

International Telecommunication Union

**ITU-T**

TELECOMMUNICATION  
STANDARDIZATION SECTOR  
OF ITU

**G.7042/Y.1305**

(03/2006)

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**Link capacity adjustment scheme (LCAS) for  
virtual concatenated signals**

ITU-T Recommendation G.7042/Y.1305



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DIGITAL TERMINAL EQUIPMENTS	G.700–G.799
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QUALITY OF SERVICE AND PERFORMANCE – GENERIC AND USER-RELATED ASPECTS	G.1000–G.1999
TRANSMISSION MEDIA CHARACTERISTICS	G.6000–G.6999
DATA OVER TRANSPORT – GENERIC ASPECTS	G.7000–G.7999
<b>General</b>	<b>G.7000–G.7099</b>
Transport network control aspects	G.7700–G.7799
PACKET OVER TRANSPORT ASPECTS	G.8000–G.8999
ACCESS NETWORKS	G.9000–G.9999

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## **ITU-T Recommendation G.7042/Y.1305**

### **Link capacity adjustment scheme (LCAS) for virtual concatenated signals**

#### **Summary**

This Recommendation specifies a methodology for dynamically changing (i.e., increasing and decreasing) the capacity of a container that is transported in a generic transport network (e.g., over SDH or OTN network using Virtual Concatenation). In general, this change of capacity does not affect the traffic. In addition, the methodology also provides survivability capabilities, automatically decreasing the capacity if a member experiences a failure in the network, and increasing the capacity when the network fault is repaired.

#### **Source**

ITU-T Recommendation G.7042/Y.1305 was approved on 29 March 2006 by ITU-T Study Group 15 (2005-2008) under the ITU-T Recommendation A.8 procedure.

#### **Keywords**

Link capacity adjustment scheme, optical transport network, synchronous digital hierarchy, virtual concatenation.

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## CONTENTS

	<b>Page</b>
1 Scope .....	1
2 References.....	1
3 Terms and definitions .....	1
4 Abbreviations.....	2
5 Conventions .....	2
6 LCAS for virtual concatenation.....	2
6.1 Methodology.....	2
6.2 Control packet .....	3
6.3 VCG capacity increase (Addition of member(s)).....	6
6.4 VCG capacity decrease: Member(s) temporary removed by the LCAS procedure (due to failure) .....	7
6.5 VCG capacity decrease: Removal (permanent) of member(s).....	8
6.6 LCAS to non-LCAS interworking.....	8
6.7 Asymmetric connections .....	9
6.8 Symmetric connection .....	9
Annex A – LCAS protocol.....	10
A.1 LCAS protocol.....	10
A.2 LCAS protocol partitioning.....	12
A.3 State diagram of member(i) in the Virtual Concatenated Group .....	14
A.4 Procedures state diagrams .....	16
A.5 State diagram for the VCG .....	20
Appendix I – LCAS Time Sequence Diagrams .....	22
I.1 Nomenclature .....	22
I.2 Numbering system.....	22
I.3 Provisioning.....	22
I.4 Commands .....	22
Appendix II – Non hit-less bandwidth modifications during Hold Off periods .....	29
II.1 Introduction .....	29
II.2 Removal of a group member at Source .....	29
II.3 TSD conditions raised while performing ADD commands .....	29
II.4 Enhanced HO procedure.....	29



# ITU-T Recommendation G.7042/Y.1305

## Link capacity adjustment scheme (LCAS) for virtual concatenated signals

### 1 Scope

This Recommendation specifies a link capacity adjustment scheme that should be used to increase or decrease the capacity of a container that is transported in an SDH/OTN network using Virtual Concatenation. In addition, the scheme will automatically decrease the capacity if a member experiences a failure in the network and increase the capacity when the network fault is repaired. The scheme is applicable to every member of the Virtual Concatenation group.

This Recommendation defines the required states at the source and at the sink side of the link as well as the control information exchanged between both the source and the sink side of the link to enable the flexible resizing of this Virtual Concatenated signal. The actual information fields used to convey the control information through the transport network are defined in their respective Recommendations, ITU-T Recs G.707/Y.1322 [1] and G.783 [3] for SDH and ITU-T Recs G.709/Y.1331 [2] and G.798 [4] for OTN.

### 2 References

The following ITU-T Recommendations and other references contain provisions which, through reference in this text, constitute provisions of this Recommendation. At the time of publication, the editions indicated were valid. All Recommendations and other references are subject to revision; users of this Recommendation are therefore encouraged to investigate the possibility of applying the most recent edition of the Recommendations and other references listed below. A list of the currently valid ITU-T Recommendations is regularly published. The reference to a document within this Recommendation does not give it, as a stand-alone document, the status of a Recommendation.

- [1] ITU-T Recommendation G.707/Y.1322 (2003), *Network node interface for the synchronous digital hierarchy (SDH)*.
- [2] ITU-T Recommendation G.709/Y.1331 (2003), *Interfaces for the Optical Transport Network (OTN)*.
- [3] ITU-T Recommendation G.783 (2006), *Characteristics of synchronous digital hierarchy (SDH) equipment functional blocks*.
- [4] ITU-T Recommendation G.798 (2004), *Characteristics of optical transport network hierarchy equipment functional blocks*.
- [5] ITU-T Recommendation G.806 (2006), *Characteristics of transport equipment – Description methodology and generic functionality*.
- [6] ITU-T Recommendation Z.100 (2002), *Specification and Description Language (SDL)*.

### 3 Terms and definitions

This Recommendation defines the following terms:

**3.1 link:** A connection through a network from termination function to termination function. This can be related to the members of a virtual concatenation group as well as the virtual concatenation group itself.

**3.2 member:** An individual server layer container that belongs to a virtual concatenated group.

**3.3 virtual concatenation group (VCG):** A group of co-located member trail termination functions that are connected to the same virtual concatenation link.

## **4 Abbreviations**

This Recommendation uses the following abbreviations:

CRC	Cyclic Redundancy Check
CTRL	Control field sent from source to sink
DNU	Do Not Use
EOS	End of Sequence
GID	Group Identification
HO	Hold Off
LCAS	Link Capacity Adjustment Scheme
MFI	MultiFrame Indicator
MI	Management Information
MST	Member Status
MSU	Member Signal Unavailable
MSU_L	Member Signal Unavailable, LCAS-enabled criteria
NORM	Normal Operating Mode
RS-Ack	Re-Sequence Acknowledge
Sk	Sink
So	Source
SQ	Sequence Indicator
TSD	Trail Signal Degrade
VCG	Virtual Concatenation Group
WTR	Wait-To-restore
$X_A$	Actual number of members of a virtual concatenated group
$X_M$	Maximum size of a virtual concatenated group
$X_P$	Number of provisioned members in a virtual concatenated group

## **5 Conventions**

The order of transmission of information in all the diagrams in this Recommendation is first from left to right, and then from top to bottom. Within each byte the most significant bit is transmitted first. The most significant bit (bit 1) is shown at the left in all the diagrams.

## **6 LCAS for virtual concatenation**

### **6.1 Methodology**

LCAS in the virtual concatenation source and sink adaptation functions provides a control mechanism to hitlessly increase or decrease the capacity of a VCG link to meet the bandwidth needs of the application. Hitless bandwidth modification can only be achieved when the transmission of

the active members belonging to the VCG – before and after the bandwidth modification – is error free (see Appendix II for details). It also provides the capability of temporarily removing member links that have experienced a failure. The LCAS assumes that in cases of capacity adjustment (i.e., creation, increase, decrease or deletion), the construction or destruction of the end-to-end path of each individual member is the responsibility of the Network and Element Management Systems. A VCG capacity increase or decrease can be initiated at either end.

## 6.2 Control packet

Synchronization of changes in the capacity of the transmitter (So) and the receiver (Sk) shall be achieved by a control packet. Each control packet describes the state of the link during the *next* control packet. Changes are sent in advance so that the receiver can switch to the new configuration as soon as it arrives.

The control packet consists of fields dedicated to a specific function. The control packet contains information sent from So to Sk and information sent from Sk to So, see also Figure 1.

Forward direction, So to Sk:

- MultiFrame Indicator (MFI) field;
- Sequence Indicator (SQ) field;
- Control (CTRL) field;
- Group Identification (GID) bit.

Return direction, Sk to So:

- Member Status (MST) field;
- Re-Sequence Acknowledge (RS-Ack) bit.

NOTE 1 – MST and RS-Ack are identical in the control packets of all members of the VCG.

Both directions:

- CRC field;
- Unused bits are reserved and shall be set to "0".

NOTE 2 – To allow consistent timing relationships, it is assumed that the LCAS control packets are processed at the Sk after differential delay compensation.

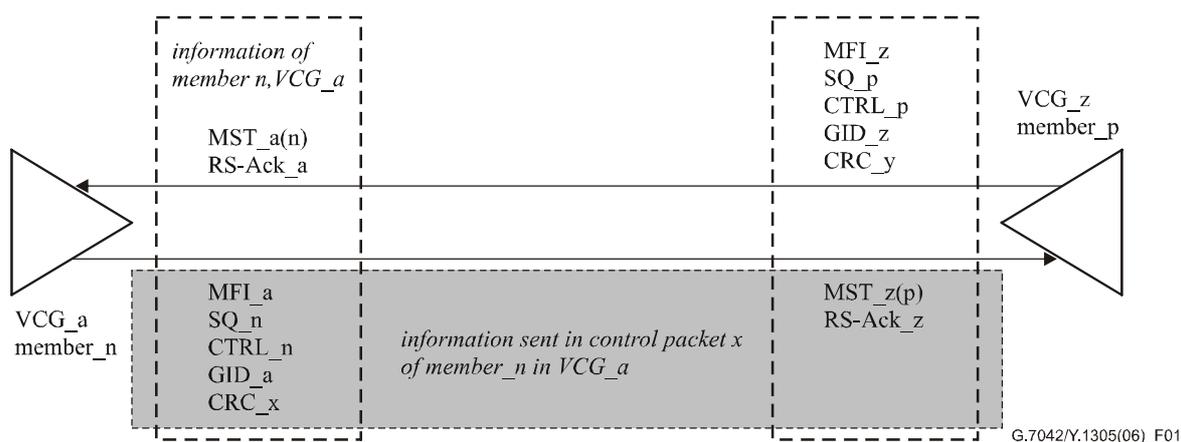


Figure 1/G.7042/Y.1305 – Allocation of information in a control packet

### 6.2.1 MultiFrame Indicator (MFI) field

At the So side, the MFI is equal for all members of the VCG. At the Sk side, the MFI shall be used to realign the payload for all the members in the group. The MFI is used to determine the differential delay between members of the same VCG. See ITU-T Rec. G.806 for more details.

### 6.2.2 Sequence Indicator (SQ) field

Contains the sequence number assigned to a specific member. Each member of the same VCG is assigned a unique sequence number, starting at 0, similar to the Recommendations for Virtual Concatenation in ITU-T Recs G.707/Y.1322 [1] and G.709/Y.1331 [2].

The SQ is ignored at the Sk end for members sending IDLE in the control field.

The SQ of a member of the VCG sending IDLE in the control field shall be set to the highest possible value.

### 6.2.3 Control (CTRL) field

The control field is used to transfer information from So to Sk. It shall be used to synchronize the Sk with the So and provide the status of the individual member of the group.

**Table 1/G.7042/Y.1305 – LCAS CTRL words**

Value msb...lsb	Command	Remarks
0000	FIXED	This is an indication that this end uses fixed bandwidth (non-LCAS mode)
0001	ADD	This member is about to be added to the group
0010	NORM	Normal transmission
0011	EOS	End of Sequence indication and Normal transmission
0101	IDLE	This member is not part of the group or about to be removed
1111	DNU	Do Not Use (the payload) the Sk side reported FAIL status

At initiation of a VCG source, all members shall send CTRL = IDLE until they are added to the VCG (and send CTRL = ADD).

### 6.2.4 Group Identification (GID) bit

Used for identification of the VCG. The GID bit of all members of the same VCG has the same value in the control packets with the same MFI.

The GID provides the receiver with a means of verifying that all the arriving members originated from one transmitter. The contents are pseudo-random, but the receiver is not required to synchronize with the incoming stream. The pseudo-random pattern used is  $2^{15} - 1$ .

### 6.2.5 CRC field

To simplify the validation of the changes in the virtual concatenation overhead, a CRC is used to protect each control packet. The CRC check is performed on every control packet after it has been received, and the contents rejected if the test fails. If the control packet passes the CRC test, then its contents are used immediately. To simplify MFI multi-framing, it is allowed to disregard the result of the control packet CRC check for the MFI element checked by the CRC so that the multi-framing process may use the MFI element equivalently with the non-LCAS virtual concatenation processing case.

### 6.2.5.1 CRC multiplication/division process

The bits of the control packet can be regarded as the coefficients of a polynomial where the first bit of the control packet to be transmitted is the most significant bit. A particular CRC- $n$  block is the remainder after multiplication of all bits in a control packet by  $x^n$  and then division (modulo 2) by the application specific generator polynomial. The remainder is a polynomial of at most degree  $(n - 1)$ .

When representing the contents of the block as a polynomial, the first bit in the block, bit 1, should be taken as being the most significant bit. Consequently,  $C_1$  is defined to be the most significant bit of the remainder and  $C_n$  the least significant bit of the remainder.

### 6.2.5.2 CRC encoding procedure

The control packet is considered to be static. This means that the CRC- $n$  checksum can be calculated *a priori* over the control packet.

The encoding procedure is as follows:

- i) The CRC- $n$  bits in the control packet are replaced by binary 0s.
- ii) The control packet is then acted upon by the multiplication/division process referred to in 6.2.5.1.
- iii) The remainder resulting from the multiplication/division process is inserted into the CRC- $n$  location in the control packet.

The CRC- $n$  bits generated do not affect the result of the multiplication/division process because, as indicated in i) above, the CRC- $n$  bit positions are initially set to 0 during the multiplication/division process.

### 6.2.5.3 CRC decoding procedure

The decoding procedure is as follows:

- i) A received control packet is acted upon by the division process referred to in 6.2.5.1.
- ii) If the remainder calculated in the decoder is zero, it is assumed that the checked control packet is error free.

### 6.2.6 Member Status (MST) field

Information about the status of all members of the same VCG is conveyed from  $S_k$  to  $S_o$  in the MST by member signals with control word ADD, NORM, EOS or DNU.

It reports the member status from  $S_k$  to  $S_o$  with two states: OK or FAIL (1 status bit per member). OK = 0, FAIL = 1. Since each control packet contains only a limited number of bits for communicating the MST field, this information is spread across multiple control packets, an MST multiframe.

The quantity of members in the VCG can be any number in the allocated range (e.g., 0-255 for High Order in SDH), and can be changed. For each member, the  $S_k$  uses the SQ number it receives from the  $S_o$  as the MST number for its response to the  $S_o$ . In this manner, the MST values received by the  $S_o$  will always correspond directly to the SQ values that it assigned.

NOTE – In the non-LCAS mode, the receiver function is provisioned to expect a fixed number of members.

To allow the receiver to determine the number of members in the VCG, the following should be noted. The highest non-failed active member will be indicating end of sequence (EOS) in the control field. The VCG may have other members with a higher SQ value in the do-not-use (DNU) state.

At initiation of a VCG sink all members shall report MST = FAIL. A transition to MST = OK occurs when a control packet is received for that member with a control field of ADD (or NORM or EOS after it has been added, or DNU after recovery from a network failure). All unused MST and members that have a control field of IDLE shall be set to FAIL.

### 6.2.7 Re-Sequence Acknowledge (RS-Ack) bit

When a renumbering of the sequence numbers of the members sending in CTRL field NORM, DNU, EOS, or when a change of the number of these members is detected at the Sk, a notification to the So per VCG has to be performed by toggling (i.e., change from '0' to '1' or from '1' to '0') the RS-Ack bit. In particular, the causes that trigger the toggling of RS-Ack bit can be listed as follows (see also SDL diagrams for a detailed description of RS-Ack use):

- SQ change for any VC of the VCG (SQ change detected by Sk for members in DNU/NORM/EOS);
- CTRL = "ADD" → CTRL = "EOS" and/or CTRL = "ADD" → CTRL = "NORM" (Addition of one or more members);
- CTRL = "NORM" (or "EOS") → CTRL = "IDLE" (Decrease bandwidth);
- CTRL = "DNU" → CTRL = "IDLE".

NOTE 1 – Following an ADD command from management interface (i.e., when a transition CTRL = IDLE → CTRL = ADD occurs), no RS-Ack has to be transmitted. In fact, RS-Ack should be toggled only when a change in sequence of the members belonging to the VCG is detected at the Sink. During the first phase of the addition of new members (IDLE to ADD state transition), even if a SQ assignment may happen, it does not yet affect the VCG, therefore no RS-Ack is needed.

The RS-Ack bit can only be toggled after the status of all members of the VCG has been evaluated and the sequence change has taken place. In case the RS-Ack is not sent to the So, the synchronization between Sk and So is achieved with the activation (during operations requiring a resequence or variation of the member's number in a VCG) of a RS-Ack time-out. The expiration of the time-out is equivalent to the detection of a toggled RS-Ack bit at So (refer to SDL protocol description, shown in Figures A.1 and A.7, for details). The toggling of the RS-Ack bit or the expiration of the RS-Ack time-out indicates that a new MST value can be considered. This means that MST values received in the control packet that contains the RS-Ack, and MST values received in subsequent control packets, correspond to the new sequence. The So can use this toggling as an indication that the change initiated by the So has been accepted and completed, and will start accepting new MST information.

NOTE 2 – No new change in the VCG should be executed, i.e., no member should be added or removed from the VCG, until the RS-Ack is received or the RS-Ack timeout has expired for the currently active change request.

### 6.3 VCG capacity increase (Addition of member(s))

When a member is added, it shall always be assigned a sequence number one larger than the currently highest sequence number that has EOS or DNU in the CTRL code. When multiple members are added, they must each use a unique sequence number so there will be a unique MST response for each additional member.

Following an ADD command, the first member to respond with MST = OK shall be allocated the next highest sequence number and shall change its CTRL code to EOS coinciding with the currently highest member changing its CTRL code to NORM (or remains DNU).

NOTE – When the CTRL = ADD is sent to initiate the addition of a new member, it shall be sent continuously until the MST = OK is received.

In case more than one member (e.g., x) is being added, and MST = OK is being simultaneously received for those members, then the allocation of sequence indicators is arbitrary provided they are the next x sequence numbers after the currently highest sequence number (which has CTRL code EOS or DNU). The newly added members will have CTRL code NORM or EOS. The CTRL code for the currently highest member will change from EOS to NORM (or remains DNU) coinciding with the highest new member's CTRL code being changed to EOS. All other new member's CTRL codes will be set to NORM.

### **6.3.1 Addition of member(s) payload**

The final step for adding a member is to send a NORM or EOS in the control field of the virtual concatenation overhead control packet for that member. The first container frame to contain payload data for the new member shall be the container frame immediately following the container frame that contained the last bit(s) (i.e., the CRC) of the control packet with NORM/EOS control field for that member.

## **6.4 VCG capacity decrease: Member(s) temporary removed by the LCAS procedure (due to failure)**

### **6.4.1 Temporary removal of a member**

When a member sending a NORM or EOS experiences a failure in the Network, this is detected at the Sk (MSU\_L, TSD) and the Sk will send MST = FAIL for that particular member. The reporting of the MST = FAIL can be delayed by a Hold-Off time to limit the number of switch actions in case of nested protection mechanisms. Upon detection of the MST = FAIL, the So will either replace the NORM condition by a DNU condition, or replace the EOS condition with a DNU condition. The active member with the highest sequence number will send EOS in the CTRL field.

#### **6.4.1.1 Temporary removal of a member's payload**

There are two reasons for a temporary removal of a member's payload:

- In case of a received MSU\_L, the final step for temporary removal of a member is to remove that particular member from the VCG. At the Sk side, the removal shall start immediately after detection of the MSU\_L defect. At the So side, the last container frame that contains payload of the removed member shall be the container frame containing the last bit(s) of the control packet containing the first DNU control field. The following container frames will contain all ZEROes in the payload area. Upon reception at the Sk of the DNU control field, the payload of this particular member shall not be used to reconstruct the original VCG payload.
- In case of a received TSD, the final step for temporary removal of a member is to remove that particular member from the VCG. At the Sk side, the payload area of that particular member will continue to be used for the reconstruction of the original VCG payload. The bit errors in the payload area of the member have to be handled by the server to client adaptation function at the sink side of the VCG. At the So side, the last container frame that contains payload of the removed member shall be the container frame containing the last bit(s) of the control packet containing the first DNU code in the control field. The following container frames will contain all ZEROes in the payload area. Upon reception at the Sk of DNU in the control field, the payload area of that particular member is removed from the VCG.

## **6.4.2 Reinstatement of temporarily removed member**

When the defect causing the temporary removal is cleared, this is detected at the Sk. The Sk will send MST = OK for that particular member. The reporting of the MST = OK can be delayed by a Wait-To-Restore time to avoid unwanted effects due to intermittent defects. Upon detection of the MST = OK, the So will either replace the DNU condition by a NORM condition, or replace the DNU condition with an EOS condition and the preceding member, that was sending CTRL code EOS, will send NORM in the CTRL field.

### **6.4.2.1 Reinstatement of temporarily removed members payload**

The final step after recovering from a temporary removal is to start using the payload area of that member again. The first container frame to contain payload data for the member shall be the container frame immediately following the container frame that contained the last bit(s) of the control packet containing the first CTRL code NORM or EOS in the control field for that member.

## **6.5 VCG capacity decrease: Removal (permanent) of member(s)**

When members are deleted, the sequence numbers shall be renumbered. If the permanently removed member contained the highest sequence number of that group, the active member containing the next highest sequence number shall change its control field to EOS in its control packet coinciding with the permanently removed member's control packet with the IDLE control field. If the permanently removed member contained the highest sequence number of that group and sends DNU in the control field, the sequence numbering and control fields of the other members in the group will not change. If the permanent removal of a member occurs somewhere other than at the highest end of the sequence, then the other members with sequence numbers between the newly permanently removed member and the highest sequence number shall update their sequence indicators in their control packets coinciding with the control packet changing the status of the permanently removed member.

Note that if permanent removal of members is initiated at the sink end first and the removed members were not the ones receiving signals with the highest SQ numbers, some of the remaining sink end members will receive SQ numbers higher than the new provisioned size at the sink end (until the members are removed at the source, too); this is not a fault condition.

NOTE – If a permanent removal of an active member is initiated at the Sk, this will result in a hit to the reconstructed data in case the Remove Timer is set to the value '0' (zero) – see A.4.1 for details. The duration of this hit will be from the time the member is removed (starts sending MST = FAIL) until the DNU would have been received from the So.

### **6.5.1 Deletion of member(s) payload**

When a member is deleted by sending an IDLE control field in the control packet on the virtual concatenation overhead for that member, the last container frame in which the deleted member contains payload data shall be the container frame containing the last bit(s) of the control packet containing the IDLE control field.

## **6.6 LCAS to non-LCAS interworking**

Interworking between non-LCAS and LCAS Virtual Concatenation can be achieved as described in 6.6.1 and 6.6.2. Changes to the number of members in the VCG will be possible only by provisioning.

### **6.6.1 LCAS transmitter and non-LCAS receiver**

An LCAS transmitter can interwork with a non-LCAS receiver in non-LCAS mode without any special consideration. The LCAS transmitter will place the MFI and SQ as designated in ITU-T Recs G.707/Y.1322 [1] and G.709/Y.1331 [2]. The receiver will ignore all other bits, i.e., the LCAS overhead information.

The member status returned from sink to source will always be MST = OK.

### **6.6.2 Non-LCAS transmitter and LCAS receiver**

An LCAS receiver expects a CTRL word that is not '0000' and a correct CRC. A non-LCAS transmitter will transmit '0000' in the LCAS CTRL field as well as the CRC field. Therefore, when an LCAS receiver is interworking with a non-LCAS transmitter and receives both CTRL word AND CRC equal to '0000', it shall:

- Ignore all information (except MFI and SQ);
- Use MFI and SQ defect detection as defined for virtual concatenation.

### **6.7 Asymmetric connections**

The LCAS generally assumes directional independence of individual members of a virtually concatenated group. This implies connection asymmetry, i.e., the bandwidth of the forward transport is independent of the bandwidth of the return transport. Based on this consideration, the enclosed Specification and Description Language (SDL) diagrams in Annex A, and the time sequence diagrams, in Appendix I, only consider the asymmetric connectivity.

### **6.8 Symmetric connection**

This is for further study.

Each constituent member in the virtually concatenated group has an accompanying member in the opposite direction (similar to bidirectional), the sink side status is only reported on its partner.

If it is desired to keep the connection symmetric, this shall be provisionable from the Element Management System.

## Annex A

### LCAS protocol

#### A.1 LCAS protocol

The operation of LCAS is unidirectional. This means that in order to bidirectionally add or remove members, the procedure has to be repeated in the opposite direction. Note that these actions are independent of each other and are therefore not required to be synchronized. When the transmission of members belonging to the VCG is error free, the scheme allows hitless addition and removal of bandwidth under control of a management system. Additionally, LCAS will autonomously remove failed members temporarily from the group. When the failure condition is remedied, LCAS will add the member back into the group. The removal of a member due to path layer failures will, in general, not be hitless for the service carried over the virtual concatenated group. The autonomous addition, after a failure is repaired, is hitless.

In this model, there are three parameters to describe the virtual concatenated group of size  $-X_v$ :

- 1) the parameter  $X_M$ , which indicates the maximum size of the virtual concatenated group. This parameter is limited by specific definitions for each transport network technology (e.g., ITU-T Rec. G.707/Y.1322 for SDH, ITU-T Rec. G.709/Y.1331 for OTN) and may be further restricted to lower values in particular implementations;
- 2) the parameter  $X_P$ , which indicates the number of provisioned members in the virtual concatenated group. Each completed ADD[i] command will increment  $X_P$  by 1, each completed REMOVE[i] command will decrement  $X_P$  by 1. Furthermore, the relationship  $0 \leq X_P \leq X_M$  holds;
- 3) a parameter  $X_A$ , which indicates the actual number of members of the virtual concatenated group as influenced by autonomous adding or deleting of members by the LCAS protocol in the case of individual member failures. The relationship  $0 \leq X_A \leq X_P \leq X_M$  holds.

Each parameter can then be further qualified in separate terms: when the source (transmit) or the sink (receive) end process need to be referenced specifically, "T" or "R" are added to the terms, respectively. For example,  $X_{PT}$  is the provisioned number of members in the source (transmit) direction and  $X_{AR}$  is the actual number of members in the sink (receive) direction.

For each member ( $X_{MT}$  times), there is a state machine at the source end that would be in one of the following five states:

- 1) IDLE: This member is not provisioned to participate in the concatenated group.
- 2) NORM: This member is provisioned to participate in the concatenated group and has a good path to the sink end.
- 3) DNU: This member is provisioned to participate in the concatenated group and has a failed path to the sink end.
- 4) ADD: This member is in the process of being added to the concatenated group.
- 5) REMOVE: This member is in the process of being deleted from the concatenated group.

For each member ( $X_{MR}$  times), there is a state machine at the sink end that can be in one of the following three states:

- 1) IDLE: This member is not provisioned to participate in the VCG.
- 2) OK: The incoming signal for this member experiences no failure condition (i.e., MSU\_L) or has received and acknowledged a request for addition of this member. When the incoming signal is degraded (i.e., TSD) the member remains in the OK state.

- 3) **FAIL:** The incoming signal for this member experiences some failure condition or an incoming request for removal of a member has been received and acknowledged.

These state machines run concurrently for all  $X_{MT}$  source and  $X_{MR}$  sink functions.

To indicate in the SDL descriptions the possible events, the following notational conventions are used:

- The following 5 control messages will be forwarded from the source end towards the sink end. A member will always forward one of these messages (so there are always  $X_{MT}$  messages transmitted). The messages pertain to the member from which the message is sent.
  - 1)  $F_{IDLE}$  = Indication that this container is currently no member of the group and no ADD requests are pending;
  - 2)  $F_{ADD}$  = Request to add this member to the group;
  - 3)  $F_{DNU}$  = Indication that the payload of this member in the group shall not be used;
  - 4)  $F_{EOS}$  = Indication that this member has the highest sequence number among the active members in the group;
  - 5)  $F_{NORM}$  = Indication that this member is normal part of the group and does not have the highest sequence number.
- $C_{EOS}$  and  $C_{NORM}$  are messages (source side only) from member(i) to member(i – 1), the previous in the sequence, to indicate that the control field sent by member(i – 1) shall be changed as requested.
- $R_{FAIL}$  and  $R_{OK}$  are messages from sink to source about the status of the sink end of all members. The statuses of all sink ends are returned to the source end in the control packets of each member. The source end can, for example, read the information from member No. 1 and, if that is unavailable, the same information from member No. 2, etc. As long as no return bandwidth is available, the source end will use the last received valid status.
- $M_{ADD}$  and  $M_{REMOVE}$  are messages from the management system to add or remove a member. The remove operation affects a specific member. Adding a new member is always at the end of the group with a new, highest, sequence number.
- $R_{RS-ACK}$  is a bit used to acknowledge the detection at the sink side of a renumbering of the sequence or a change in the number of members of the VCG. This acknowledgement is used to synchronize source and sink and to eliminate the influence of network delays. Due to the renumbering of the sequence at the time of an add or remove request, the received member status cannot be used for a time period that is determined by transmission delays and framing delays.
- $C_{RSQ}$  is a message (transmit source side only) from member(i) to member(i + 1), the next in the sequence, to indicate that the sequence number of member(i + 1) shall be decremented by 1.
- $S_{RSQ}$  is a message from the member state machines, at both source and sink side, to the VCG state machine to indicate that a change in the sequence numbering has taken place.

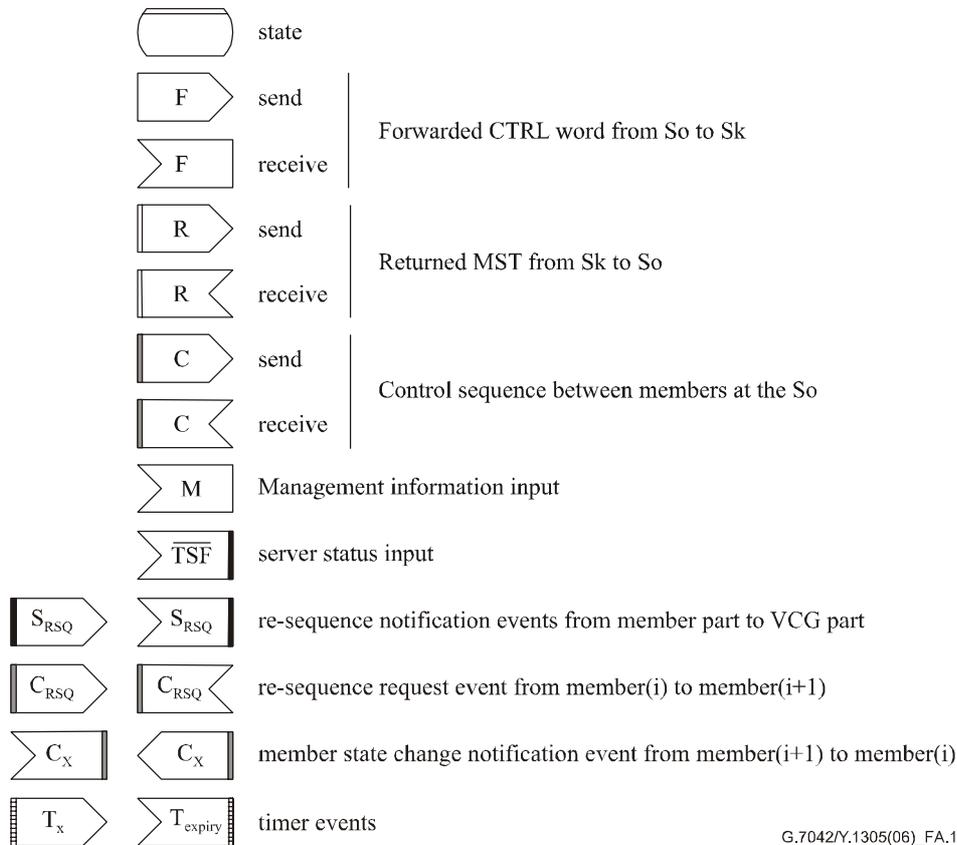
The LCAS protocol is described in SDL diagrams to detail the state transitions.

To avoid possible misalignment between  $S_o$  and  $S_k$  regarding the sequence numbers and the corresponding received far-end statuses, the number of provisioned members  $X_p$  in the VCG is only changed under management command.

The sequence number received just before an  $MSU\_L$  will be used for the reporting of the member status, but the payload will not be used to reconstruct the original signal. If the failed member is removed (by manager action), there will be a renumbering of the remaining sequence numbers.

Replacement of a failed member (in the state DNU), because the failure in the network cannot be repaired, has to be performed via a REMOVE – ADD sequence.

The SDL diagrams for the LCAS protocol description use the following conventions:



G.7042/Y.1305(06)\_FA.1

**Figure A.1/G.7042/Y.1305 – State diagram legend**

## A.2 LCAS protocol partitioning

The LCAS functionality can be partitioned as follows:

- Part of the protocol is performed at the Source side of the VCG; and
- Part of the protocol is performed at the Sink side of the VCG.

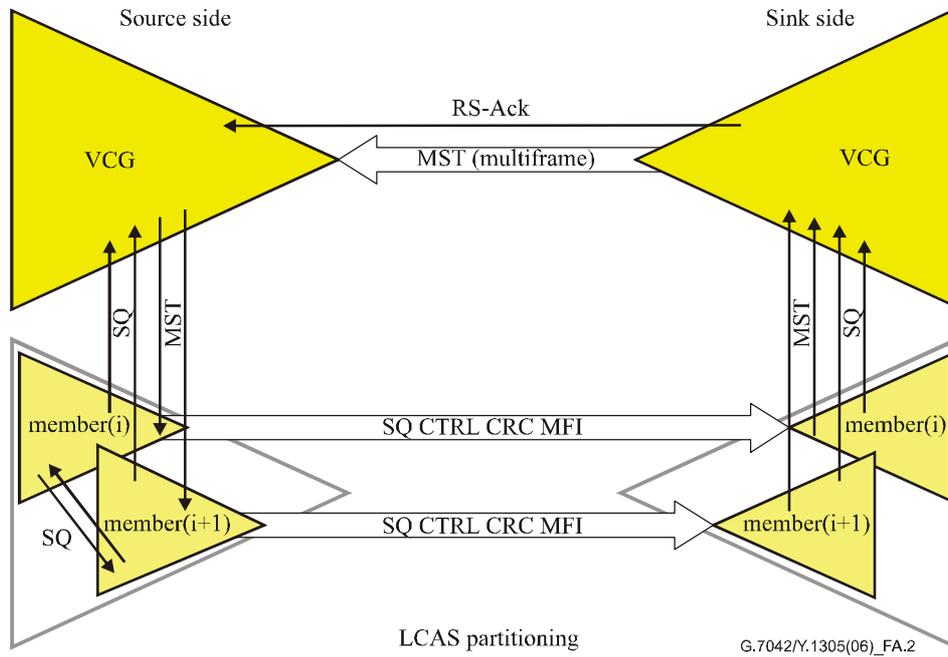
Note that the flow of information from Source to Sink is per individual member of the VCG, i.e., SQ, CTRL, CRC and MFI. The flow of information from Sink to Source is per definition common for all members of the VCG.

Using the flows a further partitioning can be made:

- The part performing the functions at the Source side transmitting the information of each individual member to the Sink side, i.e., SQ, CTRL, CRC, MFI. SQ information is exchanged between the members of the VCG. SQ information is also sent to the receiving part to control the distribution of the member MST;
- The part performing the functions at the Sink side receiving the information of each individual member from the Source side and sending SQ and member status to the next part;
- The part performing the functions at the Sink side transmitting the information concerning all members of the VCG, i.e., the VCG member status as a whole and the acknowledge of a detected change in the VCG sequence numbering;

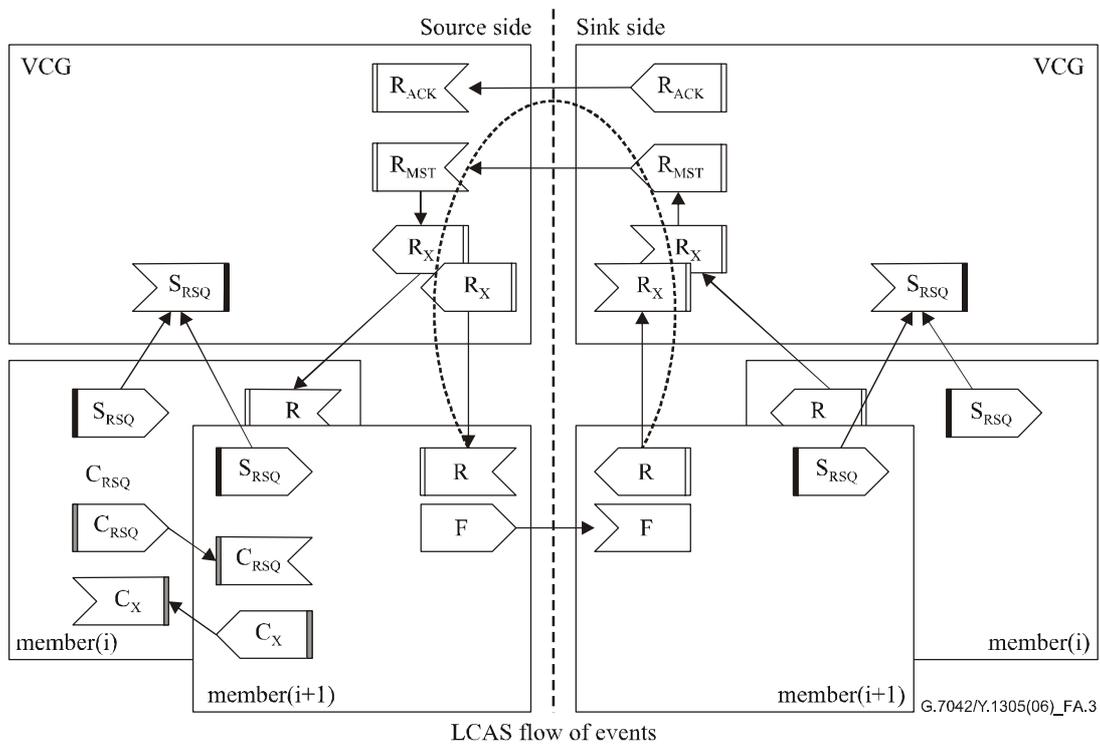
- d) The part performing the functions at the Source side receiving the information concerning all members of the VCG, i.e., VCG MST and RS-Ack, and distributing the MST to each VCG member part.

Figure A.2 illustrates these parts and shows the flow of information between the parts.



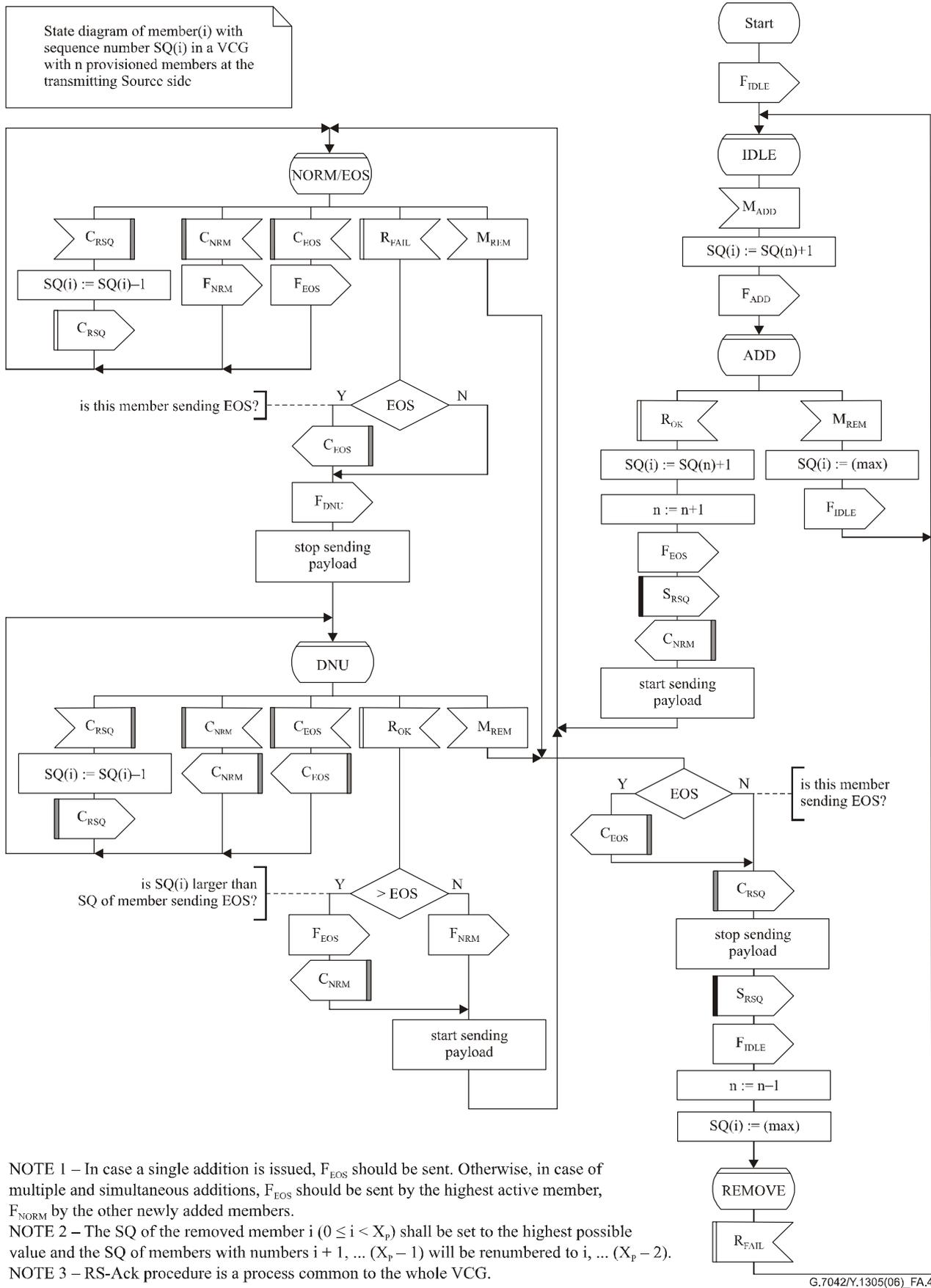
**Figure A.2/G.7042/Y.1305 – LCAS protocol partitioning**

Figure A.3 shows the events exchanged between the separate parts of the LCAS protocol.



**Figure A.3/G.7042/Y.1305 – LCAS protocol flow of events**

### A.3 State diagram of member(i) in the Virtual Concatenated Group



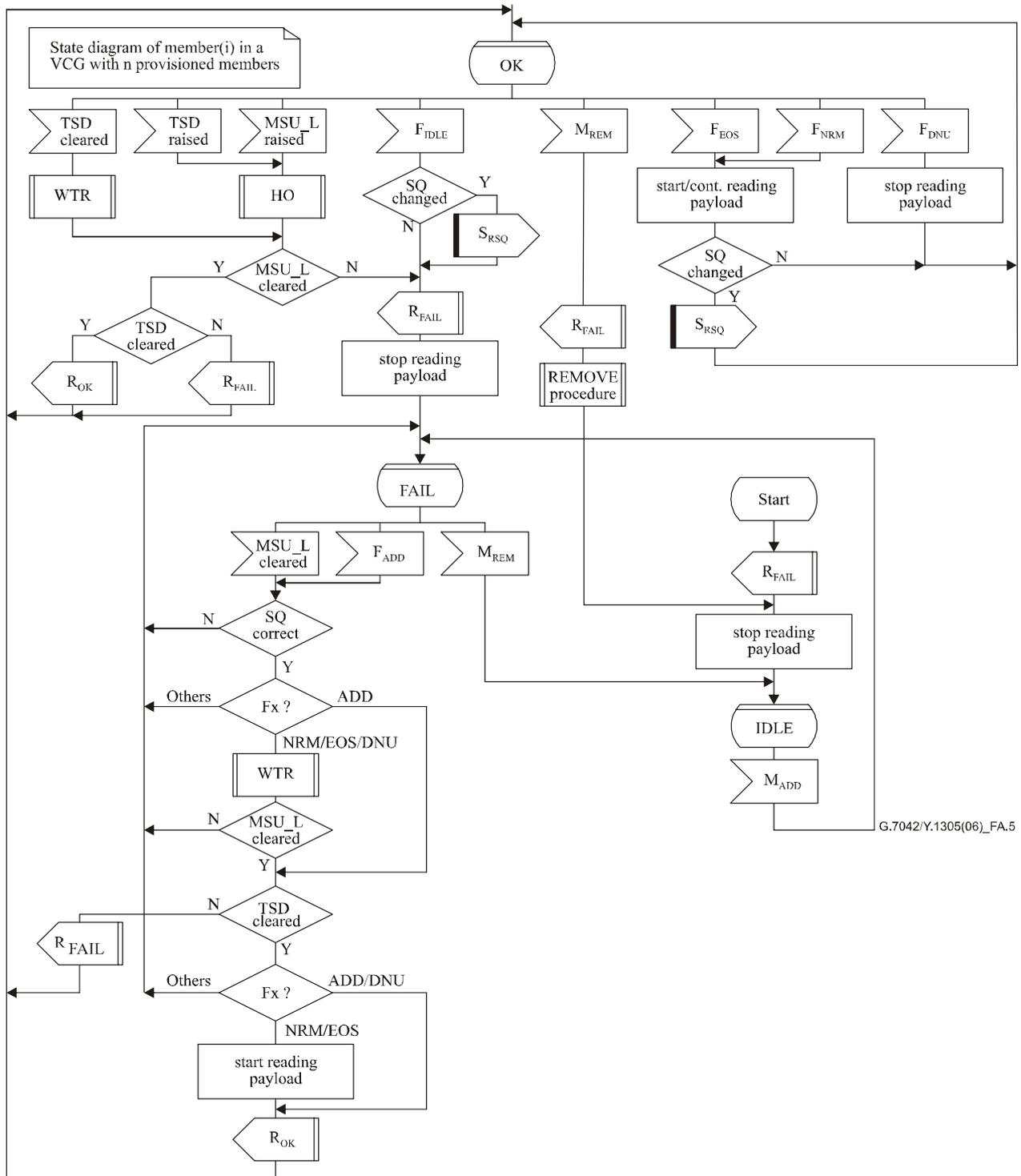
NOTE 1 – In case a single addition is issued,  $F_{EOS}$  should be sent. Otherwise, in case of multiple and simultaneous additions,  $F_{EOS}$  should be sent by the highest active member,  $F_{NORM}$  by the other newly added members.

NOTE 2 – The SQ of the removed member  $i$  ( $0 \leq i < X_p$ ) shall be set to the highest possible value and the SQ of members with numbers  $i + 1, \dots (X_p - 1)$  will be renumbered to  $i, \dots (X_p - 2)$ .

NOTE 3 – RS-Ack procedure is a process common to the whole VCG.

G.7042/Y.1305(06)\_FA.4

Figure A.4/G.7042/Y.1305 – Source side state diagram



G.7042/Y.1305(06)\_FA.5

NOTE 1 – As per 6.2.2, no specific SQ is available at the sink after receiving a control word of "IDLE" for a member. MST = FAIL is generated here according to the general rule in Annex B/G.806 for members without validated SQ.

NOTE 2 – This check verifies whether the SQ received for the present member is unique compared to those of the members in the OK state. If the received SQ is unique (i.e., not in use by any member among those in the OK state), the "y" branch is followed. Otherwise the "n" branch is followed.

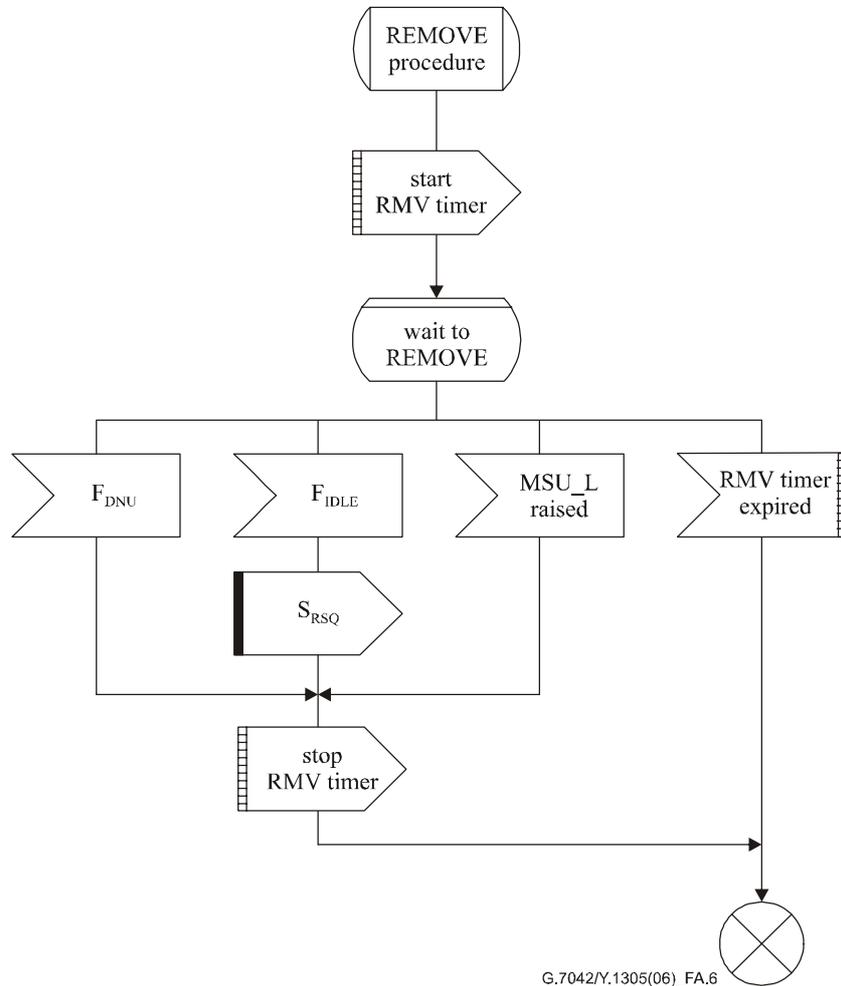
NOTE 3 – For a particular member(i), "hold off" and "wait to restore" procedures are never simultaneously active.

**Figure A.5/G.7042/Y.1305 – Sink side state diagram**

## A.4 Procedures state diagrams

### A.4.1 REMOVE procedure

The procedure describes the REMOVE timer activation and deactivation processes in order to allow hitless removal of a member from the VCG initiated at the Sink side. Figure A.6 shows the detailed SDL diagram for this procedure.



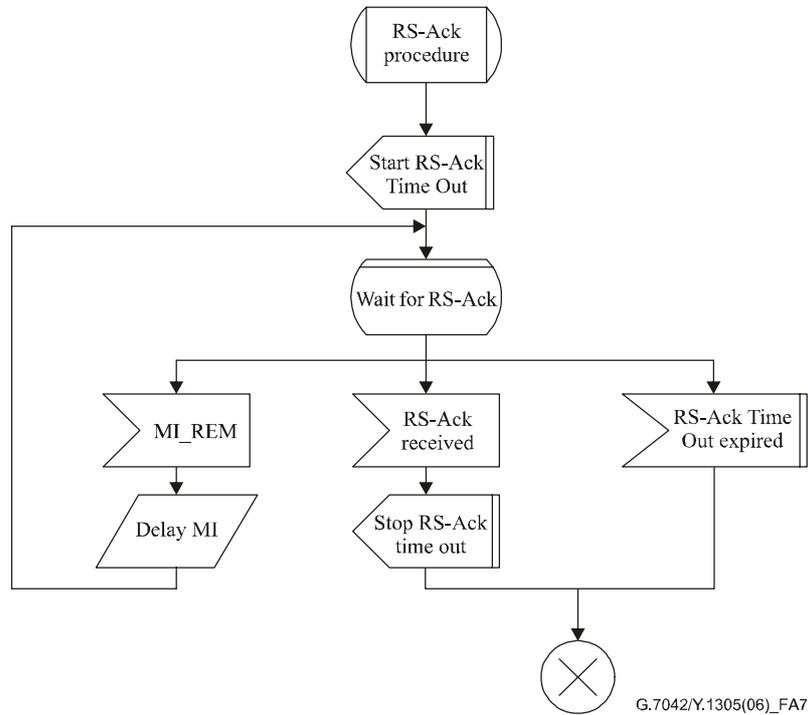
NOTE 1 – The 'wait to REMOVE' state is only a transitory state needed to get confirmation from the Source that it has recognized that a member will be removed by the Sink. Only after this confirmation is received, will the member payload be discarded. In this way, any other potential changes in the VCG, that the Source may initiate, is precluded.

NOTE 2 – In case the value of the Remove-timer is set to 0 (zero), the REMOVE procedure is disabled, and the LCAS process behaves as defined in the 2004 version of ITU-T Rec. G.7042/Y.1305.

**Figure A.6/G.7042/Y.1305 – REMOVE procedure**

## A.4.2 RS-Ack procedure

This procedure describes the RS-Ack detection process, used for validating the received MST. RS-Ack procedure is a process common to the whole VCG that is activated by a single member. Figure A.7 shows the detailed SDL diagram for this procedure.



NOTE – The 'wait for RS-Ack' state is only a transitory state needed as a confirmation that the Source needs before accepting the new MST value assignment. In this way, any other potential changes in the VCG, that the Source may initiate, is precluded.

**Figure A.7/G.7042/Y.1305 – RS-Ack procedure**

### A.4.3 WTR procedure

This procedure describes the wait-to-restore (WTR) timer activation and deactivation processes in order to avoid unwanted effects due to fleeting alarms, as described in ITU-T Rec. G.808.1. Figure A.8 shows the detailed SDL diagram for this procedure.

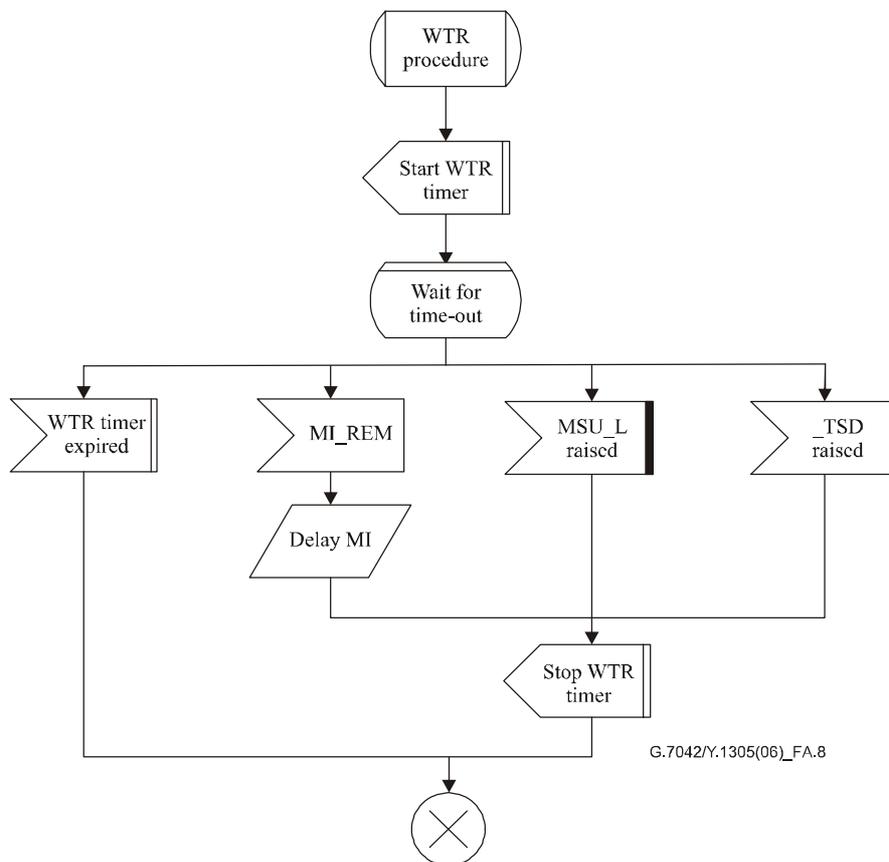
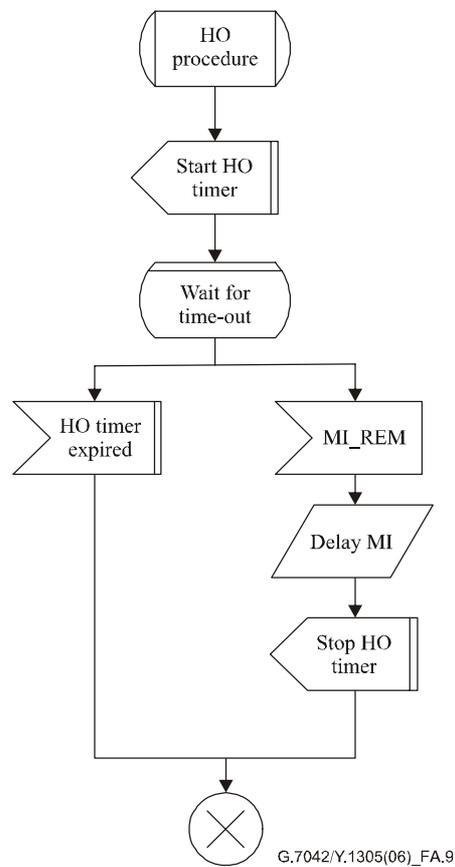


Figure A.8/G.7042/Y.1305 – WTR procedure

#### A.4.4 HO procedure

This procedure describes the Hold Off (HO) timer activation and deactivation processes in order to limit the number of switch actions in case of nested protections, as described in ITU-T Rec. G.808.1. Figure A.9 shows the detailed SDL diagram for this procedure.



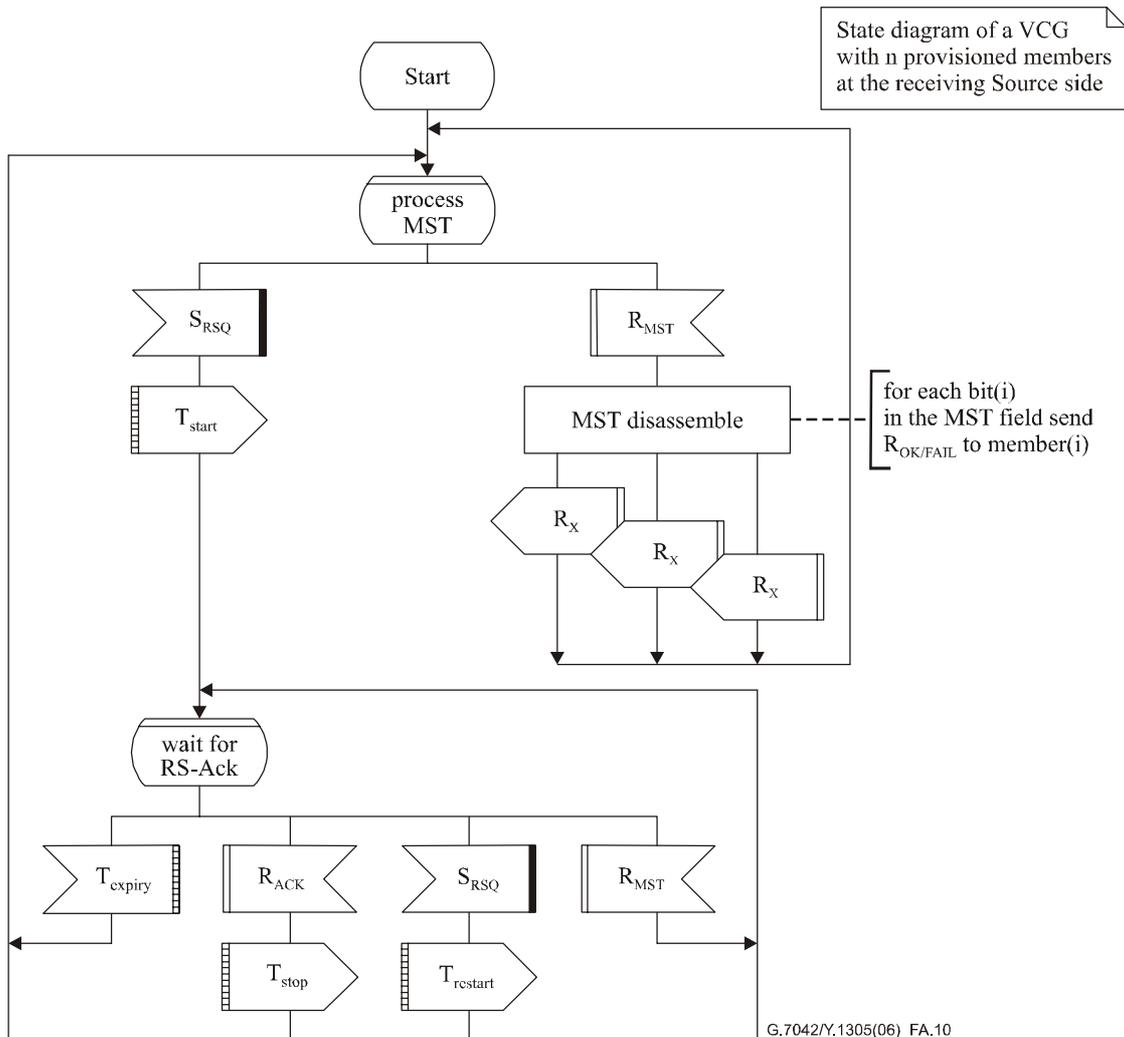
**Figure A.9/G.7042/Y.1305 – HO procedure**

NOTE – There are particular circumstances that cause non hitless bandwidth modifications under Hold Off periods. A description of the issue is described in Appendix II.

## A.5 State diagram for the VCG

For the whole VCG there is a state machine at the source receive side that would be in one of the following two states:

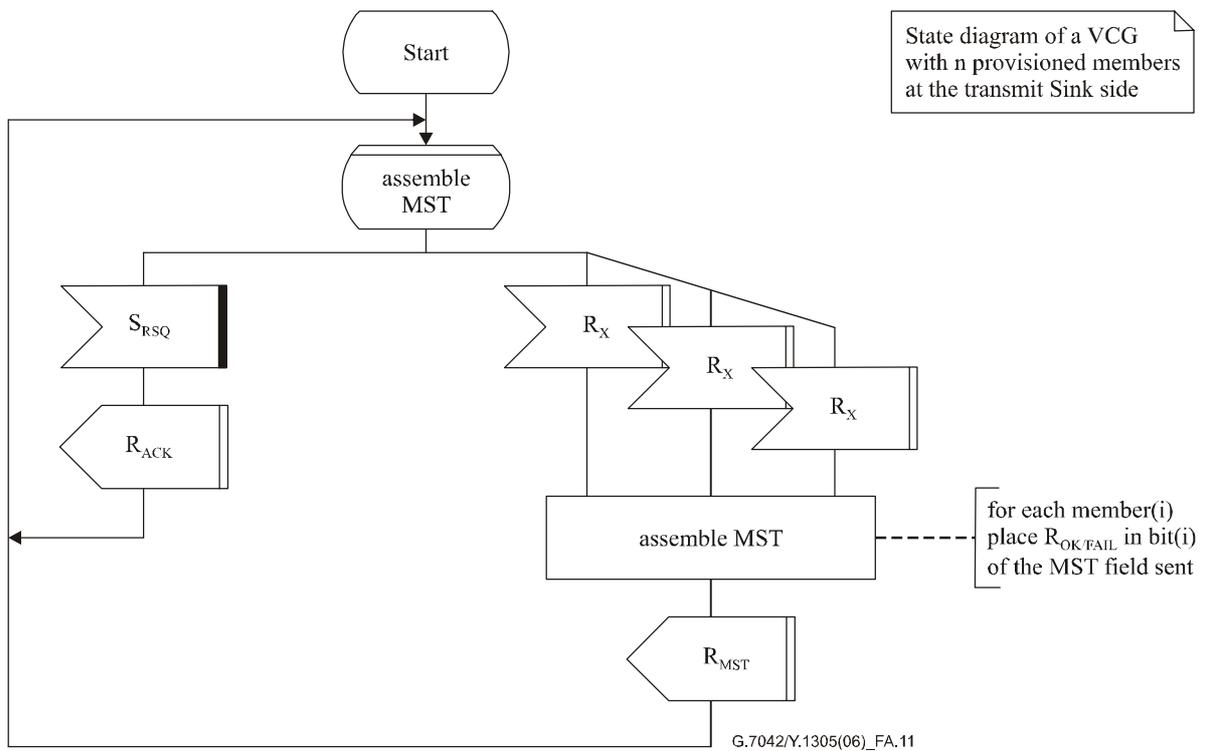
- 1) Process MST: The MST information received from one of the members will be processed and distributed to the individual members.
- 2) Wait for RS-Ack: One or more of the Source side member state machines has indicated that a change in sequence numbering has occurred. MST processing is stopped until the Sink confirms receipt by sending RS-Ack, or the RS-Ack timer expires.



**Figure A.10/G.7042/Y.1305 – Source side VCG receive state diagram**

For the whole VCG there is a state machine at the sink transmit side that has a single state:

- 1) Assemble MST: The MST information received from each of the members collected in the MST multiframe that is transmitted on all members. A change in sequence numbering detected by one or more of the members will be transmitted to the source side.



**Figure A.11/G.7042/Y.1305 – Sink side VCG transmit state diagram**

# Appendix I

## LCAS Time Sequence Diagrams

### I.1 Nomenclature

LCASC	Link Capacity Adjustment Scheme Controller
NMS	Network Management System
Sk	Sink (receiving end)
So	Source (transmitting end)

### I.2 Numbering system

Members in a virtually concatenated group shall be numbered 0 to  $(n - 1)$ , where  $n$  = total number of members in the group.

### I.3 Provisioning

When a new container is provisioned to be a member of the group, it must be allocated as follows:

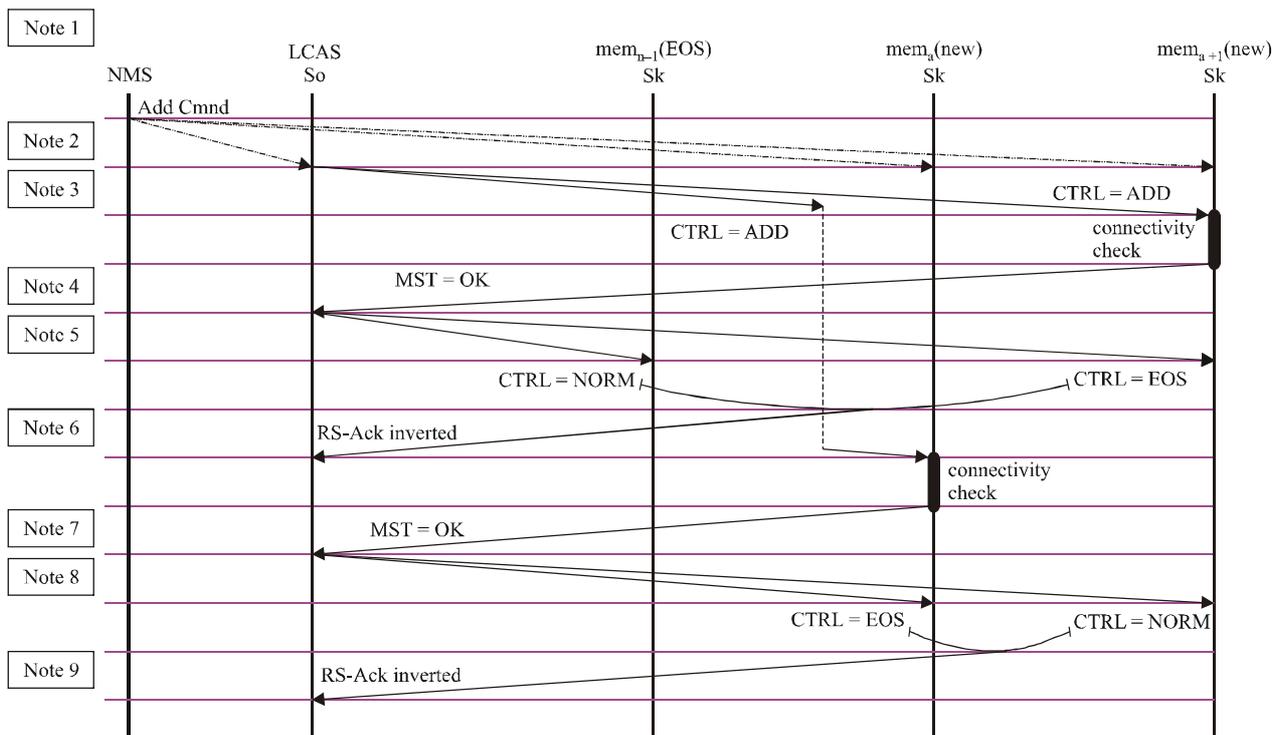
- a) CTRL = IDLE (this code indicates that it is not yet in service).
- b) SQ = Set to a value larger than the currently highest sequence number that has EOS in the CTRL code. The SQ shall not be interpreted while CTRL = IDLE (not yet in service). It is recommended to set SQ to the highest possible value. Because this highest value is technology dependent, it is not possible to indicate a precise value. In the following examples, the value (max) is used to indicate this highest value.
- c) GID = The group ID for that virtually concatenated group.
- d) MST = 1 (FAIL = 1; OK = 0).

### I.4 Commands

#### I.4.1 Increase bandwidth of VCG (ADD command)

##### I.4.1.1 Add: (ADD) multiple after last member

(Example: Add two members after last one in the group of  $n$ .)



G.7042/Y.1305(06)\_FI.1

Note		Member n			Member a (new)			Member a + 1 (new)			RS-Ack
		CTRL	SQ	MST	CTRL	SQ	MST	CTRL	SQ	MST	
1	Initial Condition	EOS	n - 1	OK	IDLE	(max)	FAIL	IDLE	(max)	FAIL	0
2	NMS issues Add command to So and Sk LCASC	EOS	n - 1	OK	IDLE	(max)	FAIL	IDLE	(max)	FAIL	0
3	So (a) sends CTRL = ADD and SQ = n; So (a + 1) sends CTRL = ADD and SQ = n + 1	EOS	n - 1	OK	ADD	n	FAIL	ADD	n + 1	FAIL	0
4	Sk (a + 1) sends MST = OK to So	EOS	n - 1	OK	ADD	n	FAIL	ADD	n + 1	OK	0
5	So (n - 1) sends CTRL = NORM; So (a + 1) sends CTRL = EOS and SQ = n	NORM	n - 1	OK	ADD	n + 1	FAIL	EOS	n	OK	0
6	RS-Ack bit inverted due to change in sequence	NORM	n - 1	OK	ADD	n + 1	FAIL	EOS	n	OK	1
7	Sk (a) sends MST = OK to So	NORM	n - 1	OK	ADD	n + 1	OK	EOS	n	OK	1
8	So (a) sends CTRL = EOS; So (a + 1) sends CTRL = NORM	NORM	n - 1	OK	EOS	n + 1	OK	NORM	n	OK	1
9	RS-Ack bit inverted due to change in sequence	NORM	n - 1	OK	EOS	n + 1	OK	NORM	n	OK	0

NOTE 1 – The example shows new member (a + 1) responding with MST = OK before new member a. This is arbitrary and the first member to respond with MST = OK shall be allocated the SQ = n, then the next new member to respond with MST = OK shall be allocated SQ = n + 1, etc. If for any reason a member being added does not respond with MST = OK within the time-out period, then the So LCASC may report a fail for that member.

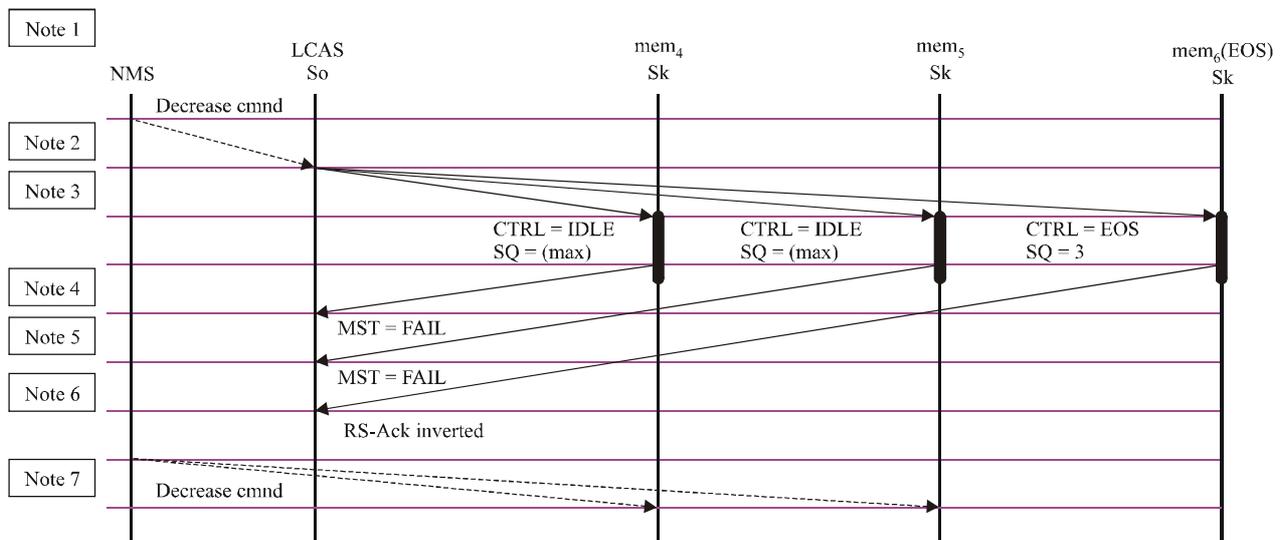
NOTE 2 – The '0' initial value for RS-Ack has been chosen arbitrarily. Only the toggling of the RS-Ack bit is relevant in the example.

**Figure I.1/G.7042/Y.1305 – ADD multiple members**

## I.4.2 Decrease bandwidth of VCG (REMOVE command)

### I.4.2.1 Decrease: (REMOVE) planned multiple NOT including last member

(Example: Remove members 4 and 5 from a VCG with n = 6 members.)



G.7042/Y.1305(06)\_F1.2

Note		Member 4			Member 5			Member 6			RS-Ack
		CTRL	SQ	MST	CTRL	SQ	MST	CTRL	SQ	MST	
1	Initial Condition	NORM	3	OK	NORM	4	OK	EOS	5	OK	0
2	NMS issues Decrease command to So LCASC	NORM	3	OK	NORM	4	OK	EOS	5	OK	0
3	So (3) sends CTRL = IDLE, SQ = (max) So (4) sends CTRL = IDLE, SQ = (max) So (5) sends SQ = 3	IDLE	(max)	OK	IDLE	(max)	OK	EOS	3	OK	0
4	Sk (unwanted) sends MST = FAIL to So	IDLE	(max)	FAIL	IDLE	(max)	OK	EOS	3	OK	1
5	Sk (unwanted) sends MST = FAIL to So	IDLE	(max)	FAIL	IDLE	(max)	FAIL	EOS	3	OK	1
6	RS-Ack bit inverted due to change in sequence	IDLE	(max)	FAIL	IDLE	(max)	FAIL	EOS	3	OK	1
7	NMS issues Decrease command to Sk LCASC	IDLE	(max)	FAIL	IDLE	(max)	FAIL	EOS	3	OK	1

**Figure I.2/G.7042/Y.1305 – Planned removal of members 4 and 5 out of 6**

The So LCASC sets CTRL = IDLE on all members to be removed.

NOTE 1 – CTRL does not change on the other members of the group.

The example above shows two members being removed with a simultaneous IDLE command from the So LCASC. Reassembly at the Sk ceases to use the 'removed' members immediately upon receipt of the IDLE command.

The response, however, from the Sk may not be simultaneous. This does not affect the Sk since the IDLE commands will have the same MFI value. The response from the Sk to the So is, of course, simply acknowledgement that the member is no longer in use at the Sk end and the NMS may proceed with de-provisioning of that member, if desired.

NOTE 2 – The removed members could be de-provisioned as indicated in Note 7 of the table above.

General rule for SQ adjustment in REMOVE function:

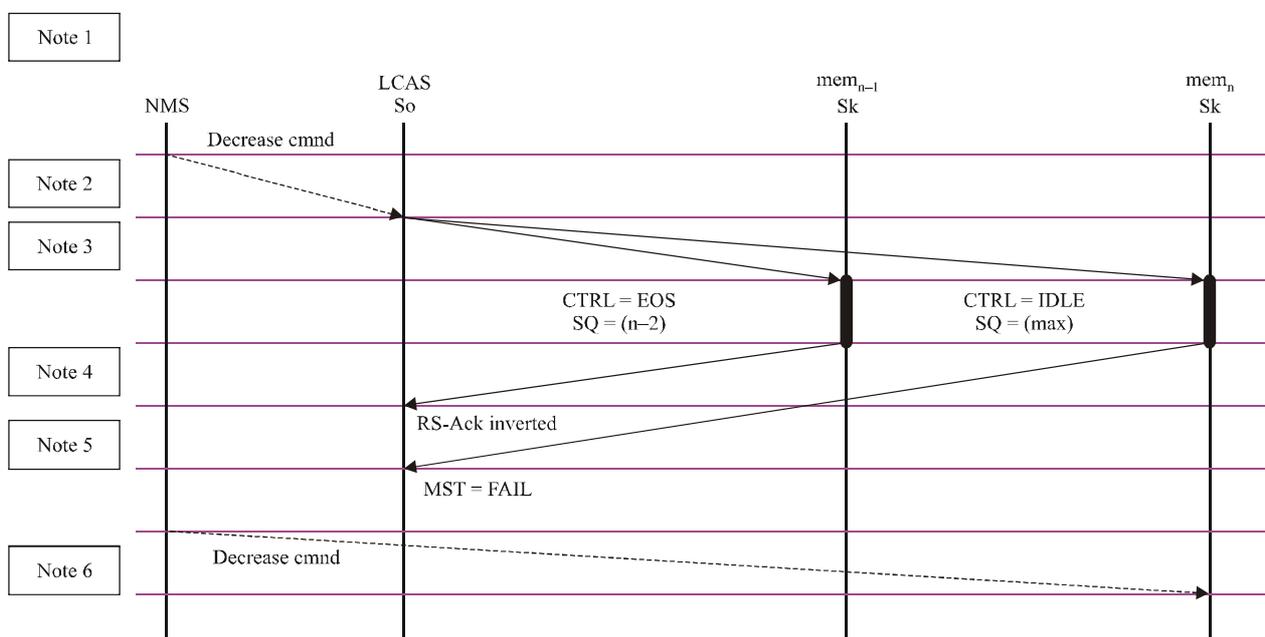
- 1) All unwanted members are reallocated an SQ greater than the SQ of the member sending the EOS control field, i.e., the highest possible value (max).
- 2) All remaining required members reallocated consecutive SQs (starting from SQ = 0).

This is best described by the following example:

	VC	A	B	C	D	E	F	G
Before	SQ	0	1	2	3	4	5	6
				U	U			U
After	SQ	0	1	(max)	(max)	2	3	(max)

NOTE 3 – The '0' initial value for RS-Ack has been chosen arbitrarily. Only the toggling of the RS-Ack bit is relevant in the example.

### I.4.2.2 Decrease: (REMOVE) planned single last member



G.7042/Y.1305(06)\_FL3

Note		Member n - 1			Member n			RS-Ack
		CTRL	SQ	MST	CTRL	SQ	MST	
1	Initial Condition	NORM	n - 2	OK	EOS	n - 1	OK	0
2	NMS issues Decrease command to So LCASC	NORM	n - 2	OK	EOS	n - 1	OK	0
3	So (unwanted) sends CTRL = IDLE, SQ = (max); So (n - 2) sends CTRL = EOS	EOS	n - 2	OK	IDLE	(max)	OK	0
4	RS-Ack bit inverted, due to a change in the sequence	EOS	n - 2	OK	IDLE	(max)	FAIL	1
5	At the same time Sk (unwanted) sends MST = FAIL	EOS	n - 2	OK	IDLE	(max)	FAIL	1
6	NMS issues Decrease command to Sk LCASC	EOS	n - 2	OK	IDLE	(max)	FAIL	1

Figure I.3/G.7042/Y.1305 – Planned decrease single (last) member

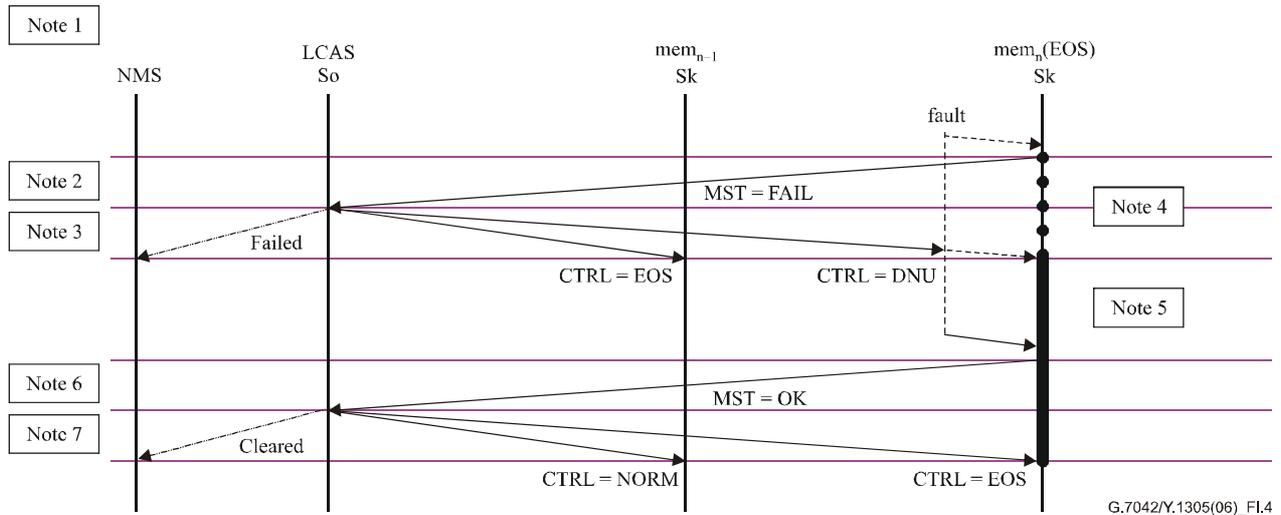
NOTE 1 – The removed member could be de-provisioned as indicated in Note 6 of the table above.

NOTE 2 – MST value should be updated at the latest in the same control packet sending the RS-Ack toggled.

NOTE 3 – The '0' initial value for RS-Ack has been chosen arbitrarily. Only the toggling of the RS-Ack bit is relevant in the example.

### I.4.3 Decrease bandwidth of VCG due to fault (DNU command)

#### I.4.3.1 Decrease (DNU) due to fault single (last) member



Note		Member n - 1			Member n (EOS)			RS-Ack
		CTRL	SQ	MST	CTRL	SQ	MST	
1	Initial Condition	NORM	n - 2	OK	EOS	n - 1	OK	0
2	Sk (fault_mem) sends MST = FAIL to So	NORM	n - 2	OK	EOS	n - 1	FAIL	0
3	So (fault_mem) sends DNU; So (fault_mem-1) sends EOS	EOS	n - 2	OK	DNU	n - 1	FAIL	0
4	See text below table	EOS	n - 2	OK	DNU	n - 1	FAIL	0
5	See text below table	EOS	n - 2	OK	DNU	n - 1	FAIL	0
6	Network Fault cleared MST = OK sent to So	EOS	n - 2	OK	DNU	n - 1	OK	0
7	CTRL changed from DNU to NORM	NORM	n - 2	OK	EOS	n - 1	OK	0

**Figure I.4/G.7042/Y.1305 – Decrease due to network fault, single (last) member**

The So LCASC sets CTRL = DNU on faulty member, and sets CTRL = EOS on preceding member.

*Text referring to Note 3 of the table above*

Even though a change has been made to the bandwidth and to which member contains the EOS, this change is a temporary change and does not trigger an RS-ACK.

*Text referring to Note 4 of the table above*

- As soon as an MSU\_L is detected, the Sk will immediately begin reassembly of the concatenated group using only the NORM and EOS members. For a time (propagation time from Sk to So + reaction time of the So + propagation time from So to Sk), the reassembled data will be erroneous because it is sent on all members as per pre-fault.
- If a TSD is detected, the Sk continues to use the payload of this member. The bit errors in the payload area of the member have to be handled by the server to client adaptation function at the sink side of the VCG. For a time (propagation time from Sk to So + reaction time of the So + propagation time from So to Sk), the reassembled data will be erroneous because it is sent on all members as per pre-fault.

Text referring to Note 5 of the table above

However, the So will stop sending data on the erroneous members (since they will have been reported back as MST = FAIL and consequently set the failed member to DNU), and send data only on the remaining NORM and EOS members.

- In case of MSU\_L: From the time the CTRL = DNU would have arrived at the Sk until the CTRL = NORM is received again, the bandwidth of the VCG is reduced.
- In case of TSD: From the time the CTRL = DNU arrives at the Sk, the bandwidth of the VCG is reduced.

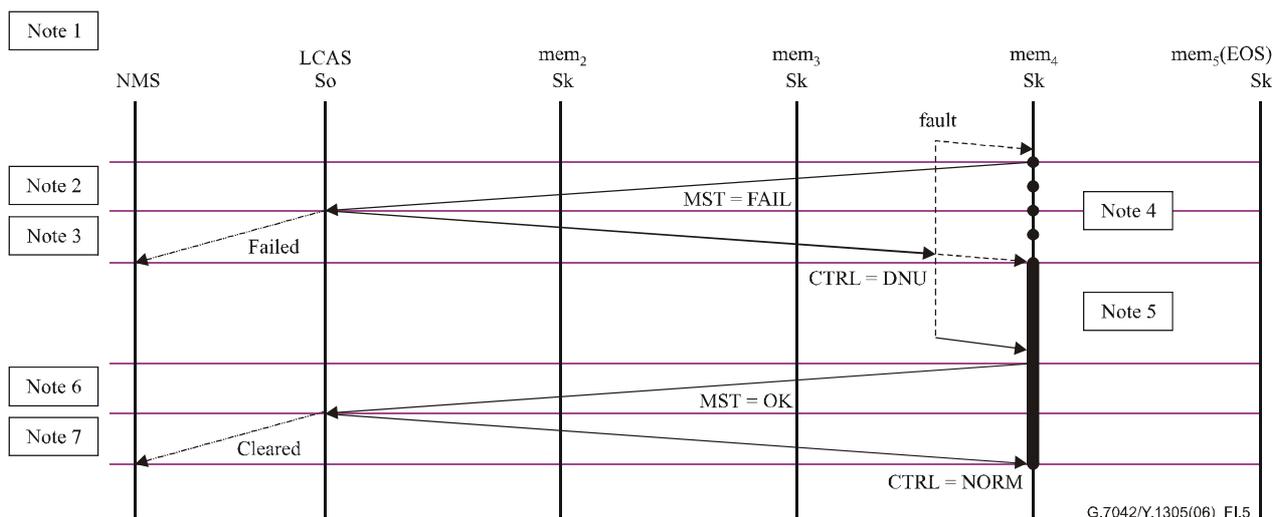
Text referring to Note 7 of the above table

When the failed member is repaired, the CTRL is changed to NORM from DNU. The Sk will then use this member's payload again to reassemble the data.

NOTE 1 – If the failed channel is subsequently deleted through a planned decrease prior to the fault clearing, the Sk will not be able to see the change in the failed member's control packet. As a result, RS-Ack will not be inverted by this planned decrease and the So has to rely on the RS-Ack timeout to continue processing MST. The bandwidth of the VCG is not affected.

NOTE 2 – The '0' initial value for RS-Ack has been chosen arbitrarily. Only the toggling of the RS-Ack bit is relevant in the example.

### I.4.3.2 Decrease: (DNU) due to fault NOT last member



Note		Member 2			Member 3			Member 4			Member 5 (EOS)			RS-Ack
		CTRL	SQ	MST	CTRL	SQ	MST	CTRL	SQ	MST	CTRL	SQ	MST	
1	Initial Condition	NORM	1	OK	NORM	2	OK	NORM	3	OK	EOS	4	OK	0
2	Sk (fault mem) sends MST = FAIL to So	NORM	1	OK	NORM	2	OK	NORM	3	FAIL	EOS	4	OK	0
3	So (fault mem) sends CTRL = DNU	NORM	1	OK	NORM	2	OK	DNU	3	FAIL	EOS	4	OK	0
4	See text below table	NORM	1	OK	NORM	2	OK	DNU	3	FAIL	EOS	4	OK	0
5	See text below table	NORM	1	OK	NORM	2	OK	DNU	3	FAIL	EOS	4	OK	0
6	Network Fault cleared MST = OK sent to So	NORM	1	OK	NORM	2	OK	DNU	3	OK	EOS	4	OK	0
7	CTRL changed from DNU to NORM	NORM	1	OK	NORM	2	OK	NORM	3	OK	EOS	4	OK	0

Figure I.5/G.7042/Y.1305 – Decrease due to network fault, single (not last) member

*Text referring to Note 4 of the table above*

- As soon as an MSU\_L is detected, the Sk will immediately begin reassembly of the concatenated group using only the NORM and EOS members. For a time (propagation time from Sk to So + reaction time of the So + propagation time from So to Sk), the reassembled data will be erroneous because it is sent on all members as per pre-fault.
- If a TSD is detected, the Sk continues to use the payload of this member. The bit errors in the payload area of the member have to be handled by the server to client adaptation function at sink side of the VCG. For a time (propagation time from Sk to So + reaction time of the So + propagation time from So to Sk), the reassembled data will be erroneous because it is sent on all members as per pre-fault.

*Text referring to Note 5 of the table above*

However, the source will stop sending data on the erroneous members (since they will have been reported back as MST = FAIL and consequently set the failed member to DNU), and send data only on the remaining NORM and EOS members.

- In case of MSU\_L: From the time the CTRL = DNU would have arrived at the Sk until the CTRL=NORM is received again, the bandwidth of the VCG is reduced.
- In case of TSD: From the time the CTRL = DNU arrives at the Sk, the bandwidth of the VCG is reduced.

*Text referring to Note 7 of the above table*

When the failed member is repaired, the CTRL is changed to NORM from DNU. The Sk will then use this member's payload again to reassemble the data.

NOTE – The '0' initial value for RS-Ack has been chosen arbitrarily. Only the toggling of the RS-Ack bit is relevant in the example.

## Appendix II

### Non-hitless bandwidth modifications during Hold Off periods

#### II.1 Introduction

SDL diagram for the Hold Off procedure described in A.4.4 shows the occurrence of the sole MI-REMOVE command as a possible input signal, causing other inputs, not explicitly depicted, to be discarded. The LCAS state machine will therefore not act on CTRL words received during the hold-off periods, thus impacting the traffic.

#### II.2 Removal of a group member at Source

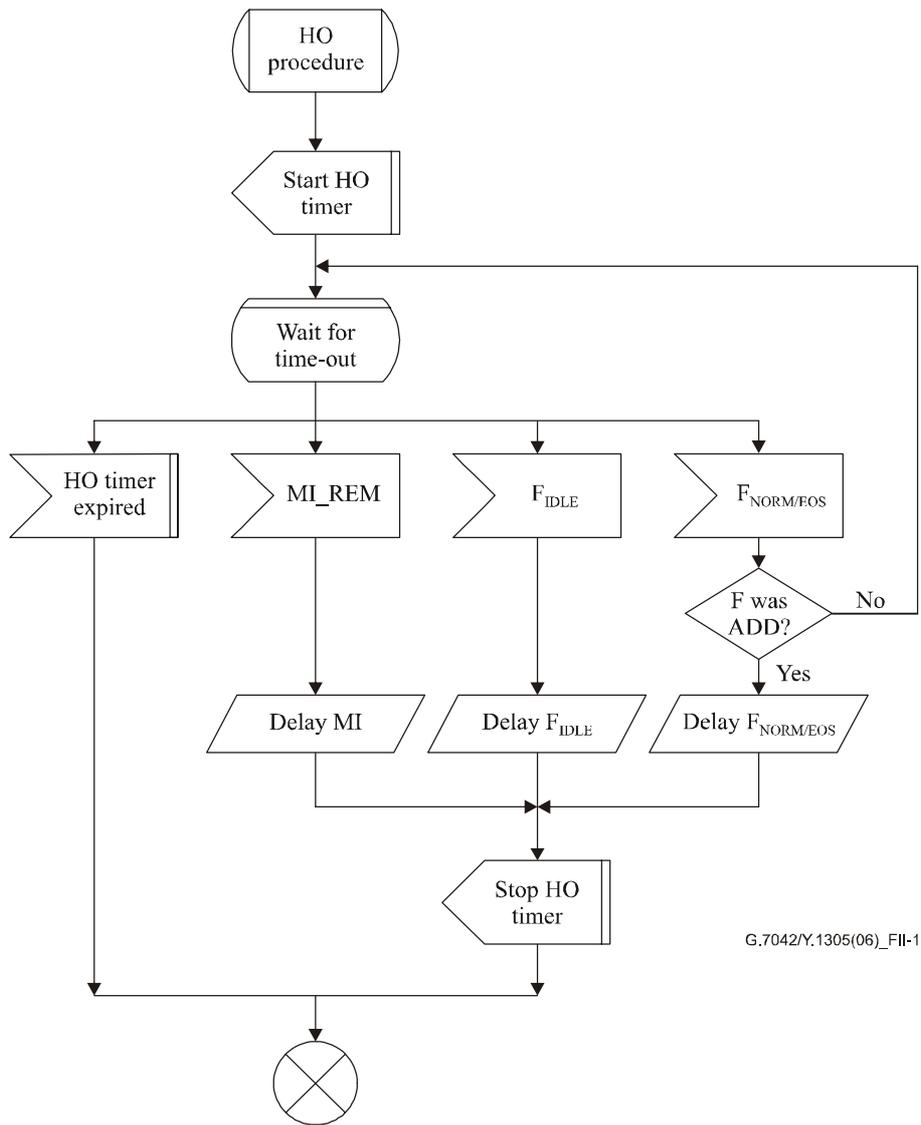
The removal action at source does not require synchronization between source and sink state machines and is therefore already performed at the source before signalling the change to the sink. Since the source already excluded the member from carrying payload, the sink should be able to react to this change immediately, even if it is currently in the hold-off state. If not, client payload will be lost until the timer expires.

#### II.3 TSD conditions raised while performing ADD commands

When performing a member's addition, at Sink a CTRL = ADD is received. Sink state will therefore move to the OK state and signal MST = OK to the source. The source will then move the member to the NORM state, signals CTRL = NORM/EOS and starts sending payload on this member. If meanwhile TSD is raised at the sink, the sink will have started a hold-off timer and is not able to react to the CTRL = NORM/EOS. Client payload will be lost until the timer expires.

#### II.4 Enhanced HO procedure

Even if the above-mentioned events are very limited in time and are characterized by a very low probability of occurrence, the HO procedure described in A.4.4 could optionally be enhanced in order to allow hitless capacity adjustments also in particular cases affected by transmission errors. The HO procedure SDL diagram to override the issue is reported below.



G.7042/Y.1305(06)\_FII-1

Figure II.1/G.7042/Y.1305 – Optionally enhanced Hold Off procedure SDL diagram

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