failures)

(Timing signals and SSM's in sub-networks under failure conditions just before node Q switches reference and changes its message)

(Timing signals and SSM's in sub-networks under failure conditions just before node N switches reference and changes its message; after some time, SSU II will switch reference)

**Figure B.2**

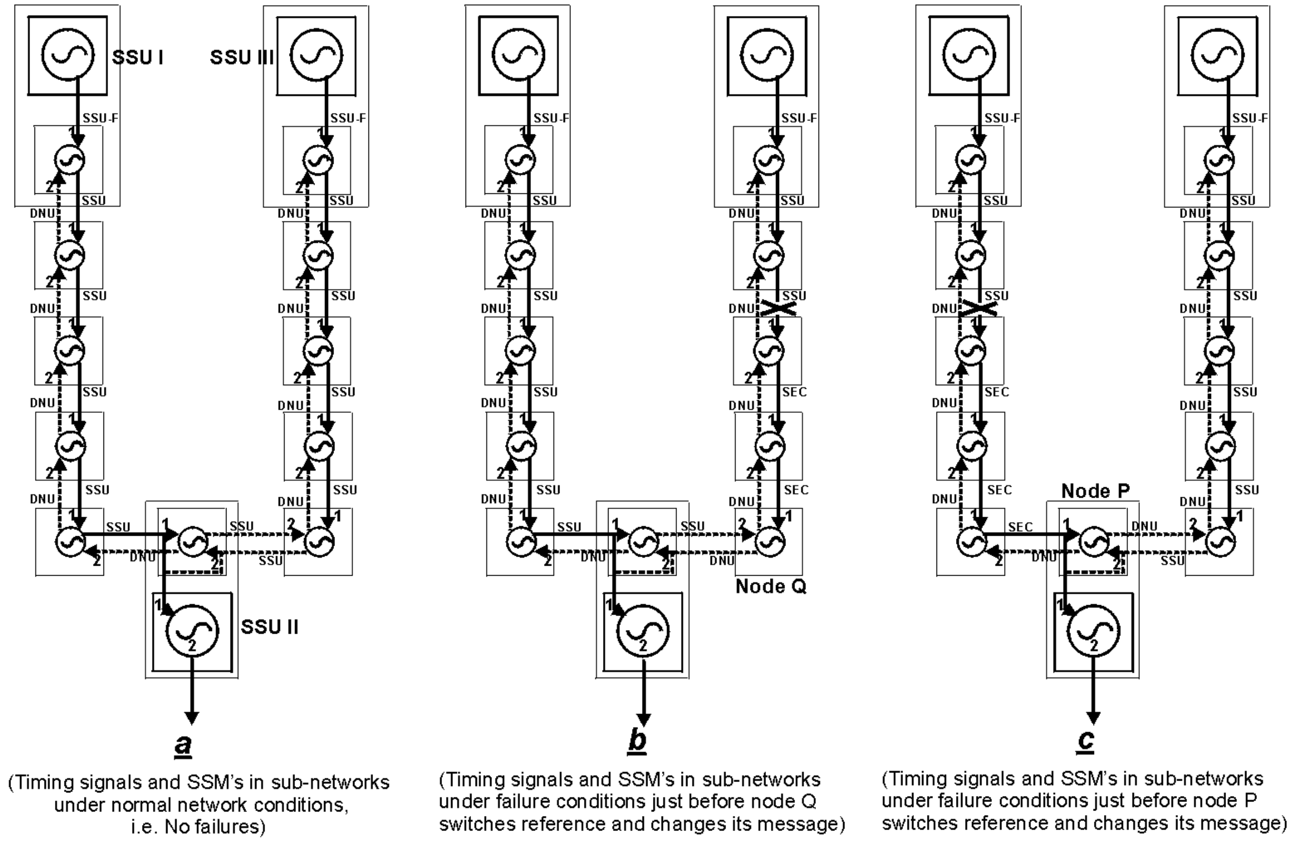


Figure B.3

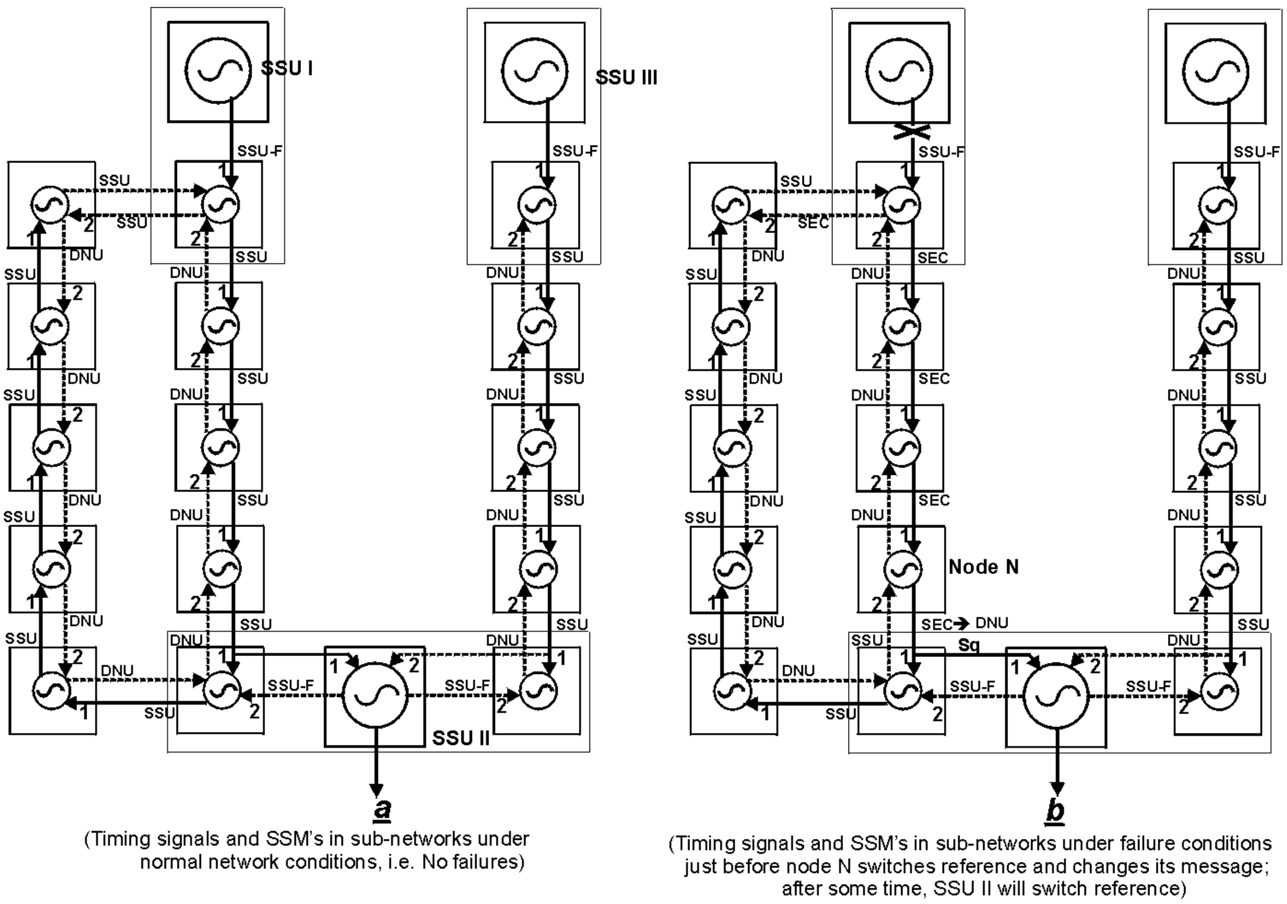
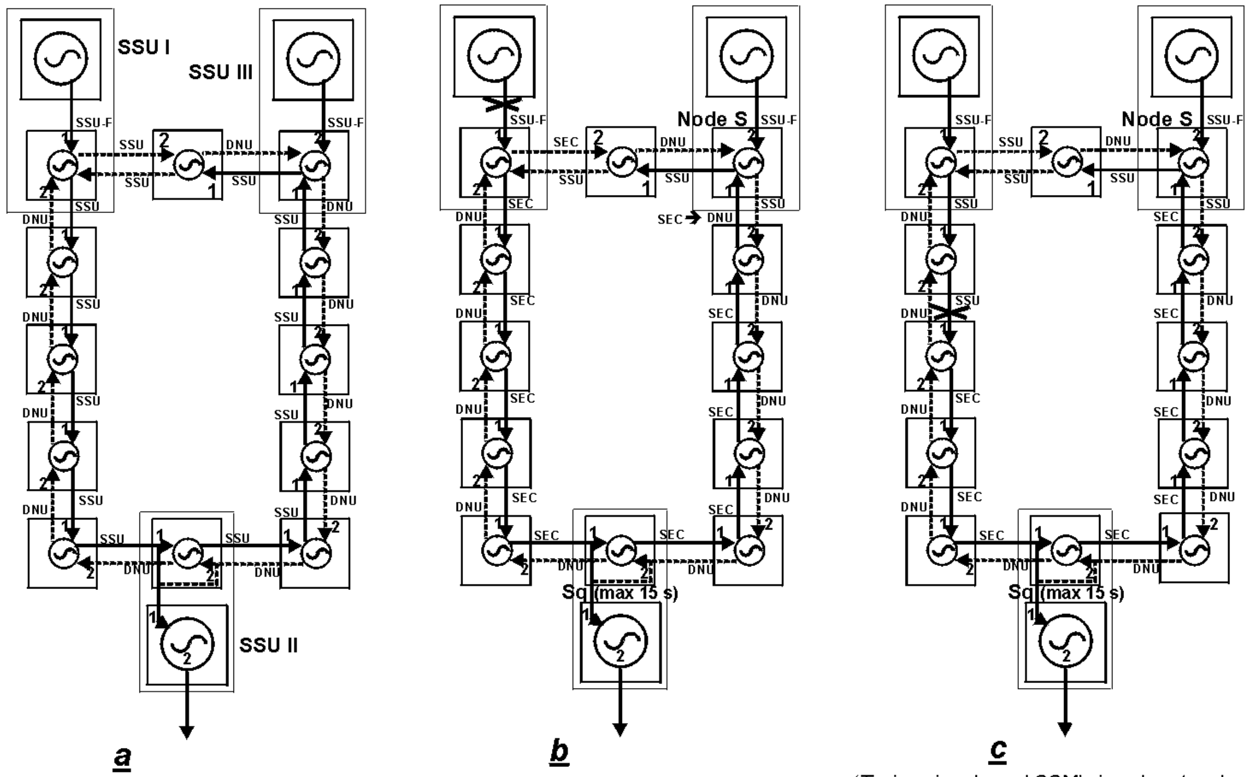


Figure B.4

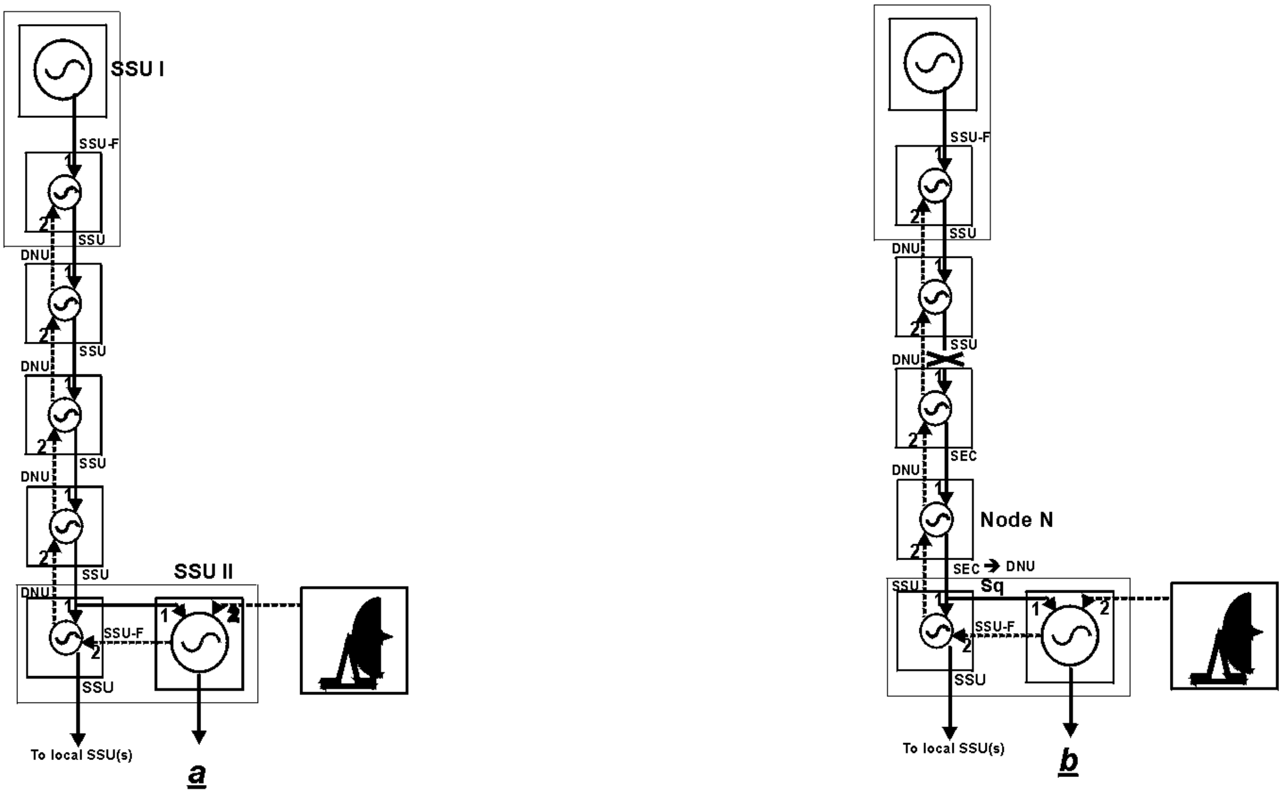



(Timing signals and SSM's in sub-networks under normal network conditions, i.e. No failures)

(Timing signals and SSM's in sub-networks under failure conditions just after node S switched reference and changed its message)

(Timing signals and SSM's in sub-networks under failure conditions just after node S switched reference and changed its message)

**Figure B.5**




(Timing signals and SSM's in sub-networks under normal network conditions, i.e. No failures)

(Timing signals and SSM's in sub-networks under failure conditions just before node N switches reference and changes its message; after some time, SSU II will switch reference)

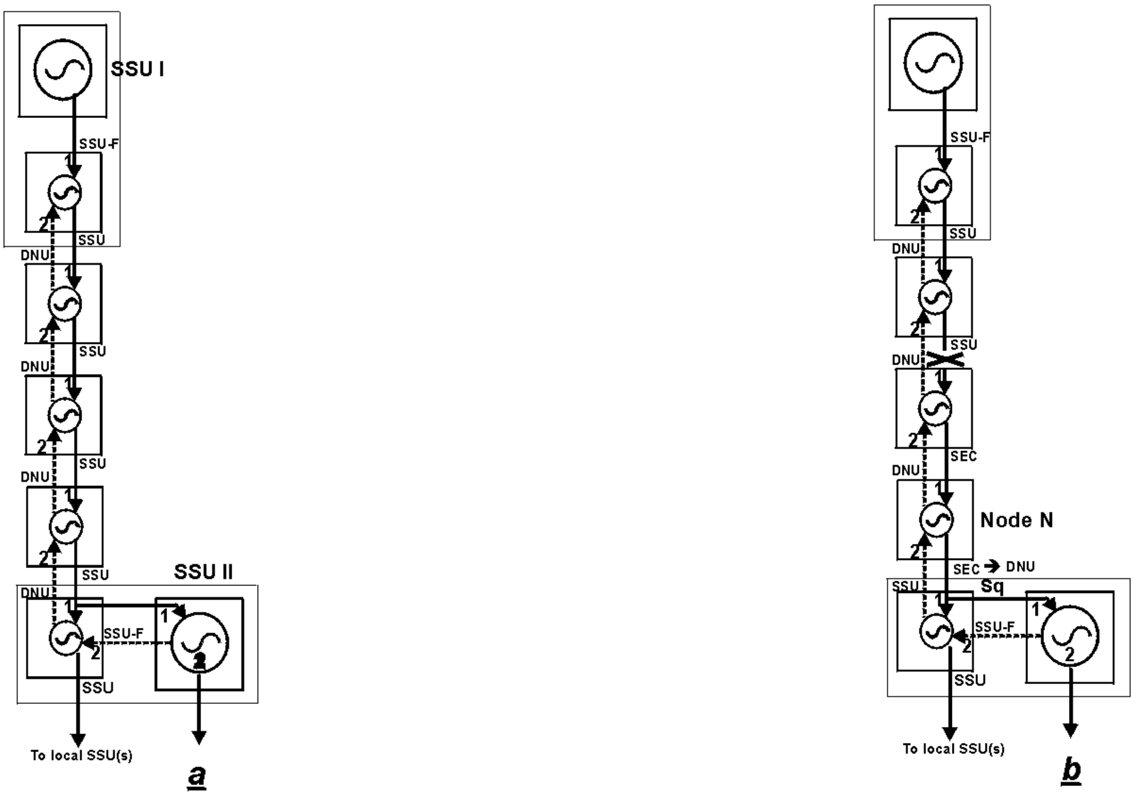
**Figure B.6**

The sub-networks, shown in Figure B.7 to Figure B.9, are not standard sub-networks. In these figures, SSU II has only one synchronization reference link or two synchronization reference links but these come from the same node clock (SSU I) or two synchronization reference links ending in a common part (Y configuration). I.e., these sub-networks don't meet the recommendations in the current standards. The sub-networks shown are under normal conditions, controlled by SSU I.

The following failure conditions are discussed:

Figure B.7 shows the sub-network that has only one synchronization reference link. Timing signals and SSM's are given.

- under normal network conditions, i.e. no failures (Figure B.7-a); and
- under failure conditions (Figure B.7-b).

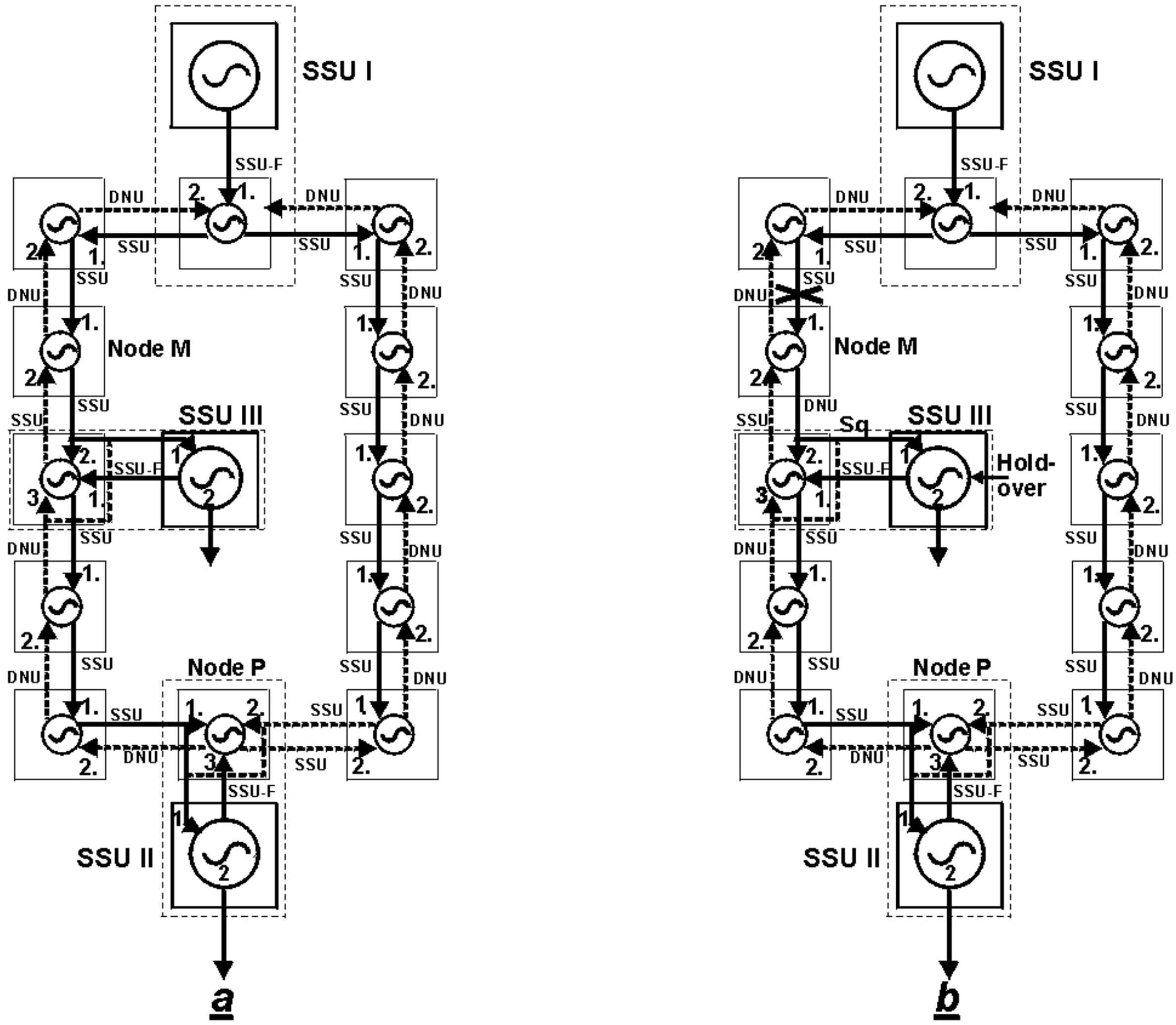



(Timing signals and SSM's in sub-networks under normal network conditions, i.e. No failures)

(Timing signals and SSM's in sub-networks under failure conditions just before node N switches reference and changes its message; after some time, SSU II goes in holdover)

**Figure B.7**

Figure B.8-a shows the sub-network that has two synchronization reference links coming from the same node clock. Further, SSU III is a part of the synchronization trail from SSU I to SSU II, i.e., SSU III is line-timed. Also, SSU III doesn't have a secondary synchronization reference. This is also not in conformity with EN 300 462-2 [2] and ITU-T Recommendation G.803 [19] /§6, but it is a practical situation. SSU III is inserted in the sync trail to reduce the number of SEC's between the SSU's I and II. In Figure B.8, timing signals and SSM's are given under normal network conditions, i.e. no failures. Figure B.8-b shows the automatic restoration in case of a failure at the input of Node M. It demonstrates that SSU III in holdover takes over the control of timing for a part of the sub-network.

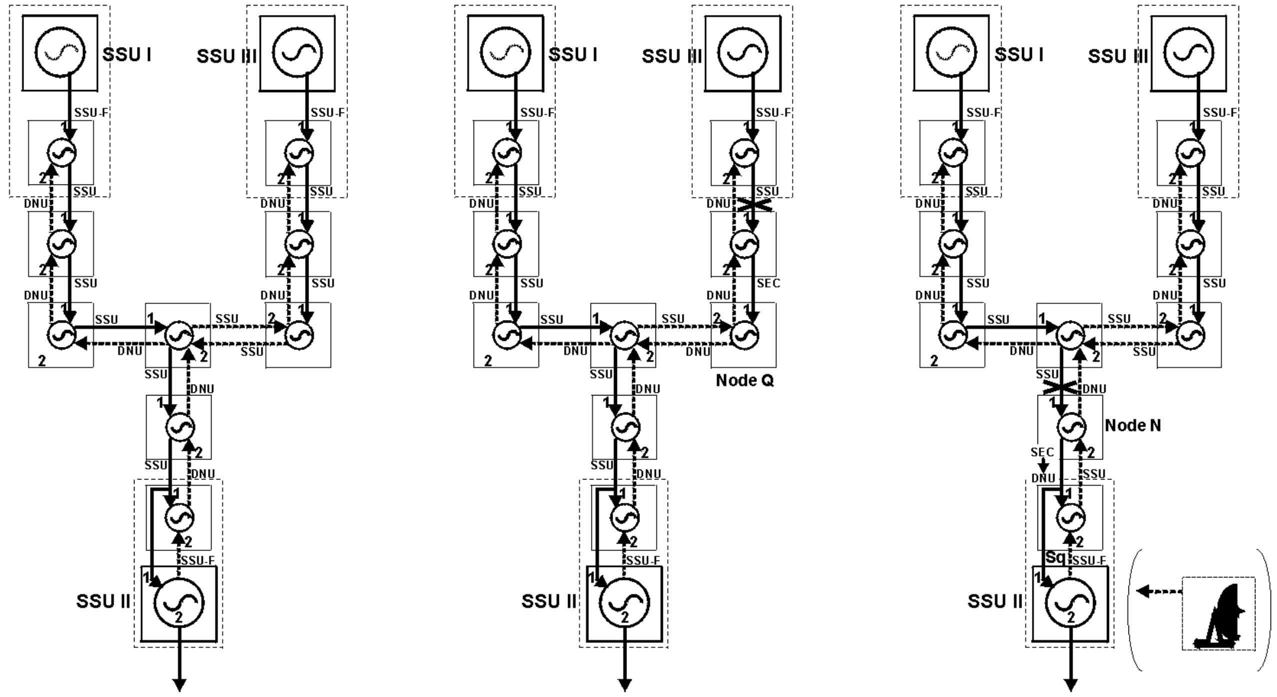



(Timing signals and SSM's in sub-networks under normal network conditions, i.e. No failures)

(Timing signals and SSM's in a sub-network under a failure condition just before node M switches reference. After some time, SSU III goes in holdover.)

**Figure B.8**

Finally, in Figure B.9 the sub-network that has two synchronization references links ending in a common part. In Figure B.9-a, timing signals and SSM's are given under normal network conditions, i.e. no failures. Figure B.9-b shows a failure condition that can automatically restored without any problems (i.e., without any additional tools). Figure B.9-c shows a failure condition that can only be solved by SSU II in holdover (unless a second synchronization reference is available).




*a*

(Timing signals and SSM's in sub-networks under normal network conditions, i.e. No failures)

*b*

(Timing signals and SSM's in sub-networks under failure conditions just before node Q switches reference and changes its message)

*c*

(Timing signals and SSM's in sub-networks under failure conditions just before node N switches reference and changes its message; after some time, SSU II goes in holdover)

**Figure B.9**

# Annex C (informative): Examples of Synchronization Network Implementation

## C.1 Dedicated Synchronization Network

A dedicated synchronization network can be achieved in several ways, as described here in clause C.1.

### C.1.1 Navigation Satellite System

There are presently two GNSS (Global Navigation Satellite Systems):

- the American NAVSTAR, commonly referred to as GPS (Global Positioning System);
- the Russian GLONASS (GLobal Orbiting NAvigation Satellite System).

NAVSTAR is funded and controlled by the US Department of Defense but have signed agreements with Department of Transportation assuring NAVSTAR availability for civil users. However, the signals available for civil users are degraded by a Selective Availability (SA) code. In spite of this code, a proper noise filtering on the NAVSTAR signal can provide suitable reference timing signals. Both the American NAVSTAR and the Russian GLONASS consists of 24 orbiting satellites (21 active and 3 flying spares) with the main purpose to provide accurate positioning information. Since accurate positioning requires accurate timing, they can also be used for network synchronization.

The GLONASS system is newer and there are not as many commercially available receivers as for NAVSTAR, but some receivers actually take in both systems.

Figure C.1 shows an example of a GNSS based synchronization network. In this configuration, an SSU is receiving a reference timing signal from the GNSS satellites and provides the appropriate filtering.

This setup, using an SSU with a GNSS receiver, is suitable for the central parts of the network. For the peripheral parts, with single equipment sites like remote concentrators or radio base stations, other strategies may have to be adopted.

The European community is currently working on the GNSS Egnos (European Geostationnary Navigation Overlay System) project that will complete and secure the GPS system.

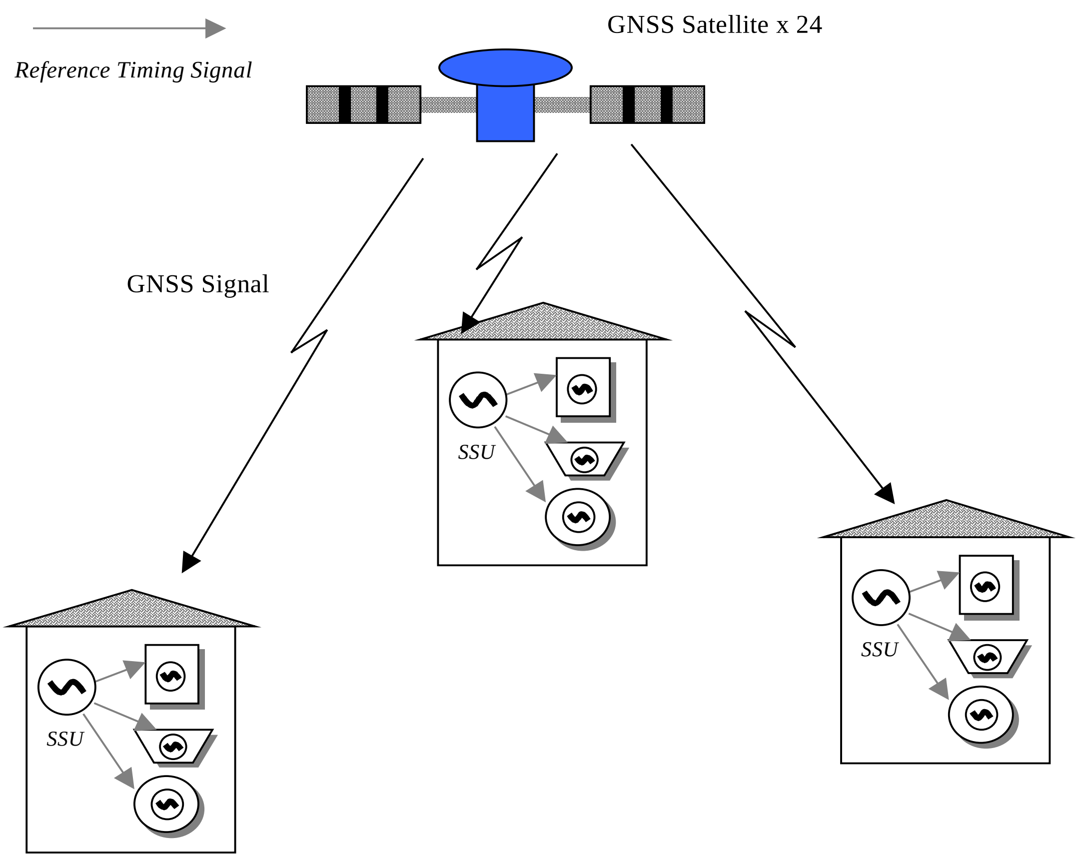



**Figure C.1: Example of a GNSS based synchronization network**

## C.1.2 Dedicated Synchronization Links

Another way of achieving a synchronization network within the full control of the operator is to set up a network of dedicated transmission links. 2 Mbit/s links are generally used for this purpose.

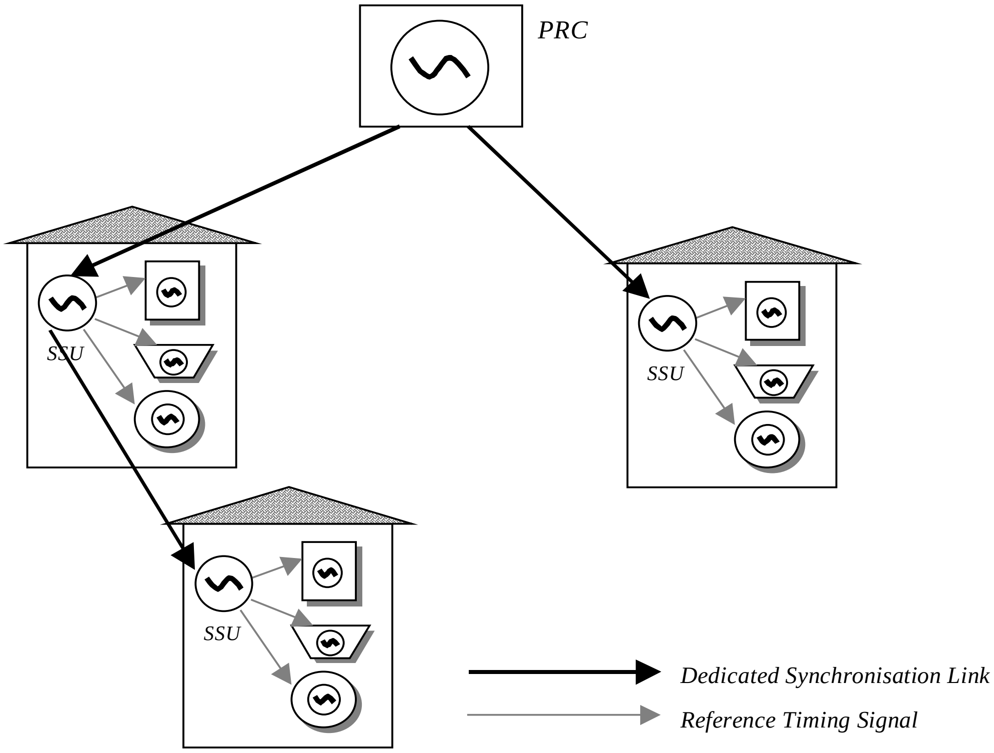



**Figure C.2: Dedicated links distributing Synchronization**

# C.1.3 Radio broadcasting

The radio broadcasting system distributes a reference timing signal that is to be received by the SSU of each site. This can be used as a backup reference.

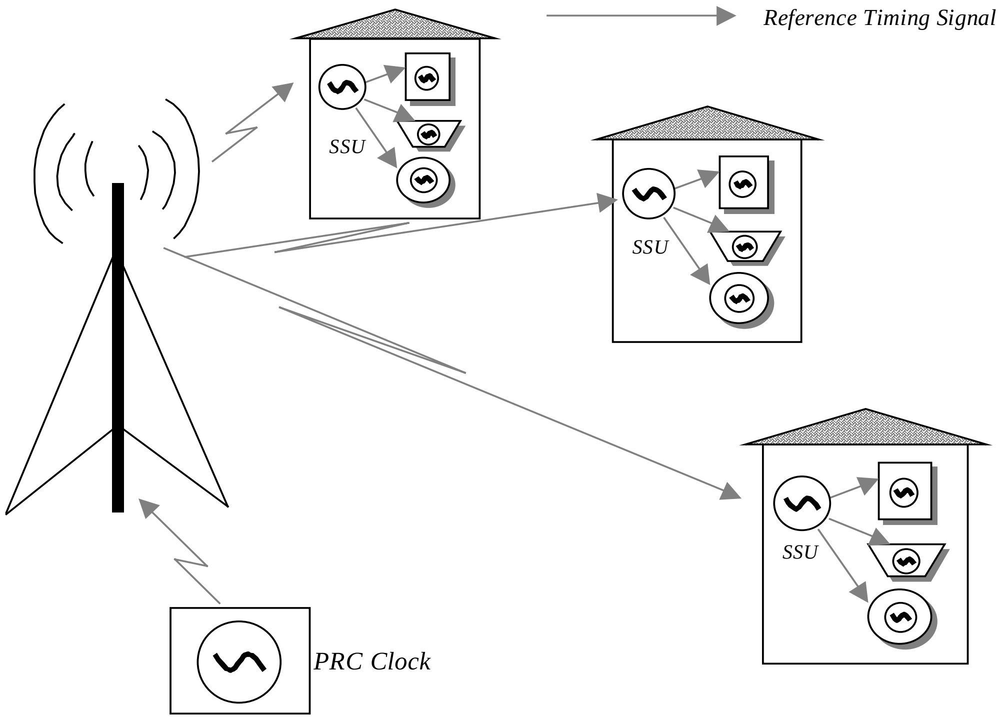



**Figure C.3: Radio broadcasting system**

LORAN C is an example of broadcasting system that can be used.

# C.2 Non-Dedicated Synchronization Network

When the synchronization network is used on the transmission network, the transport network is the carrier of the reference timing signals Therefore, there is no dedicated synchronization network. Implementation is normally done either by transporting the reference timing signal in the transport frame phase or using phase information in bit timing information.

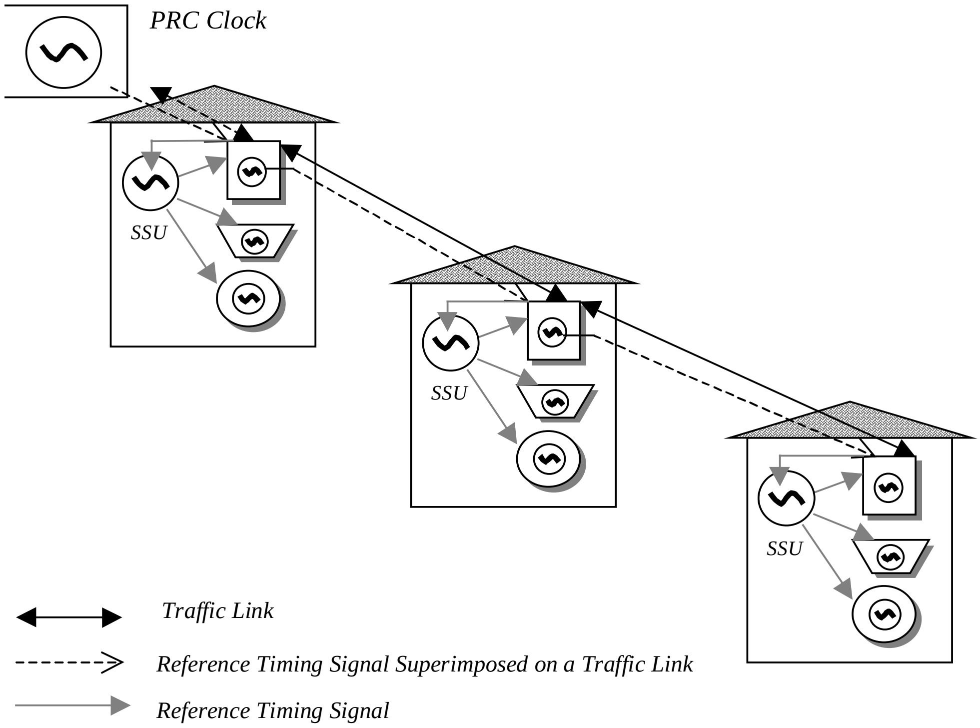



**Figure C.4: Non dedicated synchronization network**

# C.3 Mixed Synchronization network

**PRC & GPS Combination**

In practical networks many operators are deploying both Caesium based PRCs and GPS. The PRC network provides a backup in case there is a GPS failure. A part of this type of network is shown in Figure C.5. The SSUs will normally receive synchronization from the GPS receiver but in the case of the GPS receiver failure or GPS network failure the PRC will be used as the synchronization source. Normally at least two Caesium PRCs will be used to give even higher levels of availability.

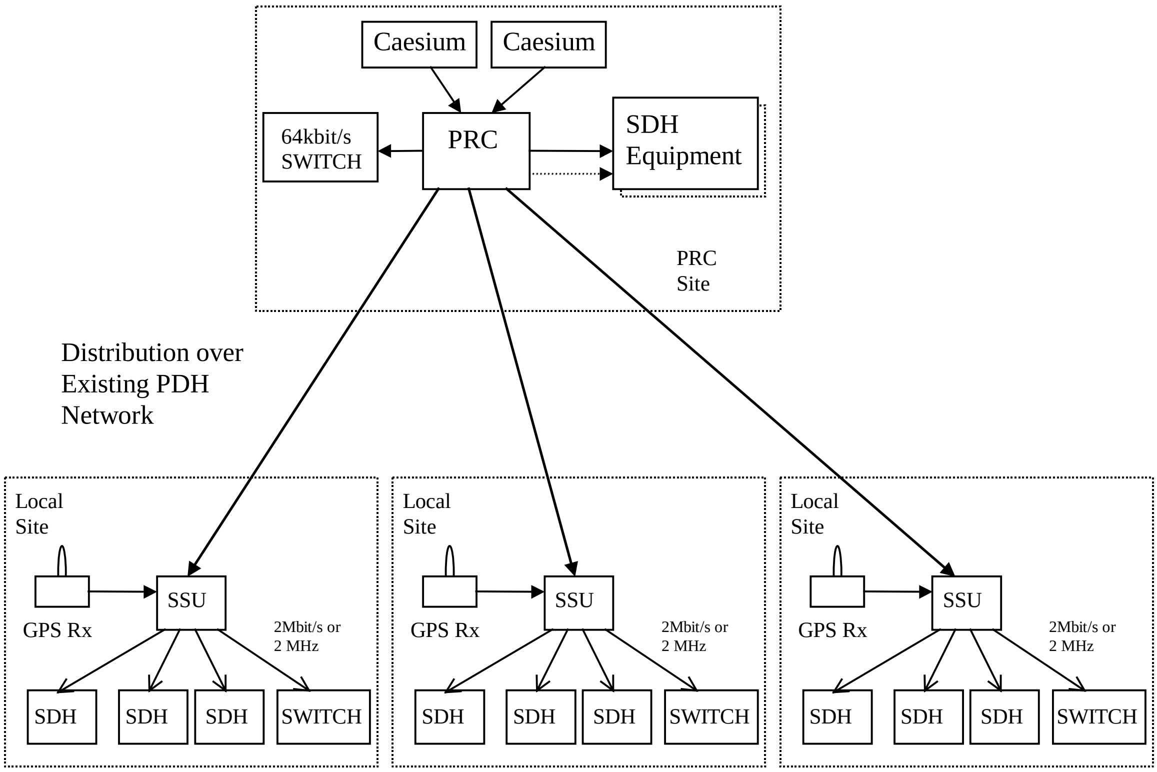



**Figure C.5: Mixed Caesium and GPS Synchronization Network**

# History

| Document history | | |
| --- | --- | --- |
| V1.1.1 | April 2000 | Membership Approval Procedure MV 20000616: 2000-04-18 to 2000-06-16 |
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