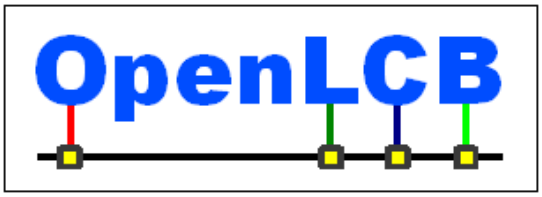
NMRA Technical Note	
Layout Command Control® (LCC) Memory Configuration	
Feb 6, 2016	**TN-9.7.4.2**

Adopted as a NMRA Technical Note

The OpenLCB Standard document appended to this cover sheet has been formally adopted as a NMRA Standard by the NMRA Board of Directors on the date shown in the *Adopted* column in the *Version History* table below.

Version History

Date	Adopted	Summary of Changes
Feb 17, 2015		Initial version submitted for public comment
Feb 6, 2016	**Feb 20, 2016**	Minor grammatical corrections and readability improvements as well as the following specific changes: • Added paragraph to section ◦ **2.4.19 Get Unique ID Command** • Added sections ◦ **2.4.21 Unfreeze Command** ◦ **2.4.22 Freeze Command** • Removed section ◦ **4.24 Enter Bootloader Command**



OpenLCB Technical Note	
Memory Configuration	
Feb 6, 2016	Adopted

1 Introduction

This Technical Note provides background for the association Memory Configuration Standard.

The protocol is called “Memory Configuration” because it makes the configuration information in the node look like it's stored in linear memory spaces.

- Don't assume that the information actually has to be stored the same way as it is accessed through this protocol, as linear memory. The node can remap the information that's being read or written into whatever internal organization it needs.
- Don't assume that no other configuration protocol exists. Some day, for example, there might be a “file access configuration protocol” where a node pulls predefined configuration information from some central store of “files”. Or something else. There's already the teach/learn method of configuring events.
- Don't assume that this is only used for persistent configuration information. The protocol is already being used for e.g. retrieving the CDI, and for providing a simple debug capability that allows programmers the ability to read (and even write) raw node RAM. It can be used for other things in the future using the memory space mechanism.

2 Annotations to the Standard

2.1 Introduction

Note that this section of the Standard is informative, not normative.

2.2 Intended Use

Note that this section of the Standard is informative, not normative.

2.3 Reference and Context

For more information on format and presentation, see:

- OpenLCB Common Information Technical Note

2.4 Message Formats

This section is about helping implementors see how to decode the message format. It's not normative.

Configuration messages use a specific datagram format consisting of the datagram type byte, followed by a single byte combining the operation “Command Type” field and flags. This is then followed by data in an operation-specific format. The table below summarizes some of the possible data formats supported by Memory Configuration messages.

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<table>
<tr><th>Byte 0</th><th>Byte 1</th><th>Byte 2</th><th>Byte 3</th><th>Byte 4</th><th>Byte 5</th><th>Byte 6</th><th>Remaining Bytes</th></tr>
<tr><td rowspan="5">Datagram Type (0x20)</td><td rowspan="5">Command Type</td><td colspan="4">Starting Address</td><td>Address Space (Optional)</td><td>Command Specific</td></tr>
<tr><td colspan="2">Available Commands</td><td>Write Lengths</td><td>Highest Address Space</td><td>Lowest Address Space</td><td>Name String (Optional)</td></tr>
<tr><td colspan="6">Node ID</td></tr>
<tr><td>Address Space</td><td colspan="4">Highest Address</td><td>Additional ...</td></tr>
<tr><td>Address Space</td><td colspan="5"></td></tr>
</table>

Byte 1 has a number of decodable fields:

Byte 1 (Command Type)	
Bits 7..6 – Command Type	0b00 – Write operations 0b01 – Read operations 0b10 – Control operations 0b11 – Not used / reserved
Bit 5 – Stream/Datagram	0b0 – Use Datagrams 0b1 – Use Streams
Bit 4 – Command/Reply	0b0 – Command 0b1 – Reply
Bit 3 – (Command) Under Mask **Bit 3 – (Reply) Fail/OK**	0b0 – Not under mask 0b1 – Under mask 0b0 – Okay 0b1 - Fail
Bit 2 – Reserved	0b0 – send as zero, check on receipt
Bits 1..0 – Address Space	0b00 – Address space in byte 6 0b01 – Address space 0xFD 0b10 – Address space 0xFE 0b11 – Address space 0xFF

2.4.1 Address Space Size

35 The four-byte address allows directly addressing 4GB of data. The use of address spaces (see 2.4.2.Address Space Selection) allows direct access to 1TB of data.

The large address range removes the need for address and paging registers and other non-idempotent accesses when accessing e.g. sound information in a large memory.

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2.4.2 Address Space Selection

Although a 32-bit address space is large enough to cover combined uses of memory, it can be more convenient to consider separate address spaces in the node. This can also be considered to be a top digit in a global address space, if desired, but note that the separate address spaces may cover the same memory objects, e.g. “all memory” and “configuration” spaces may reference the same physical (or virtual) location in memory.

2.4.3 Generic Error Handling

An unknown command in byte 1 error may result from requesting a command that is not defined by the standard, but it may also result from requesting a command the that standard defines, which the node being accessed does not support. The error code to send is not specified, however, the recommended error code to be sent in the OpenLCB Datagram Transport Datagram Rejected message the following:

- 0x1041 – Permanent error: Not implemented, subcommand is unknown.

In the appropriate situations a Datagram Rejected or a response datagram with Failed status should use the following specific error codes:

- 0x1081 – Permanent error: Invalid argument. Address space not known.
- 0x1082 – Permanent error: Invalid argument. Out of bounds, address space is valid, but the address within the space is not implemented.
- 0x1083 – Permanent error: Invalid argument. Write access to a read-only space.

In addition, all other error codes defined in the Message Network Standard or Datagram Standard may be used, for example:

- 0x1000 – Permanent error, not further specified.
- 0x1040 – Not implemented, not further specified.
- 0x1080 – Invalid arguments, not further specified.

It is possible that OpenLCB Datagram Transport is not supported by the node, and by extension OpenLCB Memory Configuration. If this is the case, the likely result is an OpenLCB Optional Interaction Rejected message as defined in the OpenLCB Message Network Standard with the error code 0x1043 (Not Implemented, unknown MTI or Transport protocol is not supported).

Additionally, the Datagram Rejected message may be received due to an OpenLCB Datagram Transport layer error. This does not mean the Memory Configuration generated the error, and could be due to a temporary inability to allocate a necessary buffer at the Datagram Transport layer, etc.

2.4.4 Read Command

This is a request to read an address space. If the address space does not exist, a Datagram Rejected message shall be sent with a permanent error. The likely error code would be:

0x1081 – Permanent error: Invalid argument. Address space not known.

The address space may be valid, however, the node may be busy or locked. In this case, the Datagram Rejected message may be used, likely with a temporary error code (see OpenLCB Message Network Standard). The requesting node may, or may not, try again later.

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If the memory configuration protocol is being used to control e.g. DCC CV reads and writes, those operations can take a very long time, 30 seconds or more. The Datagram OK message optionally specify a timeout interval in order to provide guidance as to how long the read may take before considering the read to be timed out. The timeout interval may in turn, but doesn't have to be, used to indicate in-progress status.

2.4.5 Read Reply

This message is sent in response to a Read Command which was previously responded to with a corresponding Datagram OK message having had the Reply Pending bit set. If the Read Command was previously responded to with a corresponding Datagram Rejected message, no Read Reply message is required or expected.

A Read Reply is not considered to be in error unless it responds with zero bytes of data. In this case, a failure should be indicated with an appropriate error code as defined by the OpenLCB Memory Configuration Standard and/or the OpenLCB Message Network Standard.

The figure shows a typical read operation. The Read Command is carried to the device being configured by a datagram, the read operation takes place, and the results are returned in another datagram.

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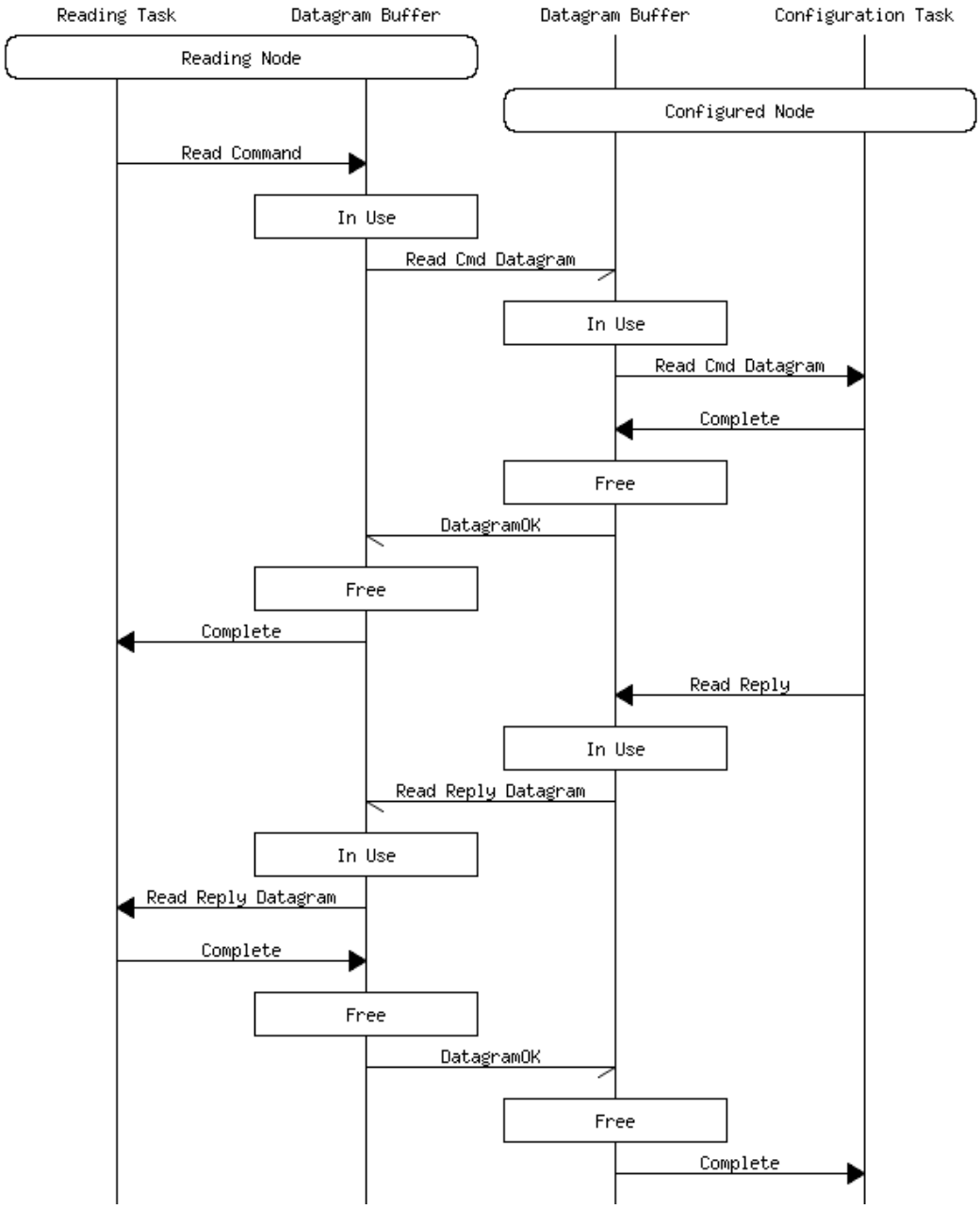

2.4.6 Read Stream Command

Stream support within the OpenLCB Memory Configuration Protocol is considered experimental. A version of this Technical Note and corresponding Standard containing updated information on the usage of streams will likely be adopted at a future time.

2.4.7 Read Stream Reply

Stream support within the OpenLCB Memory Configuration Protocol is considered experimental. A version of this Technical Note and corresponding Standard containing updated information on the usage of streams will likely be adopted at a future time.

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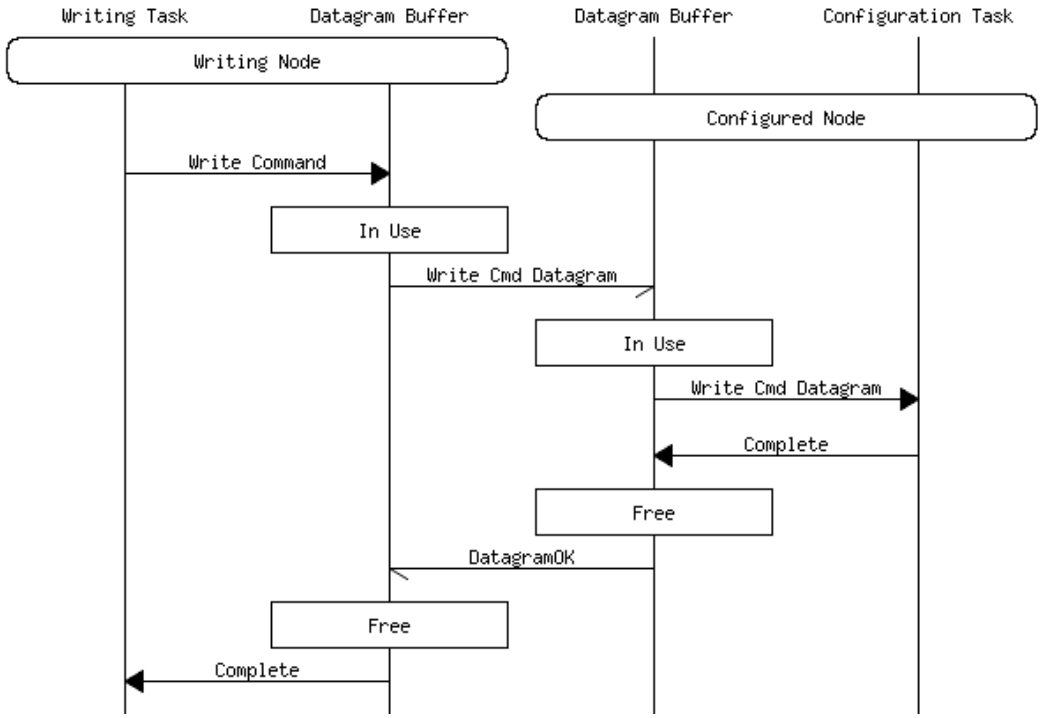
2.4.8 Write Command

Most writes are assumed to always complete immediately and without error. Writes into memory are certainly like that, but writes to DCC CVs might not be. Into-memory writes are well served by "when the positive reply to the datagram arrives, the write completed successfully". That requires no extra traffic to handle other cases.



A typical memory write operation. The Write Command and data are carried to the node being configured in a single datagram. Since the write operation succeeds immediately, the only reply needed is the datagram reply.

2.4.9 Write Reply

For the less-common case of writes that might fail and/or take a long time, the Datagram OK reply to the Write datagram can have the Reply Pending bit set, followed by a Write Reply when the operation is done. That Write Reply, in turn, informs the requester when the operation was complete, and whether it completed OK.

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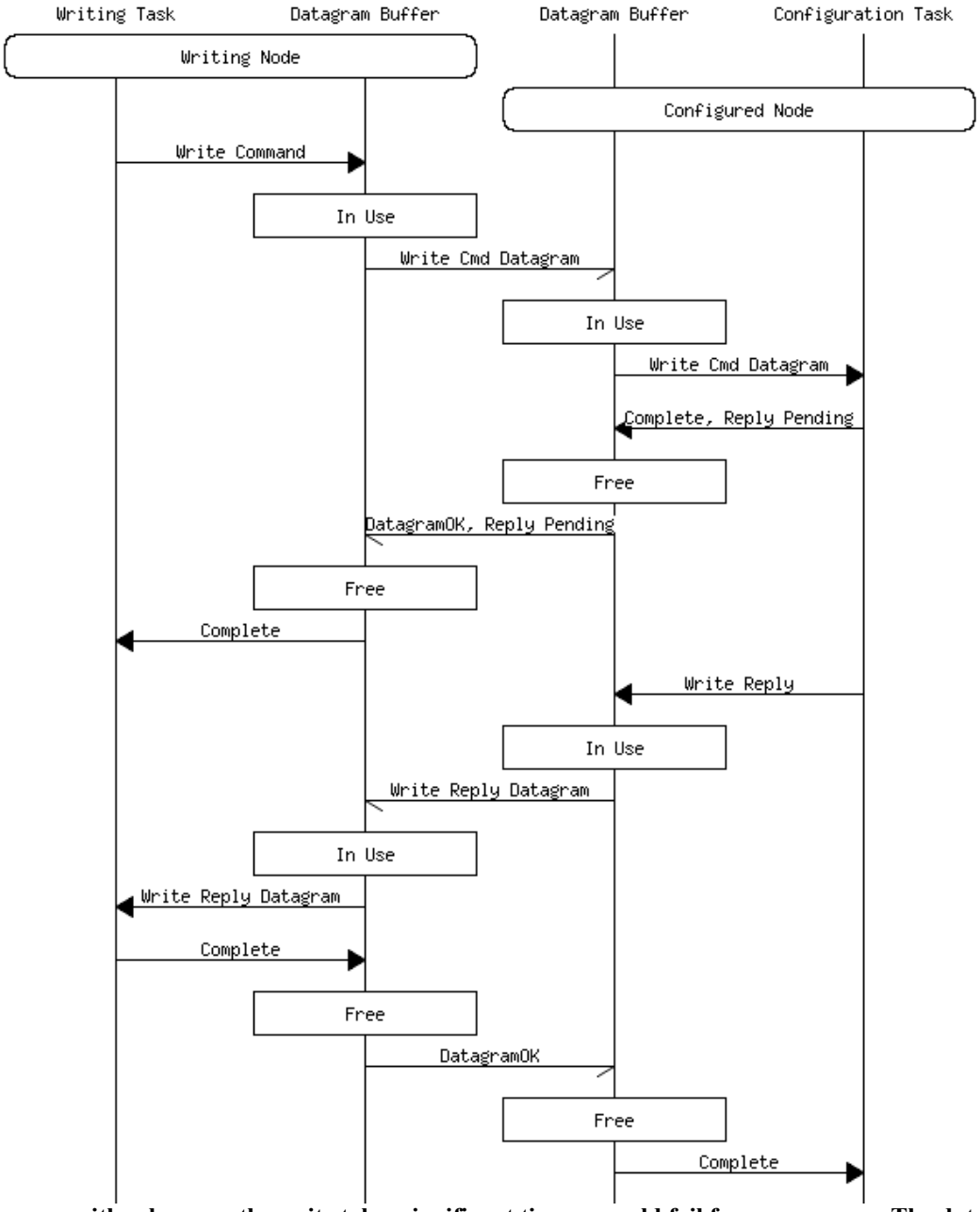

A delayed response, either because the write takes significant time or could fail for some reason. The datagram reply to the Write Command carries the reply pending bit set, and a reply datagram is send from the configured node back to the configuring node with the reply.

2.4.10 Write Under Mask Command

A write under mask differs from a standard write only in so far as it uses a stream of alternating bytes, the first of which is a mask and the second of which is a value. Otherwise a Write Under Mask Command sequence is identical to a standard Write Command sequence.

The primary use for this is to set/clear individual bits within a larger addressable type such as a byte, or multi-byte word.

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2.4.11 Write Stream Command

Stream support within the OpenLCB Memory Configuration Protocol is considered experimental. A version of this Technical Note and corresponding Standard containing updated information on the usage of streams will likely be adopted at a future time.

2.4.12 Write Stream Reply

Stream support within the OpenLCB Memory Configuration Protocol is considered experimental. A version of this Technical Note and corresponding Standard containing updated information on the usage of streams will likely be adopted at a future time.

2.4.13 Get Configuration Options Command

See section 2.4.14 Get Configuration Options Reply for additional information.

2.4.14 Get Configuration Options Reply

To make it possible to make simple/cheap nodes, not every configuration operation & option needs to be provided. The reply to “Get Configuration Options” provides information that a configuring device can use to control how it communicates with the node so that it only uses available modes.

2.4.15 Get Address Space Information Command

See section 2.4.16 Get Address Space Information Reply for additional information.

2.4.16 Get Address Space Information Reply

To ease automated access, a configuring node can inquire about the address spaces in the being-configured node. Whether or not the address space is present, a reply is required.

2.4.17 Lock/Reserve Command

Although nodes can be configured by multiple other nodes, this can also lead to inconsistencies. The optional Lock/Release command can be used to avoid this.

2.4.18 Lock/Reserve Reply

See section 2.4.17 Lock/Reserve Command for additional information.

2.4.19 Get Unique ID Command

Event IDs are considered to be 'virgin' until they are taught to another node. Learned Event IDs are not virgin by definition, since they are shared by the taught node and by the node that did the teaching.

This command is used to obtain new virgin Event IDs and return them to the requesting node. The node should draw these from some pool of unique virgin Event IDs. This may be from the 64k Event IDs assigned to the node associated with its Node ID, or some other pool, but it must maintain the uniqueness of the Event IDs. If the node maintains a counter or pointer to the pool, then the value of this variable must be maintained even if the node goes through a reboot or reset. This means that its value must be keep in non-volatile memory.

This command does not need to be implemented. However, if it is not, then some alternate method of refreshing the node to virgin Event IDs should be implemented, such as Blue/Gold or other alternate local method. Some nodes may not need even this if they only implement fixed or well-known Event IDs, and a reusable range of Event IDs, for example time-events. If this protocol is not implemented, but a button method is used, then other methods, such as the Remote Button Protocol might be used to allow this function remotely.

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Maintaining the uniqueness of Event IDs is a crucial underlying principle of OpenLCB, and needs to be understood well so that inadvertent collisions of Event IDs are prevented. Manufacturers should go out of their way to maintain Event ID uniqueness and should teach users the significance of maintaining this fundamental principle.

Once Event IDs are taught, they represent an abstract idea, although that idea may certainly have concrete consequences. For example, the abstract idea "Night has fallen" can be represented by a shared Event ID between many nodes, and sending it can have many consequences. The important point is that Event ID **cannot** be used for any other idea or purpose, unless it is removed from **all** nodes that use it. That may be possible in a closed system, like a private layout, especially with the appropriate software tools. However, not all systems are closed and not all nodes are reachable or active. Consider a node that is non-powered, or one on the work-bench, or even more important the one that you sold. The "Night has fallen" Event ID may still be used by any of those nodes, and they can be used to teach it to yet more nodes. So, in general, it is much safer to have other mechanisms available to prevent any inadvertent reuse of Event IDs.

One method is to provide a mechanism to reset the node such that all its Event IDs are replaced by a set of new virgin Event IDs. For small nodes that use 2-100 Event IDs this is reasonable. Each node has 64k Event IDs assigned to it, and so these nodes can be reset 600-30k times before running out of virgin Event IDs.

Another method, that is more frugal of Event IDs, is to only replace non-virgin Event IDs, i.e., those that have been taught or learned, on a reset. Flag-bits would be used to remember which ones are non-virgin, and thus which need replacing.

A further sophistication is to use a 'just-in-time' method. Each Event ID would be flagged as virgin or non-virgin. When the node was to teach a non-virgin Event-ID, it would be replaced with a new virgin one before the teaching occurred. The disadvantage to this method is that an EventID would only be able to be taught once, whereas there are situations where it is desired to extend an abstract idea to additional nodes. Unfortunately, by definition these Event IDs would already be considered non-virgin and would be replaced by a new virgin Event ID. This could be mitigated by a more complicated UI, but it would likely be confusing to the user.

Note that all mechanism for tracking Event IDs being "virgin" is dependent on the sole use of the teach/learn protocol. As soon as a Configuration Tool reads the CDI and uses it to display the event IDs to the user, there is no way for the node to keep track of the user copy-pasting the Event ID to some other node, or writing it down.

As stated above, in a typical node, there is enough address space to produce nearly 64K of of Event IDs based on the nodes single assigned Node ID. Though highly unlikely, it is possible that over time, a node that has been reconfigured many times, could run out of Unique IDs. How a node behaves if/when it runs out of Unique IDs is undefined, but here are some possible suggestions:

- Mark the affected Producers / Consumers with Event ID of zero, hence making them unusable;
- Reply using a Datagram Rejected message with permanent error for subsequent requests;
- Permanently stop working (never announce as initialized);
- Allow for manual user intervention to reset, or reassign the Unique ID space in the node.

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However this is managed, the implementation must ensure that non-virgin event IDs are not re-used.

Solutions to the above limitations include:

- Design the node with more than 64k Event IDs, by using some of the Node ID bits to extend the Event ID space. For example a node that is assigned a range of Node IDs, say a.b.c.d.e.00 – a.b.c.d.e.FF could use 256x64k Event IDs;
- Teach an Event ID from another node (which has not run out of its space yet);
- Overwrite the zero Event ID using a configuration tool with a value from another pool assigned to you.

2.4.20 Get Unique ID Reply

See section 2.4.19 Get Unique ID Command for additional information.

2.4.21 Unfreeze Command

The Freeze and Unfreeze commands intend to notify the target node that a sequence of configuration changes shall be applied atomically, and that the node is not expected to perform its regular operations during the time these configuration changes are downloaded and applied to the node. The expected sequence is that the Configuration Tool sends a Freeze command for the given address space, then some amount of writes, and finishes with an Unfreeze command.

Wrapping configuration changes with Freeze/Unfreeze shall be used by the Configuration Tool if and only if a specific higher level standard or specification requires so. This provision is present so as to explicitly specify which set of configuration changes require the use of Freeze/Unfreeze and not need to have the Configuration Tools or end-users be burdened with figuring out or guessing whether a given configuration change needs Freeze / Unfreeze.

There is no requirement in this standard on the Target Node on what to do or how to process the Freeze / Unfreeze command. All such requirements, if any, will be coming from the application specific standard. In general the Freeze command notifies the target node that it shall prepare for the atomic configuration change, with the understanding that the node's user-visible operation may be suspended for the duration of the changes. The Unfreeze command notifies the Target Node that the sequence of atomic changes has ended, and it shall resume normal operation.

An example such application is Firmware Upgrade, as specified by the Firmware Upgrade Standard. For purposes of replacing the node's firmware, the Freeze command will typically be implemented by the Target Node by rebooting into a secondary firmware; the subsequent changes applied will overwrite the primary firmware; the Unfreeze command will cause a reboot into the freshly updated primary firmware and/or consistency checks on the received primary firmware.

As the Freeze and Unfreeze commands may have valid implementations with the side effect of rebooting the Target Node, there is no requirement that a proper Datagram Received OK acknowledgement be sent back to the Configuration Tool. The Configuration Tool shall watch the network for Node Initialization Complete messages and interpret them as positive acknowledgement.

The Freeze and Unfreeze commands carry an Address Space identifier to allow the different higher-level protocols to be disambiguated from each other by allocating a dedicated Address Space identifier for them.

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2.4.22 Freeze Command

See Section 2.4.21 Unfreeze Command for additional information.

2.4.23 Update Complete Command

The configuration protocol does not specify the meaning of the transferred data. In particular, it doesn't specify when new configuration information takes effect. Depending on how the node is constructed, this might be immediately upon transfer (although this raises issues of write boundaries), or when an entire sequence of transfers is complete. “Update Complete” is the command that indicates that a series of configuration writes is consistent and complete, and the node can put it into effect.

2.4.24 Reset/Reboot Command

The “Reboot/Reset” command is meant to reinitialize a node, equivalent to powering it up. Nodes should finish any pending operations, e.g. non-volatile memory writes, before doing the initialization. It's expected that the datagram reply will be sent before the reset, but this might not be entirely reliable. Configuration tools should not count on the reply. The configuring node will receive a “Node Initialization Complete” when the node is back up. This operation must not reset any configuration information to default contents.

2.4.25 Reinitialize/Factory Reset Command

This is a heavy-weight operation which may require some form of interlock, e.g. the user pressing a button, to prevent inadvertent data loss. As a small safety precaution, the Node ID of the node being reset is redundantly carried in the data part of the datagram.

There may also be implications if the node supports the Get Unique ID Command. If the node has previously handed out Unique IDs, future Unique ID assignment is not prescribed by the standard. The node could choose to continue assigning Unique IDs from where it left off before the reset, require the user to enter in a new Unique ID pool into the node, or use some other unprescribed method to handle (or not handle) potential conflicts as a result of the reset.

3 General

3.1 Environment of Protocol

3.1.1 Requirements

- Nodes must carry enough context that a stand-alone configuration tool can provide a useful human interface without getting any data from an external source, e.g. needing an Internet download to handle a new node type.
- It must be possible to configure a node entirely over the OpenLCB, without physical interactions, e.g. pushing buttons. This configuration must be compatible with local configuration, including e.g. the Blue/Gold method.
- It must be possible to configure one or more nodes while the rest of the OpenLCB is operating normally.
- It must be possible to read, store, and reload the configuration of a node.

3.1.2 Preferences

- Small nodes shouldn't need a lot of processing power, e.g. to compress or decompress data in real time. Memory usage should also be limited, but is a second priority.

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- Configuration operations should be state-less and idempotent to simplify software at both ends.
- Multiple independent configuration operations can proceed at the same time. Multiple devices should be able to configure separate nodes at the same time. Multiple overlapping reads of the same node should be possible. There should be a method to coordinate separate configuration operations to simplify configuration software.
- For efficiency, atomic reads or writes of small amounts of data should fit into a single-frame CAN datagram. Single-bit writes also add efficiency.
- Multiple address spaces make it easier to handle multiple types of data.
- For large transfers, it's desirable to be able to use streams. Not all nodes support them, though, so it must be possible to Inquire about capabilities.
- Addresses should be four bytes. Two address bytes is a failure of imagination.

3.1.3 Design Points

Basic configuration is done with datagrams, which can carry 64 bytes of data to read or write.

For efficiency, writes don't need any reply except the datagram response. By sending that only after the write is complete, including non-volatile memory delays, the written node can control the transfer rate.

Read operations must return data in a separate datagram. If this carries the address, etc, in addition to the data, the operation is idempotent.

Read and write operations can address separate kinds of information in the node via specifying specific address spaces. Three of these have specified uses, and the rest are optional tools for future expansion.

There are a large number of possible configuration options, and more may be developed in the future: Reset, identify, etc. Not all nodes will implement all methods, so a query operation is needed so that tools can know what they can do.

Can't require that nodes do anything in particular to put changes into effect. Some will do it right away, some will require a reset, etc. Need flexibility for node developer, yet consistency for configuration tool builder.

3.1.3.1 Large read via stream

Stream support within the OpenLCB Memory Configuration Protocol is considered experimental. A version of this Technical Note and corresponding Standard containing updated information on the usage of streams will likely be adopted at a future time.

3.1.3.2 Large write via stream

Stream support within the OpenLCB Memory Configuration Protocol is considered experimental. A version of this Technical Note and corresponding Standard containing updated information on the usage of streams will likely be adopted at a future time.

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3.1.3.3 Performance Note

Small nodes may have only one datagram receive buffer and one datagram transmit buffer. In that case, sending multiple reads can result in poor performance if the replies go after the next request, e.g.:

Read [d] →
← datagram reply
← Read Reply [d]
Read [d] →
datagram reply →
← datagram reply
← Read Reply [d]
datagram reply →

Note that the 2nd read command was sent before the reply to the Read-Reply datagram was sent. This is valid, but nodes with only one buffer may not be able to handle that Read until the transmit buffer has been emptied by an acknowledgement. In that case, the sequence may become e.g.:

Read [d] →
← datagram reply
← Read Reply [d]
Read [d] →
← datagram negative reply (reject, no buffer, please resend)
datagram reply →
Read [d] (retransmit) →
← datagram reply
← Read Reply [d]
datagram reply →

which is significantly less efficient. Better to send the positive acknowledgement to the read reply datagram before sending the next read command.

3.1.3.4 Delays Due to Non-Volatile Memory

Some microcontrollers can't continue to operate while writing configuration information to non-volatile memory.

If the CAN buffering is sufficient (at about 200 usec per buffer) for the node to become active at the end of the memory operation and process buffered frames at the full rate, there's no issue.

If a node has missed one or more frames, it's possible that some state interaction has started and the node is inconsistent. For example, a RIM/CIM sequence could have started or even finished.

If the node misses one or more frames, the CAN controller needs to flag that and bring it to the attention of the node's microcontroller. The node then needs to emit an “Initialization Complete” message so that other nodes realize that this node may not have complete state information.

The node should also defer the reply to a write datagram until after the write is complete, to make it less likely the next-in-sequence operation arrives during dead time. Nodes doing the configuring should limit the amount of traffic they send to the node-under-configuration to reduce the need for e.g. datagram retransmission.

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There are bits that allow the node to specify what size writes are allowed. These can be used to force the configuring node to do operations in the most efficient way, e.g. to minimize dead time during writing.

The transfer buffer size for stream access is negotiated. By requiring a transfer size equal to or smaller than the memory write size (page size), the node can ensure that the stream will pause during a write operation.

3.1.4 Large Volume Operations

The stream protocol is meant for large reads and writes, but the datagram protocol can also work well on a single CAN segment. The difference in performance comes from a number of factors:

- Stream buffers may often be larger than datagram sizes.
- The header information for reads/writes only needs to be transmitted once for streams (no matter how many buffer-size the transfer is), but once for every datagram.
- Streams have one byte less data per CAN frame than datagrams. This is approximately the same overhead as 64-byte datagrams' headers.
- The setup cost of a stream is higher than a single datagram, so very short transfers are not efficient using datagrams.
- The number of roundtrips per kB of data transmitted is significantly lower using streams than datagrams. This has a huge impact on transfer rate if the originating and the terminating node is NOT on the same CAN segment, but have to traverse routers, gateways and high-latency links (e.g. wireless or links over the Internet), since for each direction change in the traffic there is no transfer during one round-trip-time length of time. Queues in gateway between busy segments will aggravate the deficiency of datagrams here.

All nodes support datagrams for configuration; not all support streams. So a least-common-denominator configuration tool would use sequences of datagrams for even large transfers. Because the need for reply, short datagrams are not particularly efficient. In the limiting case, you can only write two bytes per frame exchange. The sending node should look at the Get Configuration reply and use the largest available size.

On the other hand, if non-volatile memory timing requires that write operations to a node use a 64-byte or smaller stream buffer size, then datagrams are a more efficient method than streams. In that case, the node should indicate that stream-write operations are not supported in its reply to Get Configuration. Since read operations don't have the same timing issues, streams may still be useful in that case.

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