This document is under formal review of the NMRANET Working Group. It has not been approved by the WG, reviewed by the Manager, S&C Dept., nor approved by the NMRA Board of Directors.

NMRA TECHNICAL NOTES	
General Description of	
NMRAnet™	
All Scales	
January 2009	S-9.6

Executive Summary

This document provides an overview of the NMRAnet™ layout control bus that is intended to control the operation of accessories and trains on a model layout. Further details will be available in other Standards and Recommended Practice documents in the 9.6 group.

Guiding Principles and Design Philosophy:

- Robust yet cost effective, easy to use, plug-n-play, but allows analysis and diagnostics
- Suitable from novice to aggregate and museum layouts.
- Top-down design with bottom-up implementation reality-checks.
- Elegance and uniformity that can be applied across multiple networking technologies.
- Maintain manufacturer choice of implementation, and for further development.
- Use of existing standardized and commodity hardware/software
- No requirement for a PC or complicated tools for simple layouts, but the ability to use these as the layout expands.
- Design for the future and do not focus solely on current technology choices.
- Standards conformance validation must require minimal effort.

NMRAnet defines a set of Common Messages that include: Consumer-Producer Events; Directed Configuration messages; and Streams that are media and transport agnostic. In addition, NMRAnet defines specific application of these Common Messages to Media-Specific Messages on a variety of transports, including but not exclusive to: CAN, Ethernet, and wireless.

In addition, NMRAnet is designed to use one or more net-segments which may involve one or more media. NMRAnet allows the ease of use to implement a novice-layout involving only one segment, to very large layouts involving many segments. This is accomplished by defining both simple messaging for use on small layouts, but also more sophisticated mechanisms such as routing, which allow very large layouts to function.

Introduction

This document provides an overview of the NMRAnet™ layout control bus that is intended to control the operation of accessories and trains on a model layout. Other Standards and Recommended Practice documents in the 9.6 group describe the NMRAnet in more detail. This document is intended to give the reader a good appreciation of the main features and benefits of the NMRAnet 9.6 design. Please note that NMRAnet is still in the design phase and prototyping phase, but it was considered important at this stage to describe the NMRAnet design in sufficient detail for others to review and comment on and so this document should be considered a draft.

Guiding Principles and Design Philosophy

While this document is meant to be an overview or summary of NMRAnet it still contains a lot of higher level details. So here is a list of the guiding principles and design philosophy we have used:

- The NMRAnet must be robust yet cost effective, easy to use, plug-n-play, provide means to to attach a network monitoring tool to analyze behavior and diagnose faults.
- A single system that is suitable for novices to aggregate meets and museum layouts.
- The top-down design with bottom-up implementation reality checks.
- Elegant structure and uniformity that can be applied across multiple networking technologies.
- Openness for manufacturer choice of implementation, and for further development. No fixed media, microcomputers, etc.
- Use of existing standardized and commodity hardware/software: Consumer/Producer; CAN, Wireless, Ethernet TCP/IP, routing, etc.
- Configuration and running must not require a PC or complicated tools for simple layouts. However as the layout expands and more complicated configuration choices are made, the system should be able to simply expand, and not require starting over.
- Design for the future and do not focus solely on current technology choices. A good NMRAnet design should last many years despite changes in networking technologies over that time. The design needs to be adaptable to exploit new technologies as they develop.
- Standards conformance validation must require minimal effort.

When considering the choices commonly available for initial implementation we cannot ignore the CAN 2.0 (ISO 11989-*) networking technology from Bosch, as it is a very robust and accessible technology in 8-bit microprocessors. However it has very limited frame sizes (only 11 bytes) and so it can't do everything we may need. So, while the 9.6 NMRAnet will include features like streaming media and other high bandwidth consuming features that are commonly available, only a subset will be available on the CAN segments. However, to run a layout in the manner similarly to what can be done now using DCC vendor equipment, CAN is very adequate and can handle those duties fine. But, we have deliberately not limited ourselves to what can be done on CAN networks because, in the expected life of NMRAnet, other networking technology choices (particularly wireless) will become commodities, and therefore good candidates for NMRAnet.

Also, we have not tried to overly minimize the sizes of the data items in the NMRAnet messages. We have deliberately made Node Ids (48-bits) and Event Ids (64-bits) outrageously large. This choice was to minimize the NMRA management overhead required to manage the allocation of globally unique node addresses and also provide a way to then generate globally unique Event Ids. This has the potential to greatly simplify the way modular layout clubs configure their systems, as modules can be arranged in any combination, and with purpose-built configuration tools, even that can be substantially automated. While these choices do have a system resource impact, our design pushes the bulk of the additional resource requirements into the gateway nodes as they are likely to be few in number (likely none for many layouts) and are likely to be PCs or that class of device anyway, so the resource impact on small CAN based should be minimal. In addition, design decisions will allow reducing the overhead for CAN nodes.

What is NMRAnet?

NMRAnet defines a family of inter-operating protocols for controlling model railroads. It is structured around some common core concepts and separate implementations. The NMRAnet will be capable of supporting Accessory Control, Advanced Locomotive Control and even Multimedia and Rich Text features on the higher bandwidth networks. This protocol proposal will focus on NMRAnet Accessory Control with emphasis on CAN 2.0B, but allowance has to be made for simple Locomotive Control and implementation of the NMRAnet protocol on other network technologies like Ethernet, WiFi and other wireless networking technologies, and the global Internet.

This proposal is based on a series of use-cases *(see the Use Cases section)* that begin with a beginning modeler connecting up two boards and extend to huge modular layouts put together by several clubs. To achieve this range, and to allow for future technologies, NMRAnet is defined so that it can communicate via various media. These include CAN, Ethernet and WiFi , but also programs running in a computer as these are considered NMRAnet nodes.

Key Features of the NMRAnet 9.6 Protocol Proposal

The key features of this proposal are:

- The basic communicating unit is called a "Node". A node might be a single board, or a single program in a PC, or any other addressable item. A node may control any number of actual devices on a layout. Nodes exchange messages to control the layout.
- At it's basic level, NMRAnet defines a transport layer for several types of data:
  - Events - Fixed length identifiers that can propagate from multiple source nodes to multiple destination nodes.
  - Directed messages – These are used for configuration and other protocols that require messages to be sent to specific nodes. Usingwill likely include throttle and train control messages,

  - Streams - An efficient way to move a large, variable number of bytes from one node to another.

  This transport level also has provision for interconnection of independent NMRAnet segments and filtering of messages to reduce traffic.

- NMRAnet defines a global set of common message types and their content. NMRAnet specifies how the common message types are to be used for standard interactions and optional interactions. All NMRAnet nodes must be able to properly take part in standard interactions that are originated from outside the node.

- The format of the common messages is separately specified for each of several wire protocols. The initial wire protocols are CAN and TCP/IP point-to-point; additional ones are envisaged. NMRAnet wire protocols may define additional interactions and messages for specific transport-level uses, e.g. for housekeeping on the local connection. These interactions and messages will be divided into standard forms, which all nodes must implement, and optional forms.

- The NMRAnet as a whole is considered as being comprised of one or more NMRAnet segments interconnected with repeater, bridge or gateway devices that ensure all nodes are able to communicate equally with all other nodes on the NMRAnet.

- Every node has a 48-bit "Node ID number" (NID). The assignment of the NIDs assures they are globally unique. The method of allocating NID ranges is described in another document but they are distributed to manufactures, groups and individuals. E~~e~~ach manufacturer that has a NMRA DCC Manufacturer Id will have a 24-bit address space allocated for their exclusive use. Large clubs or societies like the NMRA, MERG, FREMO, NTRAK, oNeTRAK etc. can apply for a number range which the group can then subdivide by a membership number, such that by simply being a member of one or more of these groups you will automatically be allocated ~~256~~ NIDs for your personal DIY use, for each group membership. A mechanism will also be available for individuals to request a range of NIDs for their use.

- There is no hierarchy of nodes, ~~or~~ node aggregation, ~~or~~ tree structures, or segmentation that necessarily filters NMRAnet traffic. The NMRAnet is a flat structure,, where all nodes are equally accessible and addressable.

- All NMRAnet nodes ~~can~~have the potential to see all NMRAnet messages. However, the protocol provides access to sufficient information about nodes and events to allow smart gateway nodes to dynamically learn which nodes need are interested in specific events, and to then selectively forward events seen on one segment, selectively, onto the other segments that have nodes that are interested in those events. This is an effective way to reduce network traffic in large NMRAnets with many interconnected network segments.

- All NMRAnet nodes on all segments are uniquely identified by a Node ID number and use this Node ID in all NMRAnet messages as a Source Node ID.

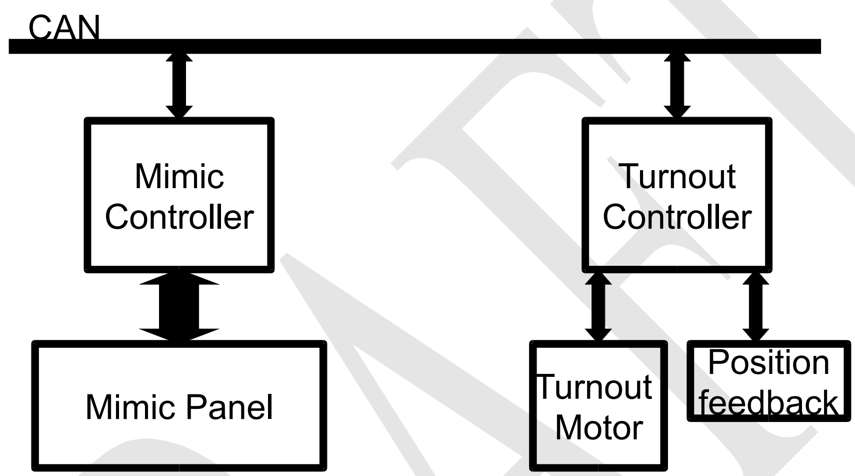
- Any NMRAnet message can be traced back to the originator using the Source Node ID.

- Above the basic transport level, NMRAnet defines methods for:

- Event transfer for layout control
- Node configuration
- Locomotive Control (although not currently part of the protocol specification)

NMRAnet Network Topology

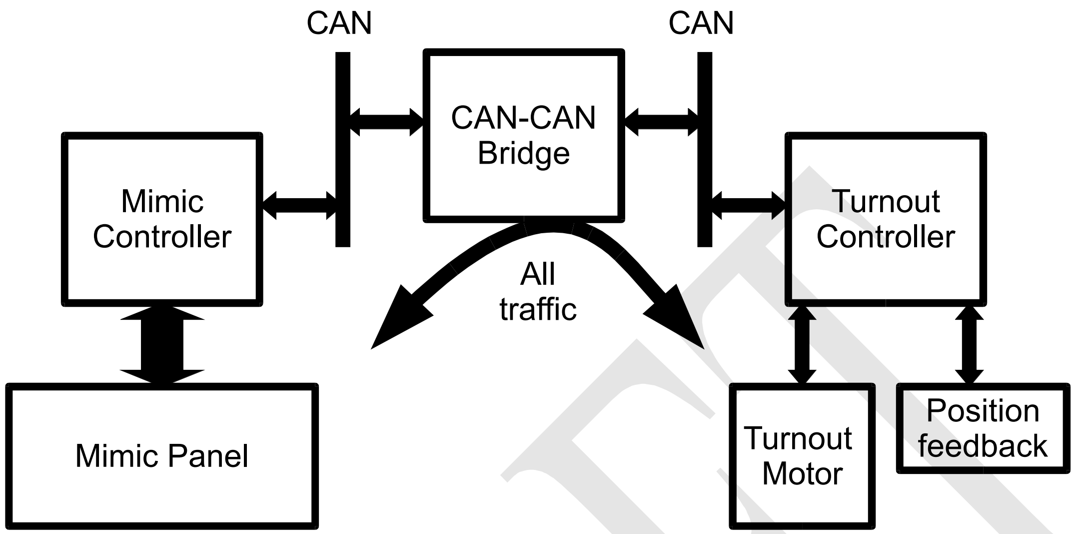
A layout with a NMRAnet will require at least one NMRAnet network segment with two Nodes as shown in the diagram below.



The diagram shows CAN but it could also be Wireless, Ethernet or WiFi and is likely a combination of several technologies. A layout may have a lengthy CAN based NMRAnet segment with many nodes, running around the entire layout and have a comparatively short Ethernet segment that provides a convenient connection to a single PC. It is likely that entry level NMRAnet compatible DCC Command Stations will just have a CAN NMRAnet interface and a USB PC interface. Medium level DCC Command Stations might add Ethernet and Wireless interfaces whereas top end DCC Command Stations may also add WiFi. It is also likely that manufacturers will provide various interface devices (repeaters, bridges or gateways) to link each of the NMRAnet segment types like CAN to Ethernet, CAN to USB (for PC access), CAN to Wireless and Ethernet to Wireless (for wireless throttles). WiFi interfaces are likely to use consumer grade Ethernet to WiFi Access Points but some markets may opt for a WiFi interface in the DCC Command Station.

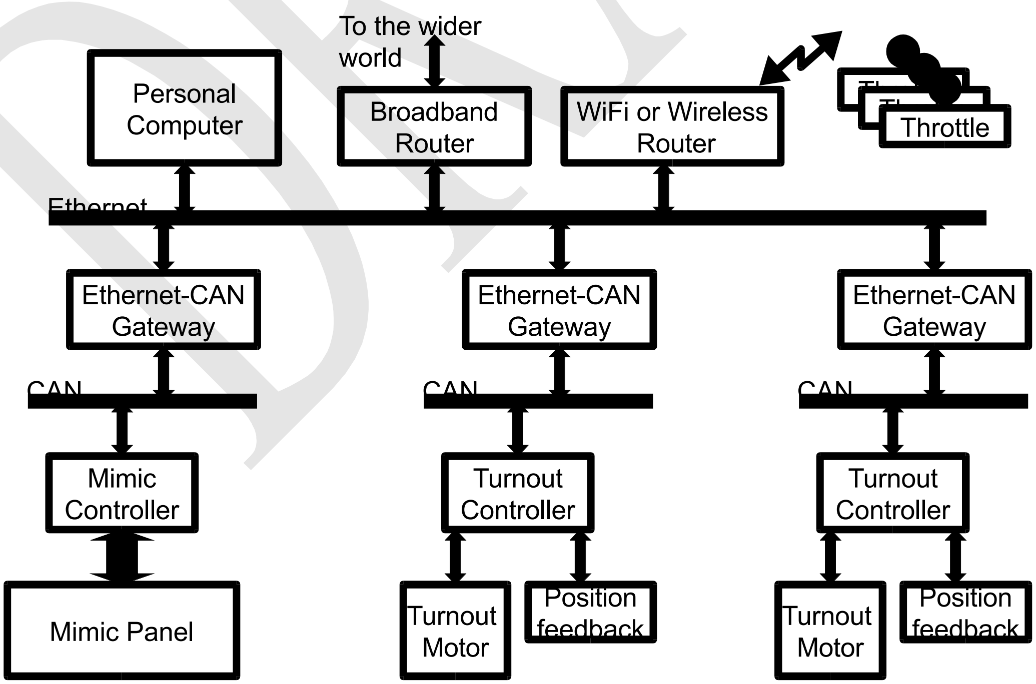
Each segment of a NMRAnet is by default transparently connected to all other segments. A single CAN cable would be a NMRAnet segment, as would two CAN cables connected by a repeater or bridge. An Ethernet link would also be a segment, as would TCP/IP network connections.

Two or more segments can be connected by repeater or bridge devices as shown in the diagram below.



Simple repeater or bridge devices do not filter any messages and all messages are forwarded to all other segments. More intelligent interconnection devices can reduce required bandwidth by filtering messages that are not needed on other segments, these are called gateways.

As an example, a CAN segment with a number of nodes can be connected via a CAN-USB or CAN-Ethernet bridge to a PC running several separate control programs. As another example, a CAN segment in a series of modules can be connected via a gateway to an Ethernet backbone, which in turn connects via several other gateways to other CAN segments in other collections of modules. Several PCs can be connected via the Ethernet and interact with all the modules via the individual CAN segments.



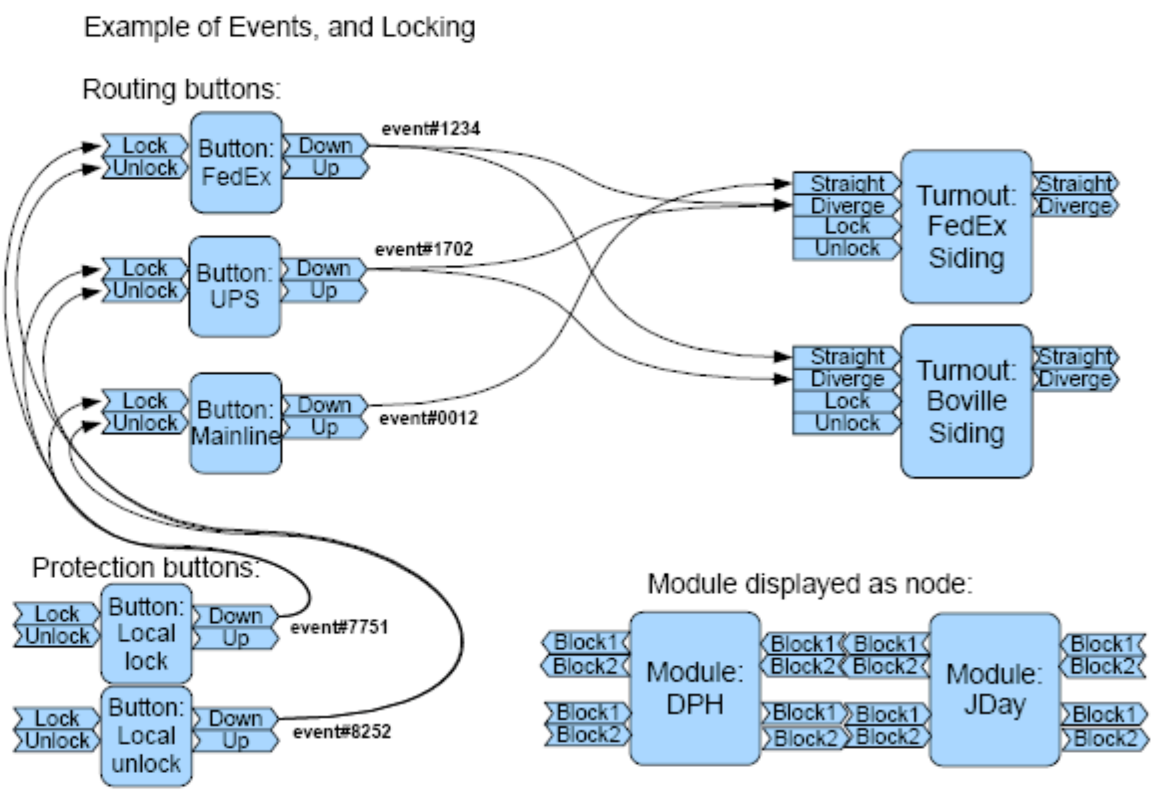
Producer/Consumer Events

The NMRAnet makes use of stateless messages called Events, which are part of a model formally called “The Consumer-Producer Model”. This is a relatively new and powerful concept that is well established in the industrial control industry. In it a producer-node reacts to a change in its environment by producing (sending) an Event-message. Similarly, a consumer-node consumes (receives and processes) this message and causes some Action to happen. For example, depressing a push-button would cause the node to which it is connected to produce an Event, and, on receiving this message, a consumer-node would cause its attached turnout to move to a new position.

Events are used to allow multi-node to multi-node interactions. One or more nodes can produce any particular Event, and none or more nodes can consume to that Event.

The Producer-Consumer model has some specific details that need to be stressed. Events indicate only that a change has occurred, but do not carry state information --- no information as to what changed can be inferred from the Event. Similarly, the eventual Action(s) cannot be inferred from the Event. The Event represents an abstract concept, rather than carrying actual information. For example, an Event might represent “Night-time running”, and it could be produced by any one of: a push-button; a timer; or a program in a computer, while it might be consumed by nodes that control: street-lights; station-displays or even automated train-routers. While this might seem limiting, the abstract nature of Events allows them to be very flexible and powerful, as they can link any consumer to any producer. This means that users can pretty much do what they like and not be constrained by the conventional control expectations like controlling a turnout position only from a toggle switch. For instance you could control a turnout position from the time of day clock that produces different Events at different times, and also use those same events to control room and layout lighting.

The diagram below shows how Events from various push buttons and turnout controllers are able to be configured to Produce and Consume different Events to effect a route selector complete with route and button locking.



XML Based Node Configuration Definitions

All NMRAnet nodes will contain a compressed XML document that contains all the relevant information for an external Configuration Tool (CT) to be able to to use to know how to configure the node. It is expected that the CT will use the data in the XML file to render some form of suitable Graphical User Interface to allow the user to easily and intuitively configure all aspects of the node's capabilities. An important design choice was to embed this XML document into each node so that the system has all it needs to configure the node without having to source the XML file externally to the NMRAnet from the manufacturer or some other on-line repository via the Internet or a CD/DVD etc. While the CT is likely to be a program running on a PC, it could be a hand-held device like mobile phone or PDA or even a custom built CT.

CAN Node Id Alias Self Assignment

Because of the small CAN frame sizes it is not possible to fit a 48-bit Source Node Id (SID) into an 11-~~bit~~byte Extended CAN 2.0 frame and have much space left for anything else. So to make NMRAnet work on CAN we ~~had to use~~have used a shortened ~~for~~form of the NID called an Node Id Alias or

NIDa. This is a 16-bit number that is dynamically assigned at system start-up by each node using ~~their~~its NID as a seed to a pseudo random number generator (PRNG) algorithm, and then ~~use~~using the PRNG to generate a sequence of potential 16-bit NIDa numbers, which it then uses in a special 29-bit CAN arbitration header only Remote Transmission Request (RTR) frame to probe the CAN network for other nodes using the same NIDa number. This probe is actually a sequence of 6 requests where the 29-bit RTR CAN frame contains 5-bits of protocol management, that is described elsewhere;~~,~~ the 16-bit NIDa; and 8-bits of the 48-bit NID taken in sequence such that each of the 6 RTR probe messages will contain a part of the NID so that any other node trying to claim the same NIDa will at some point in the 6 frame RTR sequence will send a RTR frame that contains a different 8-bit NID portion and so CAN will only allow one of the nodes contending for the same NIDa to send their RTR frame. The other nodes that were blocked by the CAN arbitration mechanism should receive the RTR frame and detect that another node is also trying claim the same NIDa and has won and so the others should generate another potential 16-bit NIDa using their PRNG and repeat the process until it finds an unchallenged NIDa. Once an unused NIDa is found that node will announce to the NMRAnet it's new NIDa along with it's full NID.

Use Cases

The table below describes the Use Cases that were and are being considered for the NMRAnet design.

Entry Level User	A model railroader wants to learn about NMRAnet. He buys two inexpensive boards at his local hobby shop. He connects them on his layout to two pushbuttons and a turnout motor, does a simple configuration, and is able to control the turnout with the pushbutton.
Expanding A Small Layout	A user has four NMRAnet boards working on his layout. He buys one more input board to provide extra pushbuttons to operate his yard ladder from the other end of the layout. He's able to configure the new board and put it into operation.
Mid-size Layout Problem	A user has twelve NMRAnet boards operating. Something changes, and the system is no longer reliable. Certain operations no longer work, and others only work sometimes. The user attempts some debugging steps using features of the existing hardware, but is unable to locate the problem, so buys/borrows diagnostic device(s).
Large Layout Upgrade	A model railroad has 40 NMRAnet boards controlling a large layout. To upgrade a major yard, the user wants to replace 12 boards with new ones that offer new (non-NMRAnet) features. He captures the existing setup, replaces old boards with new ones, configures the equipment and is back in operation.
Distant Control Panel	A model railroad has turnouts and signals controlled via NMRAnet. The owner wants to put a physical control panel in his house, a separate building, and operate it via NMRAnet.
Large Layout Expands	A large model using CAN, but not any attached computers, grows enough that it needs to have another CAN segment. This must be possible without reconfiguring all the existing nodes, event IDs, etc.

Connect Multiple Programs	The user wants to run multiple programs from multiple vendors in his home computer that simultaneously connect to the layout NMRAnet and control/monitor it.
Remote Dispatcher	A model railroad has turnouts and signals controlled via NMRAnet. NMRAnet is used to install a CTC panel at a distant location. The panel could be either a physical panel or on a computer screen.
Modular Layouts	A modular club has fifty modules, each of which as a CAN NMRAnet with two or three nodes controlling the module. These modules are separately built, with no central administration. They are brought to a central location for a meet, where they are all connected together in some pre-planned orientation. The NMRAnets are connected in some fashion, and used to operate the entire layout from both central and distributed locations.
Remote Diagnostics	A club layout is operated via NMRAnet. There's something not quite right about the signaling, and one of the members wants to check the operation of the signals. He makes a remote connection to the layout and checks the status and configuration of the hardware from his home computer.
Aggregation of Modular Clubs	Dozens of clubs put together dozens of NMRAnet segments and hundreds of modules that have been separately configured. A large FREMO meet would be an example. Collision avoidance: EventIds, NodeIds that are already configured into the modules should already be unique. It must be possible to build automated tools for translating, disambiguating Event IDs. Conventions and/or tools for connecting across the boundaries are needed so that e.g. signaling systems can work with adjacent modules they've never met before. It must be possible to build automated tools for health monitoring across the layout.

Typical Equipment

230 The table below describes the typical equipment that is likely to exist on a NMRAnet equiped layout.

Simple Board	Low cost, low engineering complexity is important.
Multiple I/O Board	Higher cost/complexity board that can do multiple input and output functions.
Simple Diagnostic Tool	A simple diagnostic tool that can plug into a CAN segment and provide limited information. Not based on a computer.
Computer-CAN Interface	Inexpensive module to allow any type of home computer to attach to a CAN segment and interact.
Ethernet-CAN	Module to allow a CAN segment on e.g. a module to be connected to an Ethernet

Interface	backbone without requiring a local computer.
CAN bridge	Low cost module to connect two CAN segments for greater length or more attached nodes.

Glossary of Terms used in NMRAnet

Common Terms

Alias	Short form of a Node ID number which can be mapped back and forth to the full number. Often used as "NID Alias", "DID Alias" or "SID Alias"", which are then written NIDa, DIDa and SIDa.
Board	Not really something that occurs in NMRAnet itself, we need to talk about how the common term "board" maps onto NMRAnet. E.g. A node (board) may connect to several things (devices) on the layout.
Bridge	Connects two NMRAnet segments with minimal changes to the content of the messages. For example, a bridge between two CAN segments would allow more nodes to be attach to the combined segments as if they were one; a bridge between a CAN segment and Ethernet segment would transform message format, but transfer every message.
Device	Not really something that occurs in NMRAnet itself, we need to talk about how the common term "device" maps onto NMRAnet. E.g. A node (board) may connect to several things (devices) on the layout.
DID	Destination Node ID - Node ID of the node to which a specific message is addressed.
Event	NMRAnet allows nodes to notify each other when specific "events" occur on the layout. These in turn can cause nodes to take particular actions. Events are not necessarily attached to a producer ('Button 2 pressed') or attached to a consumer ('Turn off light 4'), but rather to an overall state change ('Set for nighttime operation'). This is called a "Producer/Consumer model".
Event ID (EID)	A 64-bit number that identifies a specific Event. NMRAnet Event IDs must be globally unique. Events are not associated with any particular node. It may be convenient to use e.g. Node ID as a way of numbering them uniquely, but Node IDs and Event IDs are not related.
Gateway	Connects two segments of the NMRAnet, optionally suppressing messages that are known to be not relevant to the far segment. If needed, so translation from one message form to another.

Installation	An NMRAnet installation is the complete set of NMRAnet hardware, nodes, etc, that can be reached from any one of them.
Node	Unit of addressability for the network. Every NMRAnet interaction originates in a node. Every board that connects to NMRAnet is at least one node. For example, a simple turnout controller board is one node, while a PC with multiple programs running may contain several nodes.
Node ID (NID)	A 48-bit number identifying a specific node. NMRAnet node IDs must be globally unique, so they form a one-to-one mapping to the nodes themselves.
Message	The basic unit of NMRAnet communication.
MTI	Message Type Indicator - identifies a common message type. (This term is still under discussion)
Producer / Consumer Event Model	The mechanism whereby Producer or sending Nodes notify interested Consumer or listener Nodes that particular layout events, state changes or control actions have occurred by generating an Event. The Event is simply a NMRAnet Message that contains an Event Id or EID, which is simply a unique number that signals the defined event has occurred.
Repeater	Connects two segments of the same type at the physical level, without transformation of message format
Router	Rare in NMRAnet, these transform one address space into another. For example, these change EventIDs on one side of the Router into another set of EventIDs on the other side.
SID	Source Node ID - Node ID of the node which originated a specific message.
Segment	Subset of an overall NMRAnet installation which is reached via one or more translators and/or gateways. A segment typically uses a specific wire protocol.
Stream	Streams are a method of moving a large number of bytes between two nodes.
Wire Protocol	Version of the NMRAnet common messages, interactions, etc adapted to a particular transport mechanism. Examples are the wire protocols for CAN bus segments and TCP/IP links.

Wire Protocol Terms

Packet	A Packet is a single transmission on a NMRAnet segment.

CAN Wire Protocol Terms

Frame	A Frame is packet as it is defined on the CAN bus. It consists of a 11 or 29 bit CAN header and zero through 8 bytes of data.

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