EPSG Draft Standard 302-A

Ethernet POWERLINK

Part A: High Availability

Version 1.1.1

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Pre. 2 History

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Pre. 6.1 Definitions

Active Managing Node (AMN)	An Active Managing Node is a Redundant Managing Node which is in Active state (managing the POWERLINK network). At a given time there is only one Active Managing Node in the POWERLINK network, other Redundant Managing Node being Standby Managing Node.
Link Selector (LS)	A Link Selector allows a node to be connected on two different physical networks.
Redundant Managing Node (RMN)	A Redundant Managing Node is a device that is able to take over the management of an POWERLINK network if the Active Managing Node fails. A Redundant Managing Node can either be in active state (AMN) or in standby state (SMN).
Single Point of Failure	A hardware or software component whose loss results in the loss of service
Standby Managing Node (SMN)	A Standby Managing Node is a Redundant Managing Node which is in Standby State. It behaves as a Controlled Node, but can switch to Active state in case of Active Managing Node failure.

Pre. 6.2 Abbreviations

AMN	Active Managing Node
AMNI	Active Managing Node Indication
cDCF	concise Device Configuration File
CFM	Configuration Manager
CN	Controlled Node
DCF	Device Configuration File
EPL	Ethernet POWERLINK
FLS	First Link Status
LS	Link Selector
MN	Managing Node
RMN	Redundant Managing Node
SLS	Second Link Status
SMN	Standby Managing Node

Pre. 7 References

[1] EPSG Draft Standard 301 (EPSG DS 301), Ethernet POWERLINK, Communication Profile Specification

1 Introduction

With increased deployment of Industrial Ethernet, it is widely used in motion control, machinery and plant control systems. Industrial Ethernet may find its use in a large variety of applications, including mission critical applications that are usually not tolerant to system failures and the resulting loss of service. In such applications, a high level of availability is essential. Besides, most of the industries now give heed to the cost of loss of productivity induced by lack of availability of the system.

With POWERLINK High Availability, the availability of the system is ensured in the event of a component failure. Both the nodes and medium redundancy prevent having a single point of failure in the system[1].

- The Managing Node redundancy ensures the POWERLINK cycle production continuance, keeping synchronicity and very low jitter in case of Managing Node failure.
- The use of two media carrying the same information at the same time ensures to be robust to any network component (cable, media convertor, hub…) failure.

With POWERLINK High Availability, the switch-over time (recovery time) of the system is in the range of the POWERLINK cycle time. That ensures a very fast restoring of normal operation without any downtime for the system.

The POWERLINK High Availability specification is an add-on of the Ethernet POWERLINK Communication Profile Specification. It has been written in a way to ensure the full compatibility with standard Ethernet POWERLINK devices.

[1] *The occurrence of one failure (e.g. one cable broken in a chain) is compensated by the system and does not lead to a system failure. If a second failure occurs, there is no guarantee that the system works correctly any more. However the system will be robust to one failure of media added to one Managing Node failure.*

2 Medium redundancy

2.1 Topology

The medium redundancy is achieved thanks to two different physical networks. Each node shall be linked to both physical networks via a Link Selector (this functional block is described in 2.2.1).

All combinations of line and star (or tree) topology are allowed. The line topology will require external hubs or internal hubs with 4 ports.

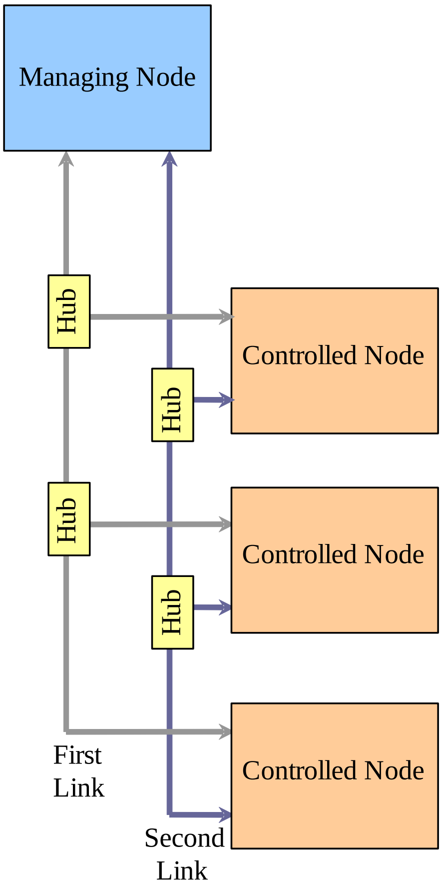


Fig. 1. Redundant medium network topology

As far as possible, the topology of both physical networks should be identical (same number of hubs, same cable length…). It will ensure that a frame will reach a node on both links at the same time. Anyway, the difference of path delay between both links shall not exceed 5.2 µs (transmission time for the smallest Ethernet frame at 100Mbit/s). Thus the first bits of a frame will be received on one link before the last bits of the frame will be transmitted on the second link. It will ensure that each node will be able to detect that a frame is present on both links or not.

2.2 Link Selector

In a redundant POWERLINK network, all nodes shall be connected to two different physical networks. Both physical networks shall convey the same redundant information.

Each node has to transmit on both links and to select one link for reception. This function is done by the Link Selector functional block.

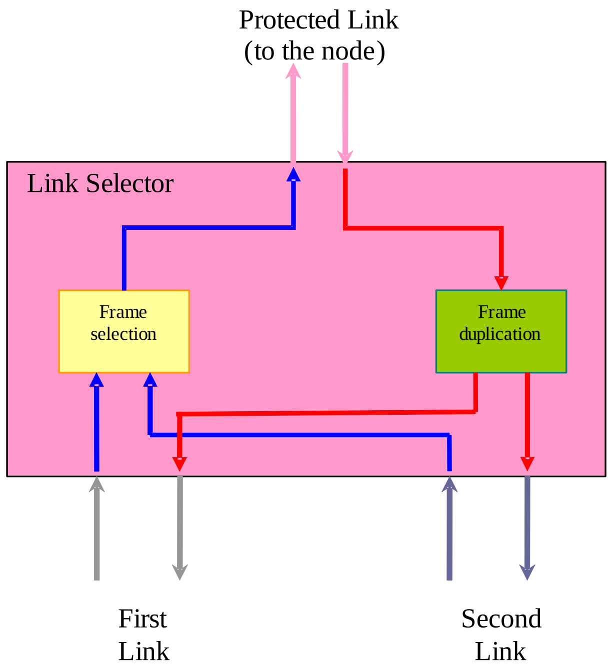


Fig. 2. Link Selector functional block

The Link Selector could be implemented within the POWERLINK node itself (Internal Link Selector), or within an external device connected to each POWERLINK node (External Link Selector).

2.2.1 Functional description

For each frame received from the node (on the Protected Link), the Link Selector shall simultaneously transmit this frame on the First and on the Second Link.

For each frame received from the redundant network (on the First Link, or on the Second Link, or on both), the Link Selector shall do a frame selection and transmit this frame to the node on the Protected Link.

The selection mechanism could be as simple as selecting the first received frame. But more information could be taken into account for the selection (percentage of frames received with a bad CRC on each Link…). As the Link Selector should be designed in the way to minimize the path delay and jitter increase, it should avoid having a store and forward mechanism.

Note: When sending a frame in response to another one, special attention has to be paid to the maximum path delay (5.2 µs). Otherwise collisions may occure.

2.2.2 Medium status

The Link Selector shall provide information about medium status to the POWERLINK nodes, in order to inform the application of a medium failure. The medium status information will be introduced inside POWERLINK SoA frames, response frames (PollResponse, StatusResponse, IdentResponse) and request frame (PollRequest).

In order to allow the detection of a cable issue in both directions (TX and RX)[2] for each node, and to easily locate the medium failure, the Link Selector should set the medium status bits in the following way:

- If the Link Selector is in front of (or inside) an AMN (SoC, SoA and PollRequest received from the protected port) :
    - For each response frame that is received from the redundant links, the medium status bits shall be set according to the medium state at reception of this response frame.

[2] *The failure of a medium in only one direction is transient (time for hardware to detect the loss of link), usually a medium failure in one direction leads to a medium not available in both directions. This depends on PHY's implementation.*

- For each SoA frame that is received from the protected link, die cable redundancy (CR) flag shall be set.

- If the Link Selector is in front of (or inside) a SMN or a CN (SoC, SoA and PollRequest received from the redundant ports)
  - For each response frame (PollResponse, StatusResponse, IdentResponse) that is received from the protected link (and so shall be sent to both redundant links), the medium status bits shall be set according to the medium state at reception of the request frame (PollRequest, StatusRequest, IdentRequest) on the redundant links.
  - For each request frame (PollRequest) that is received from the redundant links, the medium status bits shall be set according to the medium state at reception of this request frame.
- A Link Selector shall never reset a status bit which has been set by another Link Selector.

The bit 1 of byte 9 shall be used in the following message to show that cable redundancy is present in the network:

- SoA

A Link Selector shall include information inside SoA if it is placed in front (or inside) an AMN.

Bit 1 = Cable Redundancy (CR) (0 = No cable redundancy, 1 = Cable redundancy)

Note: The byte 9 of this POWERLINK frame is the 23rd byte in the Ethernet frame (not including 8 bytes of preamble)

<table>
<tr><th></th><th colspan="8">Bit Offset</th></tr>
<tr><th>Octet Offset</th><th>7</th><th>6</th><th>5</th><th>4</th><th>3</th><th>2</th><th>1</th><th>0</th></tr>
<tr><td>0</td><td>Res</td><td colspan="7">Message Type</td></tr>
<tr><td>1</td><td colspan="8">Destination</td></tr>
<tr><td>2</td><td colspan="8">source</td></tr>
<tr><td>3</td><td colspan="8">NMTStatus</td></tr>
<tr><td>4</td><td>res</td><td>res</td><td>res</td><td>res</td><td>res</td><td>xx/res</td><td>xx/res</td><td>res</td></tr>
<tr><td>5</td><td>res</td><td>res</td><td colspan="3">res</td><td colspan="3">res</td></tr>
<tr><td>6</td><td colspan="8">RequestedServiceID</td></tr>
<tr><td>7</td><td colspan="8">RequestedServiceTarget</td></tr>
<tr><td>8</td><td colspan="8">EPLVersion</td></tr>
<tr><td>9</td><td>res</td><td>res</td><td>res</td><td>res</td><td>xx</td><td>xx</td><td>CR</td><td>xx</td></tr>
<tr><td>10-45</td><td colspan="8">reserved</td></tr>
</table>

Tab. 1 POWERLINK SoA frame structure

The bits 7 and 6 of byte 5 should be used in the following messages:

- PollRequest
- PollResponse
- StatusResponse (ASnd)
- IdentResponse (ASnd)

A Link Selector shall include medium status information inside PollResponse. It may include medium status information inside the PollRequest, StatusResponse and IdentResponse frames.

Bit 7 = First Link Status (FLS) (0 = Link OK, 1 = Link not OK).

Bit 6 = Second Link Status (SLS) (0 = Link OK, 1 = Link not OK)

Note: The byte 5 of these POWERLINK frames is the 19th byte in the Ethernet frame (not including 8 bytes of preamble)

	Bit Offset							
Octet Offset	7	6	5	4	3	2	1	0
0	Res	Message Type						
1	Destination							
2	source							
3	xxx							
4	xx	xx	xx	xx	xx	xx	xx	xx
5	FLS	SLS	PR			RS		
6-n	xxx							

Tab. 2 POWERLINK frame structure

Note: The following two examples are only transient cases, a medium failure in one direction usually leads to a medium failure in both directions after the hardware has established a loss of link condition.

- **Example 1:**

In the following example, the Link Selector in CN2 has only received the request frame on the Second Link. So the Link Selector inside the CN2 will indicate in the response messages (PollResponse, StatusResponse,) that First Link is in failure. The Link Selector inside the CN2 will also provide the medium failure information to CN2, setting the FLS bit of the PollRequest frame coming from the MN.

The Link Selector inside the MN will see both links ok, as a matter of fact it will receive the response of the CN1 and CN2 on both links. But as it will not reset the medium status bits, the application in the MN is able to detect that there is a medium issue between CN2 and MN.

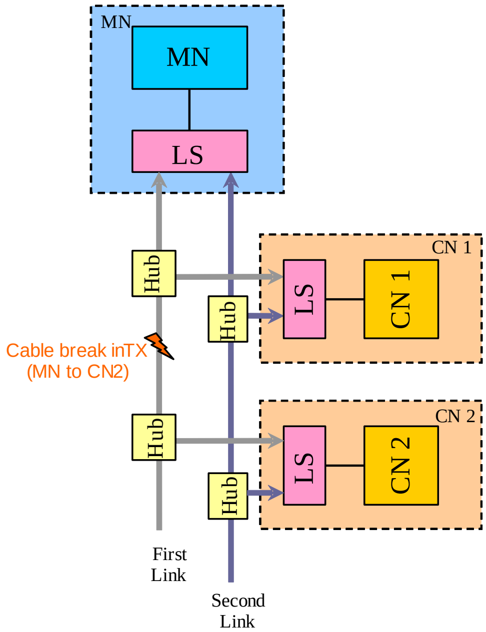


Fig. 3. Example of medium failure

- **Example 2:**

In the following example, the Link Selector inside the CN2 will receive valid frames on both links and will not set the medium status bits of the response messages (PollResponse, StatusResponse) and request messages (PollRequest).

The Link Selector inside the MN will not see valid frame from CN2 on the First Link, and so will set the FLS bit on the response message. Then the application in the MN is able to detect that there is a medium issue between CN2 and MN.

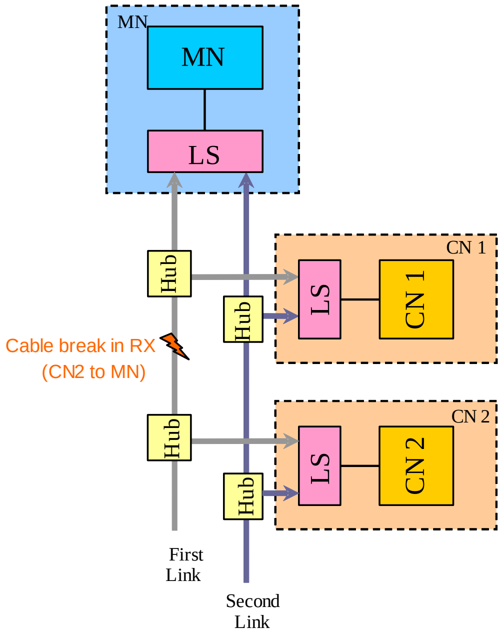


Fig. 4. Example of medium failure

3 Managing Node Redundancy

3.1 Principles

The redundancy of a Managing Node is achieved with several (at least two) Redundant Managing Nodes (RMNs) being deployed in the network. The POWERLINK network is monitored from them, and due to pre-defined specifications one of them can take over the role of a Managing Node (MN) in case of the AMN fails.

A RMN has two states: active and standby. For this reason, a RMN in an active state is called an "Active Managing Node" (AMN). On the other hand a RMN in a standby state, a "Standby Managing Node" (SMN). An AMN behaves like a MN, and a SMN normally like a CN. The only difference between a SMN and a CN is the continuous monitoring of the network traffic. In case of failure of the AMN, a SMN shall be capable of taking over the duty of the failed AMN and to manage the POWERLINK network.

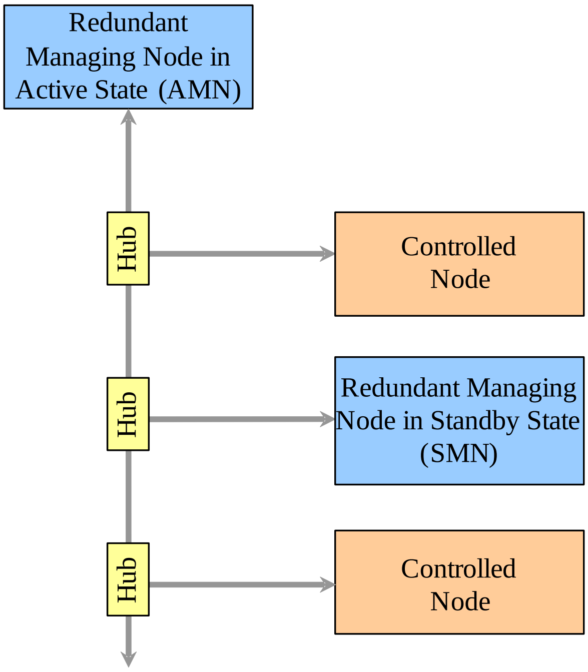


Fig. 5. MN redundancy

Although it is possible to deploy several RMNs at the same time, only one of them can be a MN in an active state, whereby all of the others are concurrently in a standby state.

During boot up, an election mechanism will ensure that the RMN with the highest priority will become AMN. The same applies to a failure of the AMN – a specification of the priority of each individual RMN determines the order in which the SMNs try to take over the duties of the MN. Refer to 3.5 for more details about the priorities and the election mechanism.

A very critical phase in the POWERLINK network is the takeover of the AMN function by the SMN. During this time it shall be guaranteed that all of the CNs remain fully functional. During and after the switching, they are not allowed to leave their OPERATIONAL state, and de-synchronize themselves. This can be achieved with the use of an identical network configuration for all RMNs.

Another requirement is that when a RMN takes over the task of an AMN, this shall take place without going through the boot-up procedure. Therefore, a RMN shall be capable of monitoring the POWERLINK network during the standby phase (SMN), to gather information about the connected CNs.

Also the synchronization of the "TIME producer" within the MN shall take place during the standby phase, as during the switching to an AMN, the SoC time stamp shall be synchronized.

Beside these special SMN functionalities, the communication between an AMN and a SMN is the same as between an AMN and a CN.

In order to remain compliant to the POWERLINK specifications, the AMN shall behave exactly as a MN, communicating asynchronously and isochronously with the network.

The Controlled Nodes have to be configured in a way that they tolerate the loss of at least one cycle. As a matter of fact, the detection of the AMN failure leads to have a missing SoC or SoA on the network.

Inside a high available POWERLINK network only RMNs shall be used. The use of a standard MN (that does not have high availability features inside) in combination with RMNs is not allowed inside the same POWERLINK network.

It is recommended that a RMN is an optional node.

3.2 Managing Node addresses

As all other POWERLINK nodes, each RMN is addressed by a unique POWERLINK node-ID. Two ranges of POWERLINK node-IDs can be used for a RMN:

- [1..239]
- [241..250]

The range [241...250] should be used by default if the configuration tool does not manage the RMN priorities. As a matter of fact the Node-Id is used by default as priority differentiator. Refer to 3.5 for details about RMN priorities.

In order that the redundancy design of the “flying Managing Node” works, the AMN shall use the “flying” Node-Id 240 in addition to its own Node-Id. Above all, the regulation in the POWERLINK specifications (refer to [1]) are met, that only one MN with Node-Id 240 is allowed to be present in the network at a time.

The active/standby mechanism of the RMNs remains hidden to standard nodes. Only one active MN is seen in the network at a given time – always with the Node-Id 240. Thus the networking devices do not see whether this is a standard MN or an AMN.

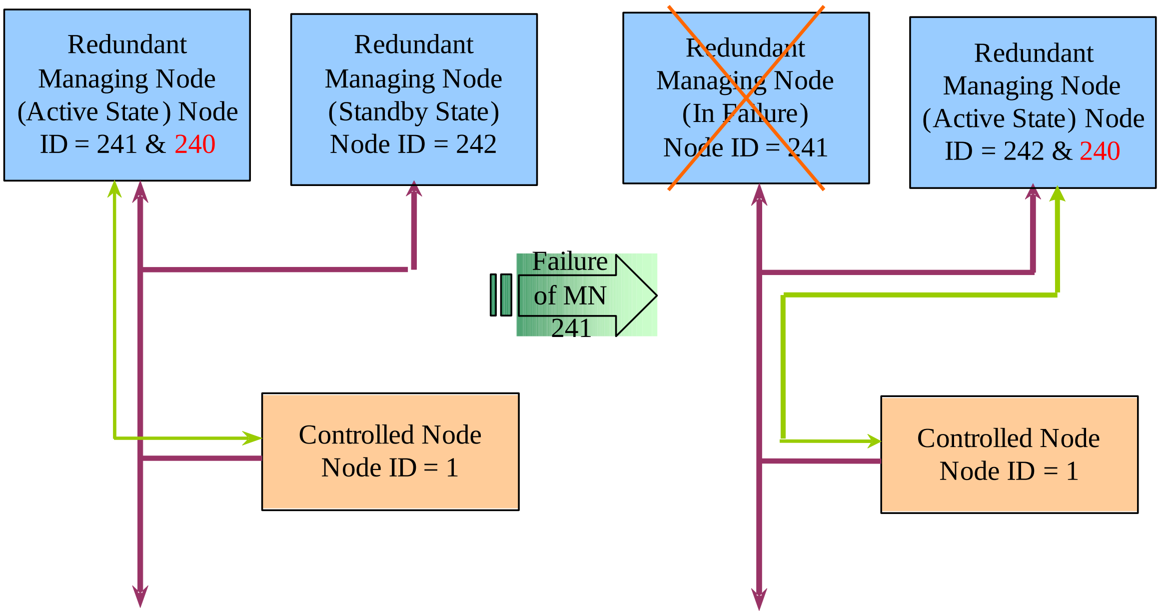


Fig. 6. Flying "240" Node-Id on failure of Active MN

An AMN will use the “flying” Node-Id 240 as POWERLINK source address for messages related to the management of the POWERLINK cycle (SoC, SoA, PollRequest…). But it will use its own Node-Id (241 for example) as POWERLINK source address for PollResponse.

As it will not produce the POWERLINK cycle, a SMN will only use its own Node-Id (241 for example) as POWERLINK source address for all sent messages.

After a switch-over the AMN should send an NMTFlushArpEntry NMT command to all the nodes in order to flush all ARP tables. As a matter of fact, the MAC address of the Node-Id 240 (IP address 192.168.100.240) will be changed after the switch-over. However it is not recommended to use the "flying" 240 address in IP communication, the own Node-Id of the RMN should be preferred.

An AMN should answer to requests addressed to both NodeId 240 and its own NodeId (241 for example).

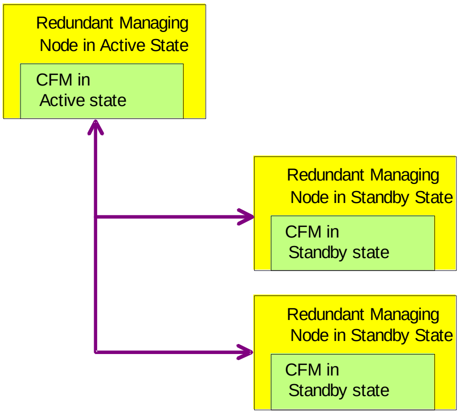
The following table shows the MAC and POWERLINK addresses of the messages flow before and after the switch-over described in Fig. 6.

MAC Source	MAC Destination	Message Type	POWERLINK src	POWERLINK dest
MAC-MN1	01:11:1E:00:00:01	SoC	240	255
MAC-MN1	MAC-CN1	PollRequest	240	1
MAC-CN1	01:11:1E:00:00:02	PollResponse	1	255
MAC-MN1	MAC-MN2	PollRequest	240	242
MAC-MN2	01:11:1E:00:00:02	PollResponse	242[3]	255
MAC-MN1	01:11:1E:00:00:02	PollResponse	241[3]	255
MAC-MN1	01:11:1E:00:00:03	SoA	240	255
Switch-over, MN2 becomes active				
MAC-MN2	01:11:1E:00:00:01	SoC	240[4]	255
MAC-MN2	MAC-CN1	PollRequest	240	1
MAC-CN1	01:11:1E:00:00:02	PollResponse	1	255
MAC-MN2	MAC-MN1	PollRequest	240	241
MAC-MN1	01:11:1E:00:00:02	PollResponse	241[3]	255
MAC-MN2	01:11:1E:00:00:02	PollResponse	242[3]	255
MAC-MN2	01:11:1E:00:00:03	SoA	240	255

Tab. 3 POWERLINK message flow showing MAC and POWERLINK addresses

3.3 Configuration Manager

The Configuration Manager (CFM) functionality is an optional feature of the RMN that shall be indicated by the device description entry D_CFM_ConfigManager_BOOL. The CFM is responsible for the correct configuration of all devices belonging to a network. There is only one active CFM in the network at a time while there can be several other inactive CFMs present on the Standby Managing Nodes.



[3] *The switch-over does not modify the list of Poll Response from RMNs, but the order of sending will be changed because the AMN will send its Poll Response at the end without sending any Poll Request.*

[4] *After the switch-over the SoC is sent by the RMN2, but still with the "flying" POWERLINK node-ID 240.*

Fig. 7. Multiple Configuration Managers

It is possible to have only one RMN with CFM functionality but several RMNs without this function in the network. In this case, the switchover to a RMN without CFM is only possible after the network was successfully configured once. Configuration consistency is no more guaranteed if a RMN without CFM is running the network. Therefore it is recommended that all RMNs of a network have the CFM functionality.

The priority-based master election algorithm determines the AMN during boot up of the network. It shall be ensured, that the RMN with the CFM feature enabled (device description entry D_CFM_ConfigManager_BOOL) are preferably used.

3.3.1 Device Configuration Data

The CFM of the RMN uses the object dictionary entries specified in the Ethernet POWERLINK Communication Profile Specification. There is no need for further or different objects on the RMN. The device configuration data itself contain all data to allow a CFM the complete network configuration.

For the network consistency it is important, that all CFMs within a segment have the same network configuration data. In case of a switch over of RMNs, the new AMN will then be able to configure all nodes of the network. To keep the entire network configuration process as simple as possible for the application, the distribution of the device configuration data is performed automatically by the active CFM as described in section 3.3.2. This mechanism also ensures the configuration consistency among the CFMs.

The device configuration data are normally provided by a configuration tool and should contain all configuration data to set up a device. For the configuration of the RMNs with CFM functionality, the configuration tool also has to provide the configuration data needed to configure the networking nodes. This network configuration data are part of the RMN device configuration and are locally stored on the RMN either as DCF (CFM_StoreDcfList_ADOM) or cDCF file (CFM_ConciseDcfList_ADOM).

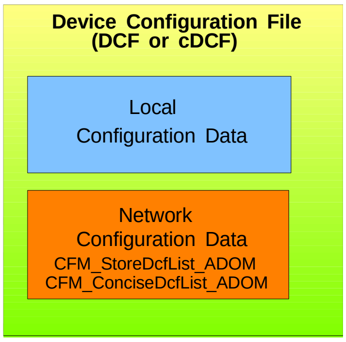


Fig. 8. Redundant Managing Node Device Configuration File

It should be possible for any active CFM in the network to completely configure all the other networking nodes, especially the standby CFMs. To do so, the network configuration data inside the device configuration file should contain all the local configuration data of the CFMs including himself.

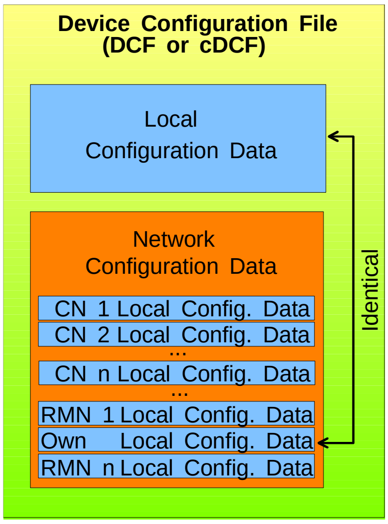


Fig. 9. Setup of the network configuration data

The local configuration data of the RMNs contain data that may be set up individually to the location of the RMN in the network. An example for such parameters is the individual PRes timeouts configured in the RMN object NMT_MNCNPResTimeout_AU32. These values depend on the number of hub levels and the line length between the RMN and the CNs.

While the local configuration data may be individual to all RMNs, the network configuration data are identical to all.

3.3.2 Distribution of Configuration Data

To ease up the network configuration for the user, a mechanism shall be provided by the active CFM that manages the automatic update of all standby CFMs. Based on this mechanism, the user only has to update the configuration of the first AMN. During boot up, the active CFM distributes all relevant data to the standby CFMs of the network.

The distribution process of the configuration data is split up into two parts:

- Download of the local configuration data stored in the DCF or cDCF file for a certain node
- Download of network configuration data from the active CFM to the standby CFMs

The download of the local configuration data stored in CFM_StoreDcfList_ADOM or CFM_ConciseDcfList_ADOM is handled by the CFM processes defined in the Ethernet POWERLINK Communication Profile Specification. The network configuration data is not part of the local configuration data that is sent to the standby CFM during the standard update process. The network data were excluded from there to avoid the recursion of configuration data within the RMN device configuration files and to decrease the DCF and cDCF file sizes.

Distribution of the network information from the active CFM to the standby CFMs is done in a separate process. The active CFM can easily determine which RMN needs to be updated with the network configuration by evaluating NMT_FeatureFlags_U32.Bit8 of a node. During boot up this value is transferred within the IdentResponse of each node.

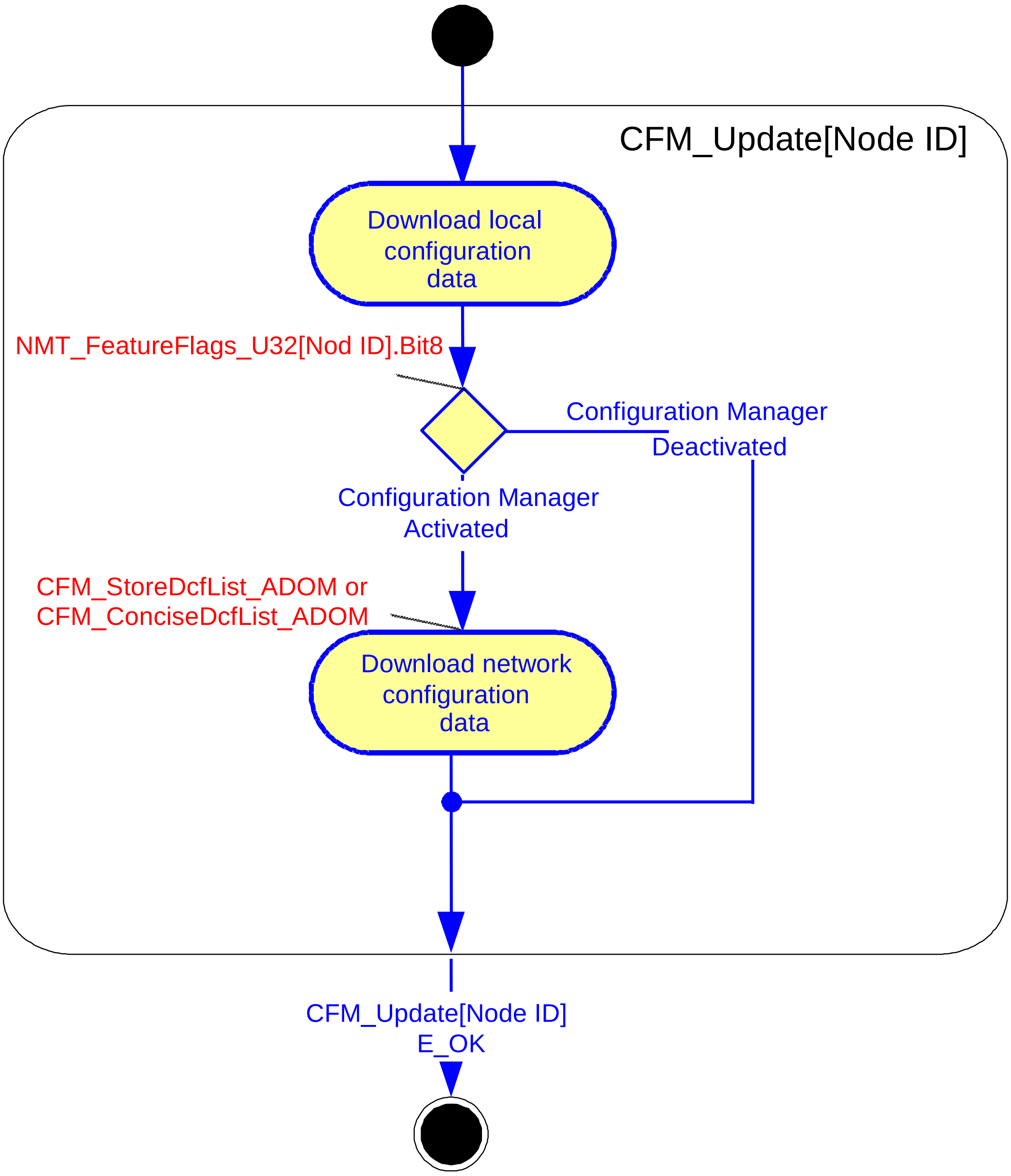


Fig. 10. Download of configuration data

3.3.2.1 Configuration Example

There are three RMNs in the network (Node-Id 241 to 243) and one “normal” CN (Node-Id 1). RMN 241 and 242 both have the CFM feature enabled. RMN 243 has no CFM functionality. The configuration tool provides a device configuration file (in concise DCF format) for the RMN 241 only. This device configuration file is locally downloaded to the object dictionary of the RMN 241.

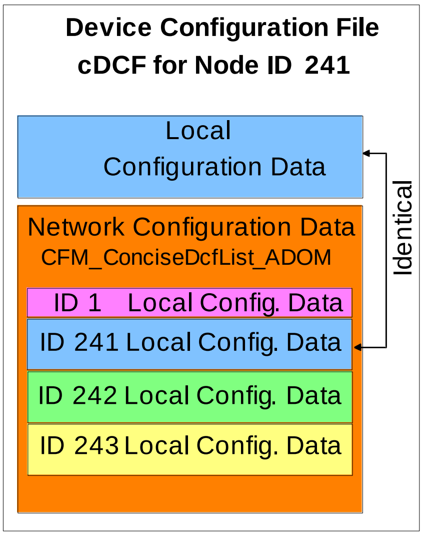


Fig. 11. Example Configuration for RMN 241

At network boot up the RMN 241 becomes the AMN and starts to update the local configuration data of all nodes in the network (see Fig. 12).

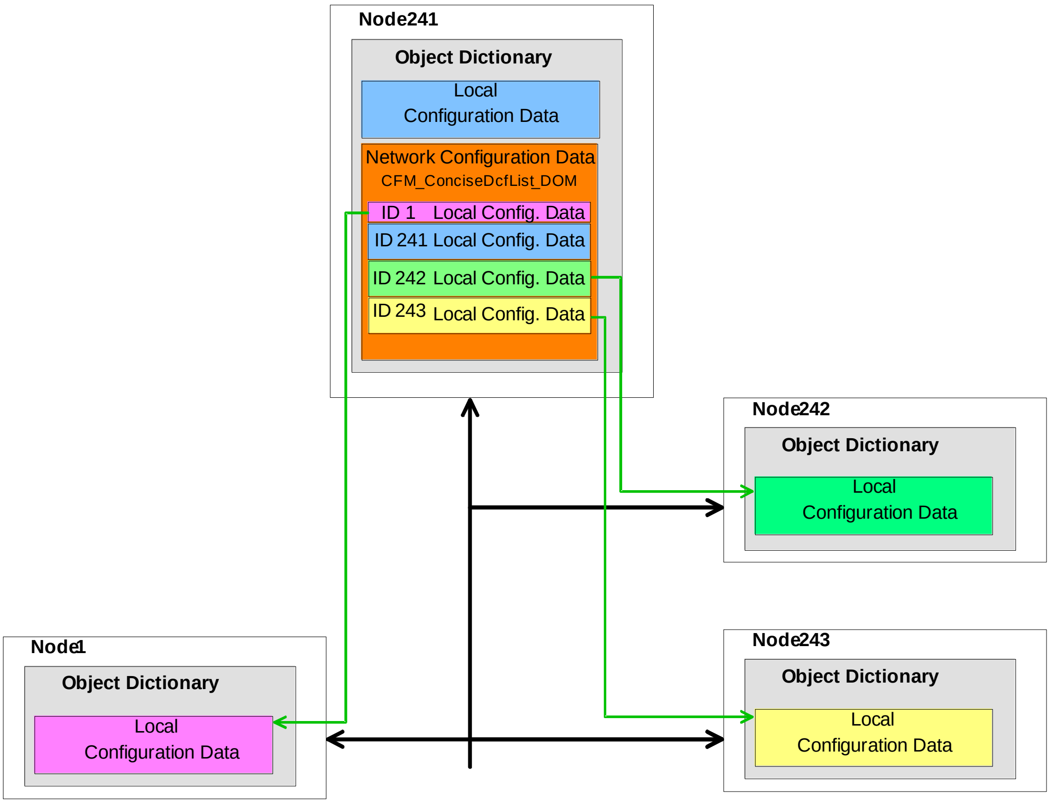


Fig. 12. Download of local configuration Data

After the Download of the local configuration data via the standard CFM functionality, the distribution process for the network configuration data takes place. The RMN 241 downloads the content of object CFM_ConciseDcfList_ADOM to the RMN 242 object CFM_ConciseDcfList_ADOM (see Fig. 13). This download is required, as the node 242 indicated the support of the CFM feature via NMT_FeatureFlags_U32.Bit8.

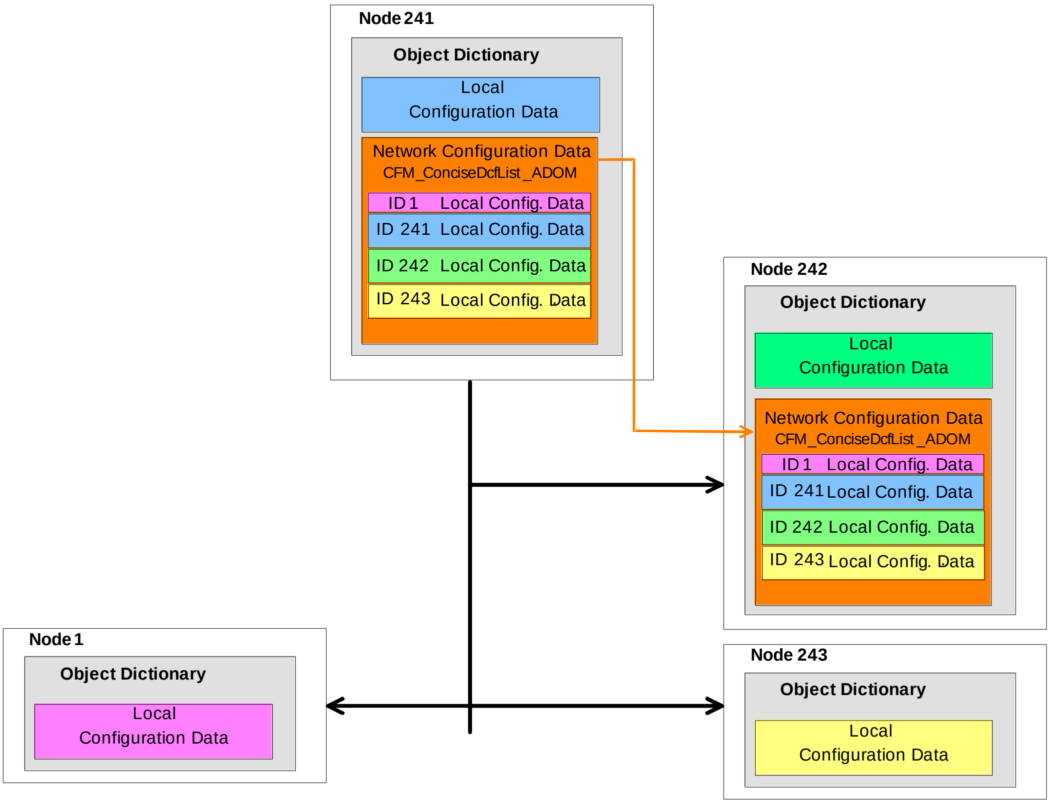


Fig. 13. Update of the network configuration data on RMN 242

Now the RMN 242 has exactly the same network configuration data as the currently active CFM. Upon switch over to RMN 242, the network configuration can be completely restored on every node, even on the RMN 241 if necessary.

RMN 243 is obviously not capable to do the network configuration as it did not receive the network configuration data from the RMN 241 during boot up. All this node can do when becoming the AMN is to keep the communication with the currently configured nodes alive.

3.4 Managing Node NMT

3.4.1 Common Initialisation NMT State Machine

The initialisation of the NMT state machine is common to MN, CN and RMN.

The NMT_StartUp_U32 object (index 1F80h), used to configure the boot up behaviour, will indicate if the node can start as a RMN (bit 14). If the node can start as a RMN, it will enter in NMT_RMS state to start as an Active MN or as a Standby MN.

- **NMT_StartUp_U32 Value Interpretation**

<table>
<tr><th>Octet</th><th>Bit</th><th>Value</th><th>Description</th></tr>
<tr><td rowspan="2">1</td><td rowspan="2">14</td><td>0</td><td>The Node-Id shall be used for the boot-up procedure to determine if the node shall start as MN or CN.
The Node-Id is used while leaving NMT_GS_INITIALISATION to decide if the node should enter in NMT_CS or NMT_MS state machine.</td></tr>
<tr><td>1</td><td>The Node-Id shall not be taken into account for boot-up procedure. The node shall start as RMN whatever the value of its Node-Id.
The state NMT_RMS will be automatically entered while leaving the state NMT_GS_INITIALISATION.</td></tr>
</table>

A RMN should reset the bit 14 of NMT_StartUp_U32 upon reception of NMT_RestoreDefParam_REC. This bit should be set only after a successful configuration of the RMN. That will prevent a misconfigured (or not fully configured) RMN from becoming AMN.

If the bit is not set the RMN will not enter the NMT RMN State Machine but the NMT CN State Machine (see Fig. 14).

A new NMT_RMS state machine is introduced. For details see 3.4.2.

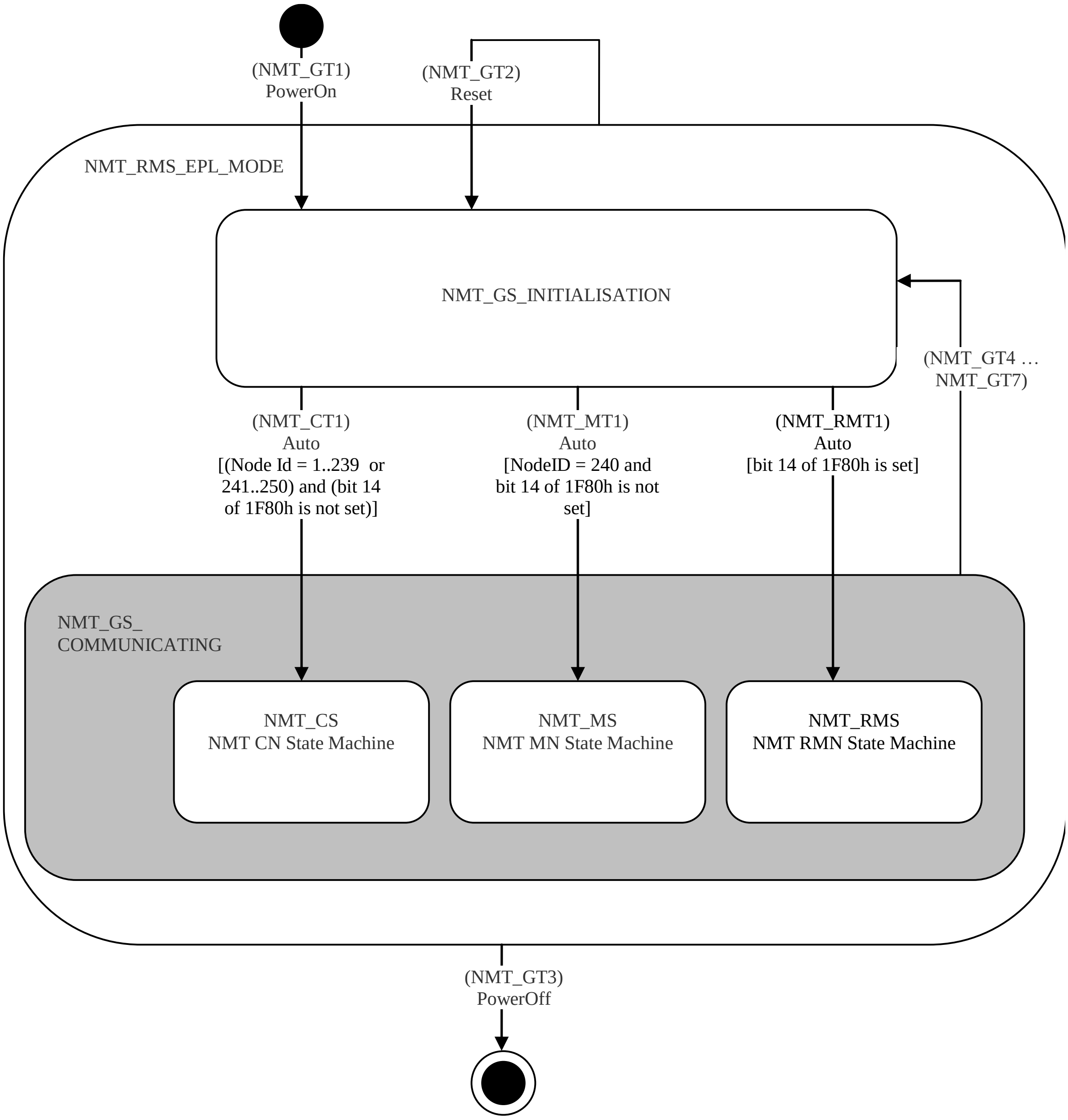


Fig. 14. Common Initialisation of NMT State Machine

Note: A node with Node-Id from 241 to 250 shall be capable to be RMN.

3.4.2 RMN NMT State Machine

The RMN NMT state machine should be regarded to be hosted by common initialisation NMT state machine. In the state NMT_RMS_NOT_ACTIVE, the RMN will monitor the bus activity. If no activity is detected, the RMN will enter in the state NMT_RMS_ACTIVE_EPL_MODE. If SoC or SoA are detected on the bus, the RMN will enter in NMT_RMS_STANDBY_EPL_MODE.

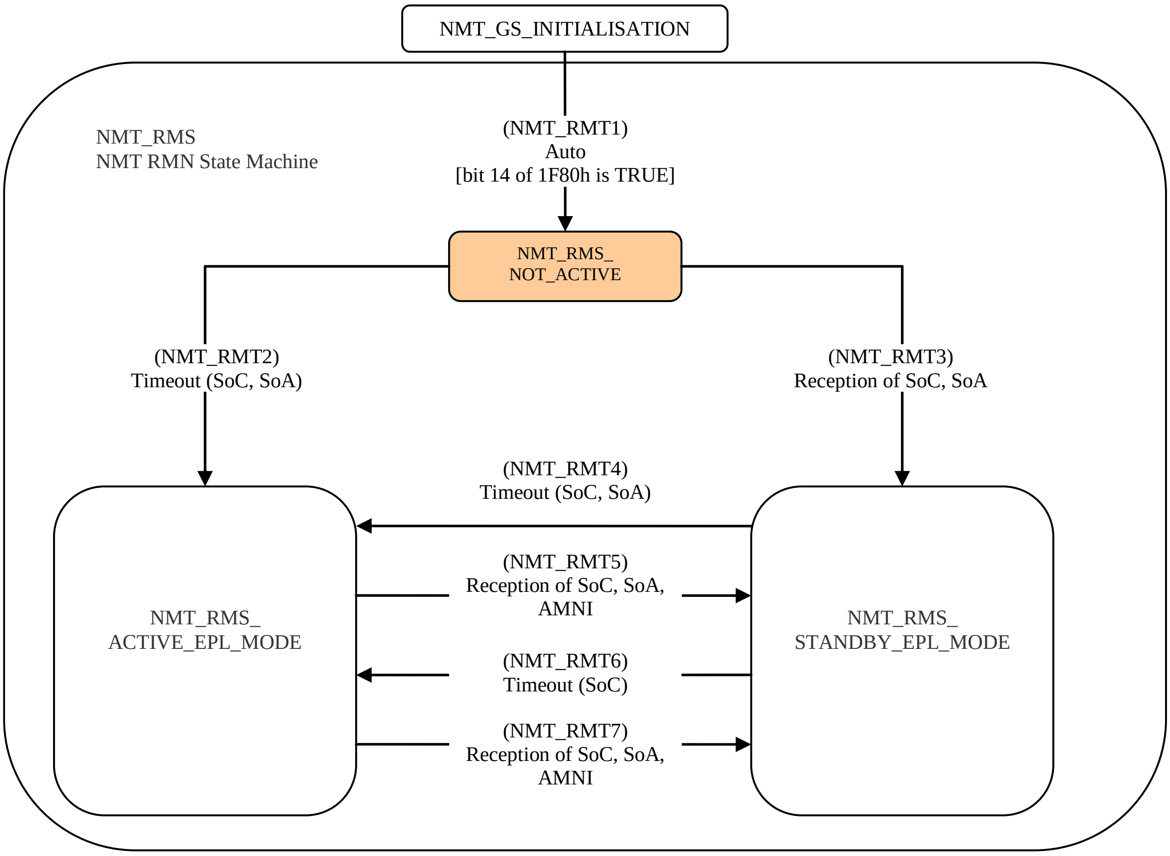


Fig. 15. NMT State Diagram of a RMN

3.4.3 NMT RMS ACTIVE State

The RMN NMT state machine should be regarded to be hosted by common initialisation NMT state machine.

The NMT_RMS_ACTIVE_EPL_MODE has the same functionality than the NMT_MS_EPL_MODE specified in Ethernet POWERLINK Communicatin Profile Specification (check identity, state, configuration and communication of configured CN). Addtionionally it shall manage the transitions between the active and standby states.

There are two ways to switch from the active to the standby state:

- Upon detection of another RMN communicating on the bus.
- On reception of the new NMTGoToStandbyState command, in order to force the switch-over.

A RMN in NMT_RMS_ACTIVE_EPL_MODE state is called an AMN, it is in charge of managing the POWERLINK network and shall produce the POWERLINK cycle.

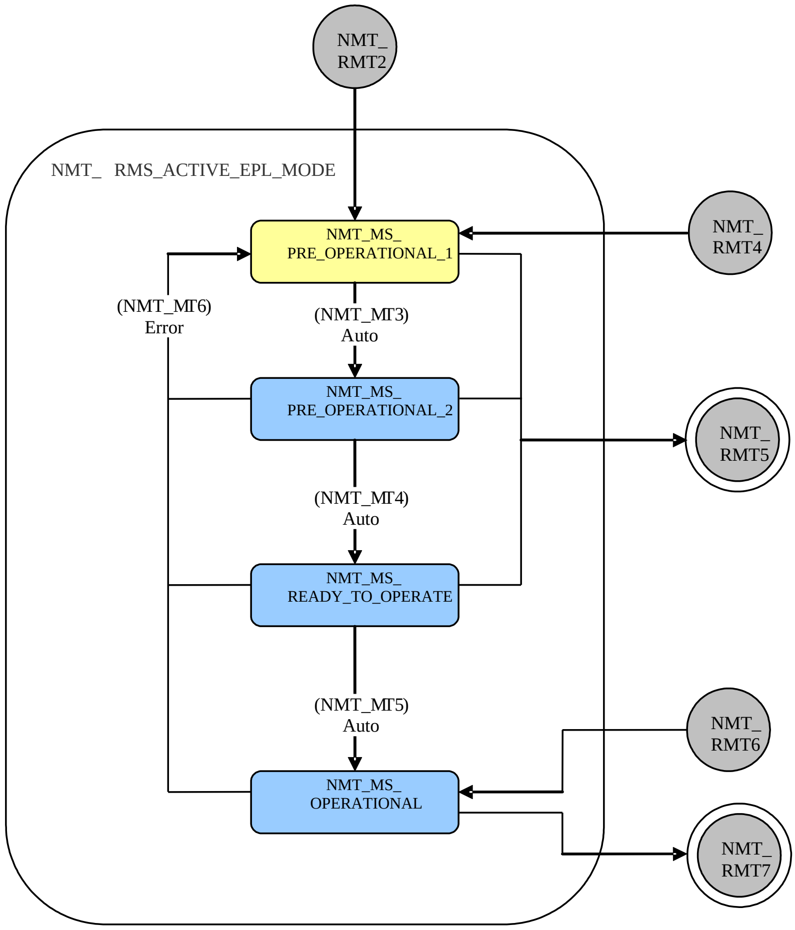


Fig. 16. Detail state NMT_RMS_ACTIVE_EPL_MODE

Recommendation for the transition NMT_MT6: The error threshold for collisions may depend on the priority of the RMN in order to ensure that the highest priority RMN remains in NMT_MS_OPERATIONAL state while a lower priority RMN goes back to NMT_MS_PRE_OPERATIONAL_1 state.

3.4.4 NMT_RMS_STANDBY State

The RMN NMT state machine should be regarded to be hosted by common initialisation NMT state machine.

In NMT_RMS_STANDBY_EPL_MODE, the RMN behaves as a CN up to NMT_CS_OPERATIONAL state. After that it has to prepare itself to be ready to switch-over to NMT_RMS_ACTIVE_EPL_MODE in case of current AMN failure. The SMN monitors the network to detect the loss of the AMN (no more SoC or SoA received).

In NMT_CS_OPERATIONAL state, the SMN will get information from the other nodes by listening to the PollResponse/StatusResponse/IdentResponse. As a matter of fact, the SMN needs to know the list of CNs that shall be polled after switchover.

The SMN shall get multiplexing information from SoC message, as the multiplexing shall be kept after switch-over.

In state NMT_CS_PRE_OPERATIONAL_2 the SoC will be monitored with NMT_BootTime_REC.MnWaitNoAct_U32 timer. Upon expiry of this timer, the RMN will enter NMT_CS_PRE_OPERATIONAL_1 state (error condition, NMT_CT11).

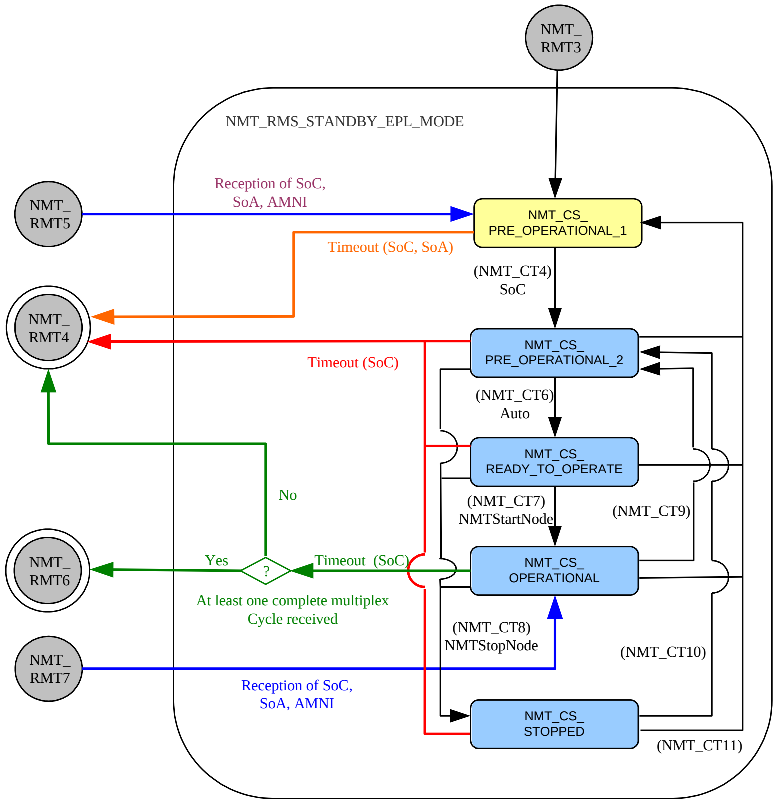


Fig. 17. Detail state NMT_RMS_STANDBY_EPL_MODE

3.4.5 Transitions

NMT_RMT1	Auto [configuration setup completed, Configuration flag is TRUE / start observing network traffic to decide whether to boot as AMN or SMN
	If NMT_GS_INITIALISATION sub-state NMT_GS_RESET_CONFIGURATION is completed and configuration flag is TRUE, state NMT_RMS_NOT_ACTIVE shall be entered autonomously, e.g. the NMT RMN state machine shall be entered.
NMT_RMT2	Timeout SoC, SoA
	No SoC or SoA message is received within the time defined by NMT_BootTime_REC.MnWaitNoAct_U32 (see 3.5.1). No AMN is present in the network. Boot as an AMN i.e. NMT_RMS_NOT_ACTIVE to NMT_RMS_ACTIVE_EPL_MODE
NMT_RMT3	Reception of SoC, SoA
	Reception of SoC or SoA within the time defined by NMT_BootTime_REC.MnWaitNoAct_U32 (see 3.5.1). Start as a SMN i.e. NMT_RMS_NOT_ACTIVE to NMT_STANDBY_EPL_MODE.
NMT_RMT4	Timeout (SoC, SoA(1))
	No SoC or SoA message is received within the time defined by $T_{reduced\_switch\_over\_MN}$ resp. $T_{switch\_over\_MN}$.(see 3.5.2) No AMN is present in the network. The RMN NMT state machine is not in NMT_CS_OPERATIONAL state or the multiplex cycle has not been fully received yet, so go to NMT_MS_PRE_OPERATIONAL_1. (1) SoA are only monitored in NMT_CS_PRE_OPERATIONAL_1
NMT_RMT5	Reception of SoC, SoA or AMNI.
	Reception of SoC, SoA or AMNI within the time defined by $T_{reduced\_switch\_over\_MN}$ resp. $T_{switch\_over\_MN}$ (see 3.5.2), go to standby mode and stop sending messages immediately. The MN state machine is not in NMT_MS_OPERATIONAL so start from NMT_CS_PRE_OPERATIONAL_1. Application can also trigger this transition on the local node.
NMT_RMT6	Timeout (SoC)
	No SoC message is received within the time defined by $T_{switch\_over\_MN}$. No AMN is present in the network. The RMS_STANDBY state machine is in NMT_CS_OPERATIONAL state, so go to NMT_MS_OPERATIONAL
NMT_RMT7	Reception of SoC, SoA or AMNI
	Reception of SoC, SoA or AMNI within the time defined by $T_{switch\_over\_MN}$, go to standby mode and stop sending messages immediately. The RMS_ACTIVE state machine is in NMT_MS_OPERATIONAL so go to NMT_CS_OPERATIONAL. Application can also trigger this transition on the local node.

Tab. 4 Standby State Transitions

3.5 Election mechanism

Only one RMN is allowed to become an AMN, assuming the presence of more than one RMN, which requires a suitable election mechanism.

The election mechanism is based on priorities assigned to each RMN. Each RMN shall have a unique priority, thus the election mechanism will ensure that the RMN having the highest priority will become AMN in case of failure of the current AMN.

There are two options to ensure that each RMN has a different priority:

- The configuration tool provides the priority information to each RMN via the Object NMT_BootTime_REC.MNSwitchOverPriority_U32 (index 1F89h, subindex 0Ah)
- A default priority, based on the unique Node-Id, is given to each RMN. In that case each RMN shall have a unique Node-Id in the range [241...250].

The option 1 should be the preferred option. The option 2, also called the default option, should be used only in case the configuration tool is not able to define priorities for RMNs.

3.5.1 Boot-up time

During the MN boot process the network is monitored by the MN for a period of time, given by the object NMT_BootTime_REC.MnWaitNoAct_U32 (index 1F89h, sub index 01h) to determine whether there is another MN active on the bus. A suitable configuration tool will initialise this object in each MN across the network to achieve a de facto priority for a managing node to boot the network.

3.5.2 Switch-over time

In the states where the AMN produces a reduced cycle each SMN will start the timer ($T_{reduced\_switch\_over\_MN}$) on SoA reception. If this timer expires, the SMN with the highest priority will broadcast an ActiveManagingNodeIndication (AMNI) message (see 3.5.3) and will switch to become an AMN. Then it will start producing POWERLINK reduced cycles beginning with the next scheduled cycle.

$$T_{reduced\_switch\_over\_MN} = \mathrm{MNWaitNotAct\_U32}$$

In states where the MN produces SoC's the SMN will implement a timer ($T_{switch\_over\_MN}$) to be re-triggered on reception of a SoC. Should the timer expire, the SMN with the highest priority shall broadcast an AMNI message (see 3.5.3) and shall switch to become an AMN. Then it will start producing SoC's beginning with the next scheduled cycle.

The POWERLINK cycle is divided in MNSwitchOverCycledivider_U32 slices, the difference of $T_{switch\_over\_MN}$ between two nodes will be at least one slice.

The timer value will be computed by each SMN on the following way:

$$T_{switch\_over\_MN} = T_{cycle\_MN} + \frac{T_{cycle\_MN} * (MNSwitchOverPriority\_U32 + MNSwitchOverDelay\_U32)}{MNSwitchOverCycleDivider\_U32}$$

Where: T_{cycle_MN} is the POWERLINK cycle length (Object NMT_CycleLen_U32)

MNSwitchOverPriority_U32 is the priority of the node at switch-over (the highest priority node should take over the bus when the AMN fails).

MNSwitchOverDelay_U32 is an optional delay added to $T_{switch\_over\_MN}$ to give a lower priority to a node which is not yet ready to switch-over.

MNSwitchOverCycleDivider_U32 indicate in how many slices the cycle will be divided, the difference between $T_{switch\_over\_MN}$ for every node will be at least one slice of the cycle time.

The configuration tool shall ensure that all $T_{switch\_over\_MN}$ values for all Nodes are unique.

In addition to the sub-indices of the Object NMT_BootTime_REC defined in the POWERLINK specification the following sub indices will be implemented in a RMN.

3.5.2.1 Additional sub-indices in NMT_BootTime_REC (1F89h)

All these sub-indices shall only be implemented if the MN supports managing node redundancy.

- **Sub-Index 0A: MNSwitchOverPriority_U32**

Sub-Index	0A		
Name	MNSwitchOverPriority_U32		
Data Type	UNSIGNED32	Category	Cond
Value Range	UNSIGNED32	Access	rw, valid on reset
Default Value	NodeID_U8 – 240[5]	PDO Mapping	No

This sub-index describes the priority that the RMN will have during switch-over (in case of AMN failure). Value 1 is the highest priority value for MNSwitchOverPriority_U32. Value of MNSwitchOverPriority_U32 shall be strictly greater than 0, otherwise no priority should be assigned.

- **Sub-Index 0B: MNSwitchOverDelay_U32**

Sub-Index	0B		
Name	MNSwitchOverDelay_U32		
Data Type	UNSIGNED32	Category	Cond
Value Range	UNSIGNED32	Access	rw, valid on reset
Default Value	10	PDO Mapping	No

This sub-index lowers the priority of a RMN in the case that the node is not in the state NMT_CS_OPERATIONAL.

- **Sub-Index 0C: MNSwitchOverCycleDivider _U32**

Sub-Index	0C		
Name	MNSwitchOverCycleDivider _U32		
Data Type	UNSIGNED32	Category	Cond
Value Range	UNSIGNED32	Access	rw, valid on reset
Default Value	10	PDO Mapping	No

This POWERLINK cycle will be divided in MNSwitchOverCycleDivider_U32 slices. This slice will be the minimum difference between two $T_{switch\_over\_MN}$.

By default the POWERLINK cycle is divided in 10 slices (one slice per RMN, which by default have Node-Id from 241 to 250).

3.5.3 ActiveManagingNodeIndication (AMNI) frame

ActiveManagingNodeIndication (AMNI) is a new POWERLINK frame. It is sent by a RMN to inform all other RMN that there it will be the new AMN on the bus at the next start of cycle. Upon reception of this frame, other SMN will have to restart their detection timer as if they received a SoC.

This message can be sent only if no more frames are detected on the POWERLINK network. It shall be noticed that AMNI is a frame that is not explicitely requested by the AMN as all the other frames but a frame that is sent out autonomously by a RMN.

[5] *If the configuration tool does not manage RMN priorities, the RMN shall have their Node-Id from 241 to 250. The Node-Id will be used as a priority differentiator.*

	Bit Offset							
Octet Offset[6]	7	6	5	4	3	2	1	0
0	Res	Message Type						
1	Destination							
2	source							
3	res							
4	res	res	res	res	res	res	res	res
5	res	res	res			res		
6	Reserved							
7	Reserved							
8	Reserved							
9	Reserved							

Tab. 5 AMNI frame structure

Field	Abbr	Description	Value
Message Type	mtyp	POWERLINK message type identification	AMNI (07h)
Destination	dest	POWERLINK node ID of the addressed node(s)	C_ADR_BROADCAST
Source	src	POWERLINK node ID of the transmitting node	RMN NodeID

Tab. 6 AMNI frame data fields

A MAC multicast address is assigned to AMNI, such as described in the following table.

	MAC-Multicast address	Value
Active Managing Node Indication (AMNI)	C_DLL_MULTICAST_AMNI	01.11.1E.00.00.05

Tab. 7 Assigned multicast address

3.5.4 Example with default values

In this example, we have 3 RMN (POWERLINK node-ID 241, 242, 243). Node-ID 241 was the AMN, it fails and we consider that Node-Id 242 is not ready to switch-over (not in state NMT_CS_OPERATIONAL)

$$T_{switch\_over\_MN241} = T_{cycle\_MN} + \frac{T_{cycle\_MN} * (1+0)}{10} = T_{cycle\_MN} + \frac{T_{cycle\_MN} * 1}{10}$$

$$T_{switch\_over\_MN242} = T_{cycle\_MN} + \frac{T_{cycle\_MN} * (2+10)}{10} = T_{cycle\_MN} + \frac{T_{cycle\_MN} * 12}{10}$$

$$T_{switch\_over\_MN243} = T_{cycle\_MN} + \frac{T_{cycle\_MN} * (3+0)}{10} = T_{cycle\_MN} + \frac{T_{cycle\_MN} * 3}{10}$$

[6] *Octet offset refers to the start of the POWERLINK frame. Offset to the start of the Ethernet frame is 14 octets.*

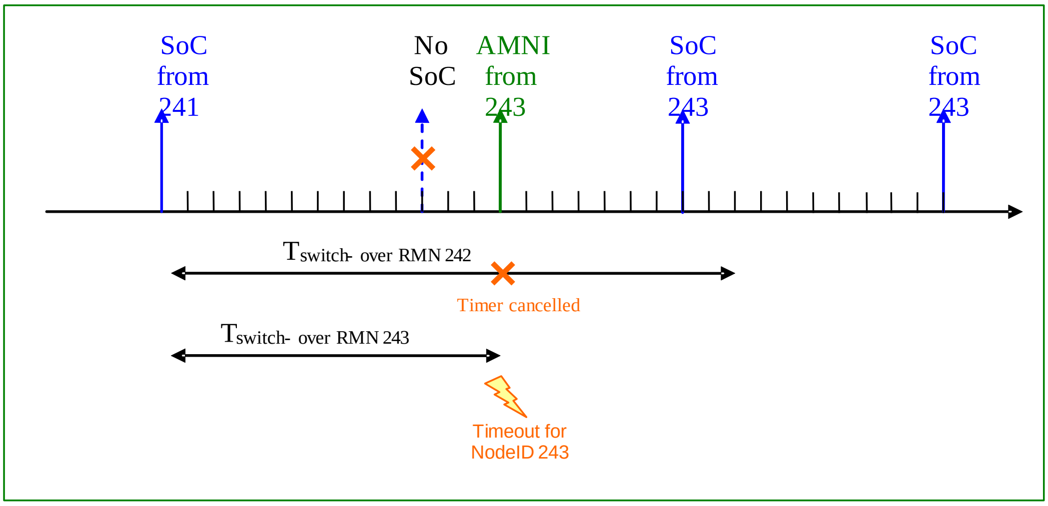


Fig. 18. Example of switch-over with default priorities

3.5.5 Example with configured values

In this example, we have 3 RMN (POWERLINK node-ID 241, 242, 2437). RMN241 was the AMN and it failed. Then the election mechanism is run.

Configuration values:

RMN241

- MNSwitchOverPriority_U32 = 1
- MNSwitchOverCycleDivider _U32 = 3

RMN242

- MNSwitchOverPriority_U32 = 2
- MNSwitchOverCycleDivider _U32 = 3

RMN243

- MNSwitchOverPriority_U32 = 3
- MNSwitchOverCycleDivider _U32 = 3

$$T_{switch\_over\_MN241} = T_{cycle\_MN} + \frac{T_{cycle\_MN} * (1+0)}{3} = T_{cycle\_MN} + \frac{T_{cycle\_MN} * 1}{3}$$

$$T_{switch\_over\_MN242} = T_{cycle\_MN} + \frac{T_{cycle\_MN} * (2+0)}{3} = T_{cycle\_MN} + \frac{T_{cycle\_MN} * 2}{3}$$

$$T_{switch\_over\_MN243} = T_{cycle\_MN} + \frac{T_{cycle\_MN} * (3+0)}{3} = T_{cycle\_MN} + \frac{T_{cycle\_MN} * 3}{3}$$

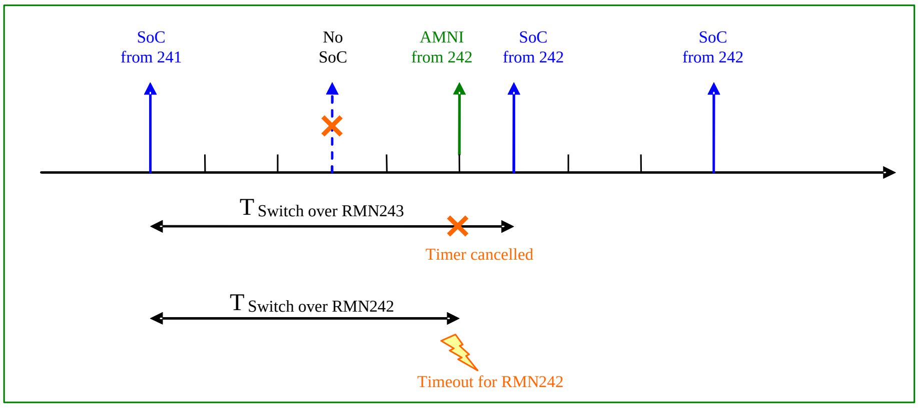


Fig. 19. Example of switch-over with configured priorities

3.5.6 Example with large configured values

In this example, we have 3 RMN (POWERLINK node-ID 241, 242, 243). RMN241 was the AMN and it failed. Then the election mechanism is run.

In this example there are large timeout values defined.

Configuration values:

RMN1

- MNSwitchOverPriority_U32 = 9
- MNSwitchOverCycleDivider _U32 = 4

RMN2

- MNSwitchOverPriority_U32 = 10
- MNSwitchOverCycleDivider _U32 = 4

RMN3

- MNSwitchOverPriority_U32 = 11
- MNSwitchOverCycleDivider _U32 = 4

$$T_{switch\_over\_MN1} = T_{cycle\_MN} + \frac{T_{cycle\_MN} * (9+0)}{4} = T_{cycle\_MN} + \frac{T_{cycle\_MN} * 9}{4}$$

$$T_{switch\_over\_MN2} = T_{cycle\_MN} + \frac{T_{cycle\_MN} * (10+0)}{4} = T_{cycle\_MN} + \frac{T_{cycle\_MN} * 10}{4}$$

$$T_{switch\_over\_MN3} = T_{cycle\_MN} + \frac{T_{cycle\_MN} * (11+0)}{4} = T_{cycle\_MN} + \frac{T_{cycle\_MN} * 11}{4}$$

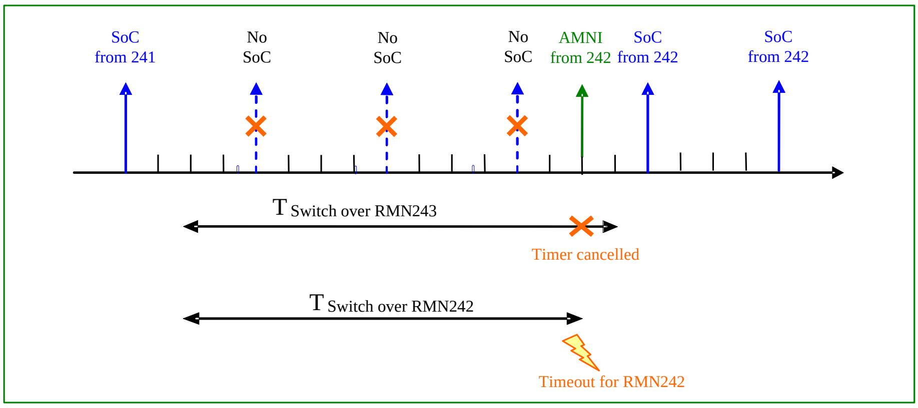


Fig. 20. Example of switch-over with configured large priorities

3.6 Switch-over required by the application

The application shall be able to require an AMN to switch-over. It shall be possible to ask the local node or a remote node to go to standby.

The application could force the local node (AMN) to go to standby. In that case the election mechanism defined in 3.5 will ensure that the most priority node will switch-over to active state.

The application could ask a remote node (AMN) to go to standby. In that case, the application on the SMN will use the NMT State Command Services to send the NMTGoToStandby NMT state command to the AMN. The remote node shall be able to reject the remote request NMTGoToStandby. In that case the AMN continues acting as an AMN.

NMTCommandID	M/O	Initial state	Destination state
NMTGoToStandby	O	NMT_RMS_ACTIVE_EPL_MODE Substate NMT_MS_PRE_OPERATIONAL_1 / NMT_MS_PRE_OPERATIONAL_2 / NMT_MS_READY_TO_OPERATE	NMT_RMS_STANDBY_EPL_MODE Substate NMT_CS_PRE_OPERATIONAL_1
		NMT_RMS_ACTIVE_EPL_MODE Substate NMT_MS_OPERATIONAL	NMT_RMS_STANDBY_EPL_MODE Substate NMT_CS_OPERATIONAL

Tab. 8 Additional plain NMT state command

Name	ID Value
NMTGoToStandby	$2C_h$

Tab. 9 Addtional NMT Command ID

The NMTGoToStandby service contains a Delay Flag (DF). If this flag is set the recipient shall include the optional delay MNSwitchOverDelay_U32 into its switch-over time computation. It will allow a SMN to put an AMN in standby state, even if its priority is the highest in the network at this time.

	Bit offset							
Octet offset	7	6	5	4	3	2	1	0
0	Reserved							DF

Tab. 10 NMTCommandData structure of NMTGoToStandby

Field	Abbr.	Description	Value
Delay Flag	DF	Indicates if the recipient shall include the optional delay MNSwitchOverDelay_U32 into its switch-over time computation	TRUE (1) / FALSE (0)

Tab. 11 NMTCommand data fields of NMTGoToStandby

3.7 POWERLINK Cycle Timing

In the following example, two RMNs and one Controlled Node are present on the POWERLINK network. On failure of RMN 241, the RMN 242 becomes AMN.

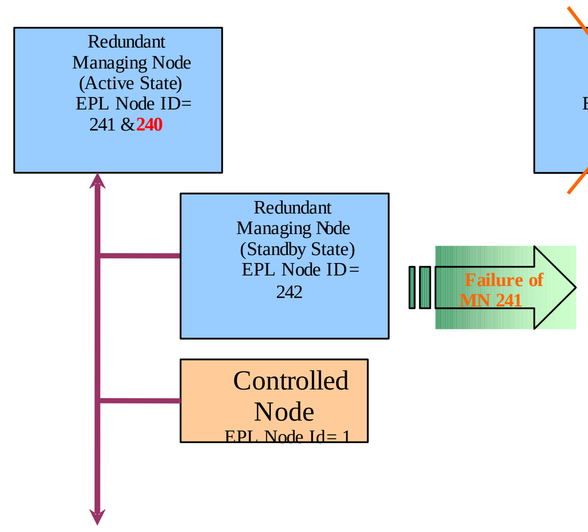


Fig. 21. POWERLINK Network timing constraints

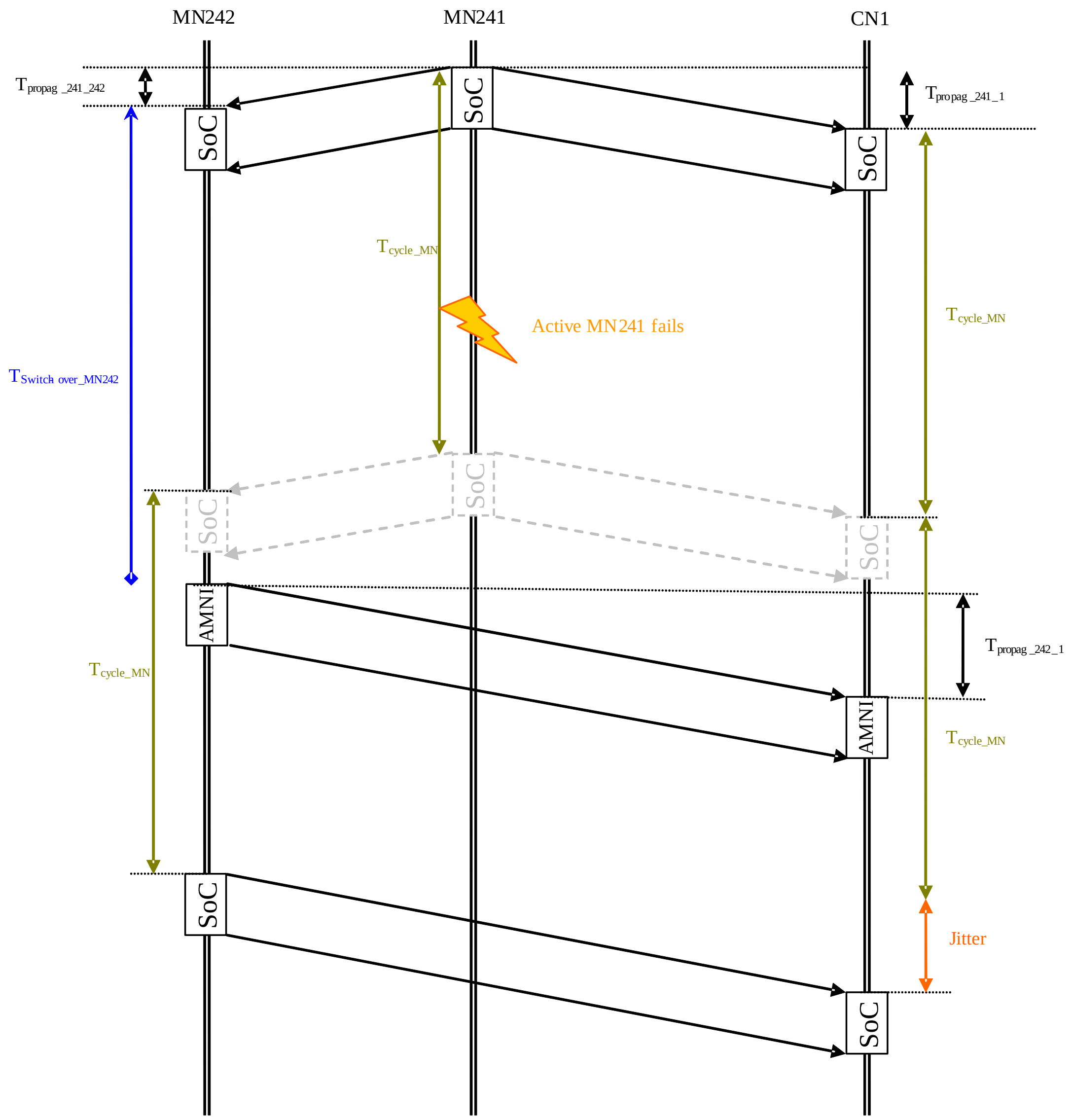


Fig. 22. POWERLINK switch-over timing in isochronous phase

Note: Jitter: The cycle periodicity will be kept after the switch-over. But the new AMN will potentially not be at the same location than the previous one. Then a jitter will be introduced in the SoC of the first cycle produced by the new AMN. The CN shall be robust to this jitter. The maximum value of this jitter can be considered as equal to the maximum propagation time between all nodes.

3.8 Flag in SoA frame

The presence of managing node redundancy shall be signalled by the AMN with a flag in the SoA frame.

Note: The byte 9 of this POWERLINK frame is the 23th byte in the Ethernet frame (not including 8 bytes of preamble)

	Bit Offset							
Octet Offset	7	6	5	4	3	2	1	0
0	Res	Message Type						
1	Destination							
2	source							
3	NMTStatus							
4	res	res	res	res	res	xx/res	xx/res	res
5	res	res	res			res		
6	RequestedServiceID							
7	RequestedServiceTarget							
8	EPLVersion							
9	res	res	res	res	xx	xx	xx	**MR**
10-45	reserved							

Tab. 12 POWERLINK SoA frame structure

Field	Abbr	Description	Value
Managing Node Redundancy	MR	Flag: Managing node redundancy is configured on the MN(s)	0…no MN redundancy 1…MN redundancy active

Tab. 13 Additional flags in SoA

4 Ring Redundancy

The ring redundancy is able to detect and cope with a single point of medium failure.

The redundancy is just achieved by a special MN interface using two ports. Any CN may be used without additional hardware.

4.1 Topology and Functional Description

The redundant ring topology requires a line topology. However, the end of the line returns to the second port of the MN.

Under normal conditions the MN will only transmit and receive data on the first port. On the other port the MN monitors the frame reception to verify that the ring is “closed”.

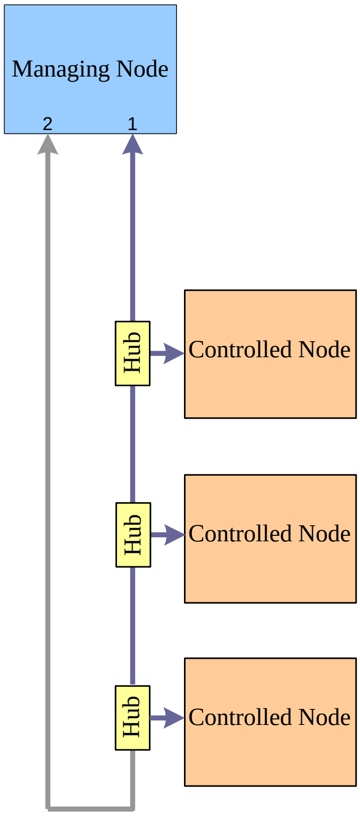


Fig. 23. Redundant ring topology

In case of medium failure the ring is “opened”. At this time the MN will not receive frames on the second port, that have been sent by itself. Then the MN will transmit and receive on both ports. PRes frames will have to be propagated to the other port to allow CN to CN communication, i.e. the two ports act as a standard hub.

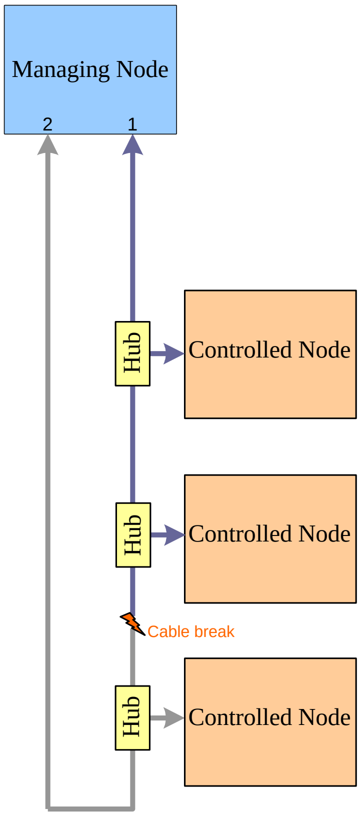


Fig. 24. “Open” Ring

If the ring is closed again, collisions will occur on the network. If such collisions are detected by the MN it shall stop transmitting frames on the second port immediately.

4.2 Ring Redundancy Status

The Managing Node shall provide information about ring redundancy status to the POWERLINK nodes, in order to inform the application of a failure. The ring redundancy status information will be introduced inside POWERLINK SoA frames.

The bits 2 and 3 of byte 9 shall be used in the following message to show that ring redundancy is present in the network:

- SoA

A Managing Node that supports ring redundancy shall include the following information inside the SoA frame.

Bit 2	= Ring Redundancy (RR)	(0 = no ring redundancy, 1 = ring redundancy)
Bit 3	= Ring Redundancy status (RRstat)	(0 = ring ok, 1 = ring broken - failure)

Note: The byte 9 of this POWERLINK frame is the 23th byte in the Ethernet frame (not including 8 bytes of preamble)

	Bit Offset							
Octet Offset	7	6	5	4	3	2	1	0
0	Res	Message Type						
1	Destination							
2	source							
3	NMTStatus							
4	res	res	res	res	res	xx/res	xx/res	res
5	res	res	res		res			
6	RequestedServiceID							
7	RequestedServiceTarget							
8	EPLVersion							
9	res	res	res	res	**RRstat**	**RR**	xx	xx
10-45	reserved							

Tab. 14 POWERLINK SoA frame structure

4.3 Additional Object Description

4.3.1 Object 1F82h: NMT_FeatureFlags_U32

The Feature Flags indicate communication profile specific properties of the device given by its design. The object shall be setup by the device firmware during system initialisation.

Octet	Bit	Name	TRUE	FALSE
2	17	Ring Redundancy	MN supports ring redundancy	MN does not support ring redundancy

Tab. 15 Ring Redundancy NMT_FeatureFlags_U32 additional bit interpretation

4.3.2 Object 1C40h: DLL_MNRingRedundancy_REC

This object enables the ring redundancy of the managing node. It shall only be implemented if the managing node supports the feature.

The object should be set by the system configuration.

Index	1C40h	Object Code	RECORD
Name	DLL_MNRingRedundancy_REC		
Data Type	DLL_MNRingRedundancy_TYPE	Category	Cond

- **Sub-Index 00h: NumberOfEntries**

Sub-Index	00h		
Name	NumberOfEntries		
Value Range	2	Access	const
Default Value	2	PDO Mapping	No

- **Sub-Index 01h: MNRingRedundancyEnable_U8**

Sub-Index	01h		
Name	MNRingRedundancyEnable_U8		
Data Type	UNSIGNED8	Category	M
Value Range	0 (FALSE), ≠0 (TRUE)	Access	rw
Default Value	0 (FALSE)	PDO Mapping	No

This sub-index enables the ring redundancy. If the value is FALSE the ports of the managing node work like a hub. If the value is TRUE the hub is disabled and the second port is able to detect a broken line.

- **Sub-Index 02h: MNRingRedundancyStatus_U8**

Sub-Index	01h		
Name	MNRingRedundancyStatus_U8		
Data Type	UNSIGNED8	Category	O
Value Range	0 (ok), ≠0 (error)	Access	ro
Default Value	0	PDO Mapping	No

This sub-index holds information on the medium failure.

If the value is OK the ring is “closed”. The Managing node is just monitoring the incoming frames on the second port.

If it is not OK the ring is “open”. The ports of the Managing Node work like a hub.

4.3.3 Object 043Bh: DLL_MNRingRedundancy_TYPE

Index	043Bh	Object Type	DEFSTRUCT
Name	DLL_MNRingRedundancy_TYPE		
Sub-Index	Component Name	Value	Data Type
00h	NumberOfEntries	02h	
01h	MNRingRedundancyEnable_U8	0002h	UNSIGNED8
02h	MNRingRedundancyStatus_U8	0002h	UNSIGNED8

App. 1 Device Description Entries (normative)

Additional device description entries:

Name	Description	Type	Category		Default	
			MN	CN	MN	CN
D_NMT_MNRedundancy_BOOL	Ability of a MN to perform managing node redundancy functions	BOOLEAN	M		N	-
D_DLL_MNRingRedundancy_BOOL	Ability of a MN to perform ring redundancy functions	BOOLEAN	M	-	N	-

end-of-file