

DeviceNet of Things Use Cases, Value Proposition and Status of Specification

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Abstract

This paper introduces the key technical concepts associated with the specification enhancements proposed for Volume 3 (DeviceNet) of the CIP Specification related to “DeviceNet of Things” SIG work. It includes discussions around the following topics:

- How DeviceNet will be enhanced as an in-panel cabling and communication system solution. Connection methods and ease of use will be improved without posing business or compatibility risk to those already applying DeviceNet.
- An overview of the new “DeviceNet of Things” specification enhancement set that builds on the existing DeviceNet specification, including:
 1. The proposed in-cabinet cabling and connector solution.
 2. Support for the discovery and presentation of the physical topology of network nodes based on their relative geographical position on the network.
 3. How network geographical information will be provided to remote clients when a DeviceNet of Things network is implemented as a subnet to other CIP networks such as EtherNet/IP.
 4. How simplified network commissioning will be performed by remote client tools and/or CIP Routers
 5. How the system will facilitate the development of low cost communication interfaces for devices with extremely cost sensitive bills of materials.
 6. How the system will support the automatic replacement of defective nodes with compatible nodes of the same type during full system operation, and how “geographic device keying” will help facilitate this.
 7. How a new “Power Tap” architecture will allow commercial off the shelf power supplies to be used in DeviceNet of Things systems.
 8. How “Smart Taps” and “Smart Terminators” will provide improved network diagnostic capabilities in a DeviceNet of Things system.
 9. How “Smart Drops” can be developed to allow existing DeviceNet nodes to work in a DeviceNet of Things system.
- How the DeviceNet of Things will help pave the way for future adoption of EtherNet/IP as Ethernet costs continue to decline.

Keywords

DoT - DeviceNet of Things
Smart Tap
Smart Terminator
Smart Drop
Nodal Geography
Actual Nodal Geography
Reference Geography
Network Power
Select Line
Select Line Protocol
Group 5 Messaging
IDC - Insulation Displacement Connector
Device Commissioning
Network Commissioning

Definition of terms

The terms “Switched Power” and “Control Power” are used interchangeably throughout this paper.

Nodal Geography is defined for the DeviceNet of Things as an ordered set of identity object device keys for all nodes on a network.

Device Commissioning for a traditional DeviceNet network is the setting of the MAC ID and Baud Rate for the device.

Device Commissioning for a DeviceNet of Things network is the setting of the MAC ID for the device since the Baud Rate is fixed at 500 kBaud for the DeviceNet of Things.

Network Commissioning is the process of commissioning all devices on a network.

Introduction

The increased popularity of EtherNet/IP and the “Internet of Things” movement establishes a basis for innovation of new smart “Things” in the automation world. However, the costs associated with deploying EtherNet/IP prevent it from being successfully deployed on many low end “Things” such as contactors and push buttons. Enhancing DeviceNet as an in-panel cabling and communication solution for low end devices would:

- Lower the cost of deployment below the levels provided by DeviceNet today.
- Provide greater information delivery capabilities over hard-wired solutions.
- Enhanced ease-of-use over existing networked solutions (including DeviceNet).
- Simplify physical/mechanical connection methods leading to lower panel build costs.

Since DeviceNet and EtherNet/IP share the CIP protocol at the application level, DeviceNet of Things enhancements may also help pave the way for future adoption of EtherNet/IP as Ethernet costs continue to decline.

This paper provides an overview of a new “DeviceNet or Things” specification enhancement set that builds on the existing DeviceNet specification.

Customer Requirements for the DeviceNet of Things

Extensive customer listening sessions resulted in the following key requirements for a DeviceNet of Things system:

It must be **Functional**:

- It must simplify in-cabinet wiring for panel builders.
- It must deliver both Network Power to power device electronics and Switched (Control) Power to facilitate the actuation of Contactors and Relays.
- It must support Non-Safety and Safety devices on the same wire.

It must be **Simple** to use:

- It must use a single easy to use media connector.
- It must include a simple (or no) network commissioning methodology.
- It must eliminate the need for media trunk and drop distance calculations.

It must be **Economical**

- It must use low cost media.
- It must allow for a reduction in price and size of typical DeviceNet products.
- It must allow the use of commercial off-the-shelf power supplies.
- It must result in a lower “total cost of ownership” than hard wired solutions.

To satisfy these requirements, Volume 3 (DeviceNet Adaptation of CIP) will be enhanced as follows:

- New in-cabinet media and connector will be specified to simplify in-panel wiring and deliver both Network power and Control power. The new media introduction will also address the need to simplifying cable trunk and drop lengths calculations.
- Miswiring protection circuitry will be removed from the physical layer specification, reducing component cost and board real estate. Connector and cable keying will render it unnecessary.
- A new power tap architecture will be defined and will include Network and Switched power taps for use with standard off-the-shelf DC power supplies.
- New device commissioning and device replacement methods will be defined to simplify the node commissioning and replacement process, including new network topology discovery, storage and delivery mechanisms.
- The baud rate for the network will be fixed at 500Kbaud.
- New network master functionality and restrictions will be introduced.
- EtherNet/IP to DeviceNet routing enhancements will allow a more consistent user experience in mixed EtherNet/IP / DeviceNet systems.

Volume 1 (Common Industrial Protocol) will also be enhanced as follows:

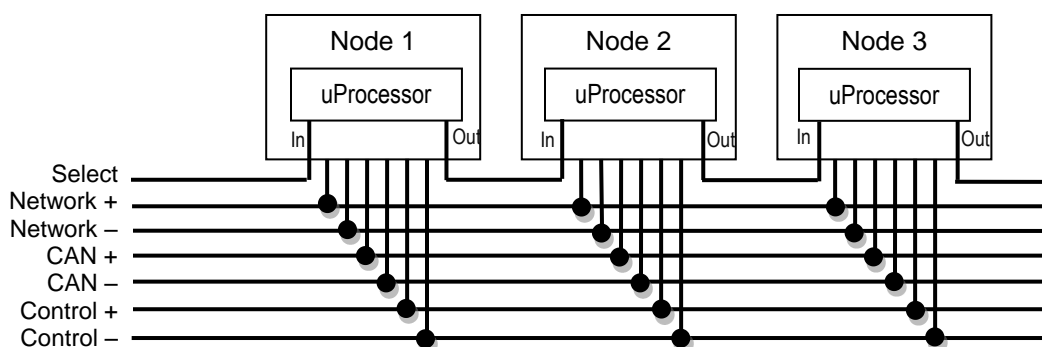
- New device profiles will be defined as the “DeviceNet of Things” drives communications capabilities into simpler classes of devices such as push buttons and relays.

Compatibility with existing DeviceNet products will be facilitated. New “Smart Drops” will allow existing DeviceNet products to participate in the new network topology discovery and delivery mechanisms.

DeviceNet of Things Media

The figure below depicts the signals that will be conducted in the DeviceNet of Things media. Note that the Select line needs to be broken into “Select In” and “Select Out” lines that connect to separate microprocessor pins. This facilitates the passing of simple Select line messages from the “Select Out” pin of one node, to the “Select In” pin of a geographically adjacent node. In the figure below, this facilitates the passing of Select line messages from left to right on the network. Messages on the Select line may be implemented without the use of a peripheral such as a UART. They can easily be clocked out the “Select Out” pin, essentially implementing a shift register, clocking one bit at a time. The “Select In” pin of the adjacent node receives the clocked messages.

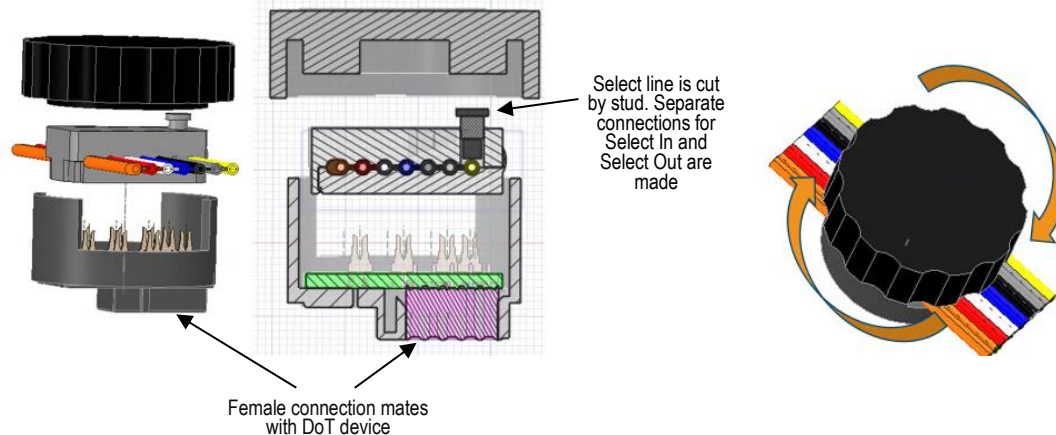
Figure 1: DeviceNet of Things Signals



Note that the CAN+, CAN-, Network+ and Network- conductors are the same as in currently available DeviceNet media. The new Control+ and Control- lines will be used for device actuation in devices such as contactors and relays. This is necessary since the actuation of these devices can be electrically noisy and should be isolated from the Network power which is generally used to power device electronics.

A new 7 wire ribbon cable will be specified. Network topology will be restricted to a linear topology only. The maximum length of the network will be 50 meters. This will allow vendors to sell 50 meter spools of ribbon cable, and when the 50 meter spool is used up, the user will know that he must start a new network. No “trunk and drop” calculations will be required to effectively deploy the network. The ribbon cable will be “keyed” for use with a new “Insulation Displacement Connector” (IDC). The ribbon cable/connector keying will insure that the cable is always attached to the ribbon cable in the correct orientation. Figure 2 below shows an initial concept of what the media and connector might look like.

Figure 2: DeviceNet of Things Preliminary Media Concept



Note that the yellow “Select” line is cut and individual “Select In” and “Select Out” pins are available at the device connector (represented in purple in the middle diagram).

Simplifying DeviceNet of Things Network Commissioning

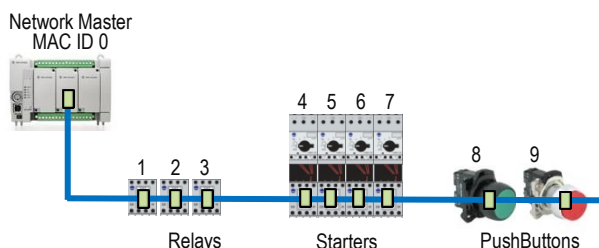
Node commissioning in traditional DeviceNet systems (the setting of the MAC ID and Baud Rate) is inconsistent, time consuming and susceptible to mistakes. In a recent “Voice of Customer” survey, node commissioning difficulties and resulting network fault conditions were one of the most often mentioned dislikes about traditional DeviceNet. (Note that other common dislikes cited include the complexity of DeviceNet scanner mapping and the complexity of media selection). What users want is simplicity when it comes to commissioning their network.

To prevent baud rate mismatches, the baud rate for the DeviceNet of Things will be fixed at 500 kBaud.

The topology of DeviceNet of Things networks will be exclusively linear. The simplicity of the topology will allow DeviceNet of Things systems to determine the linear Nodal Geography of the network. This will allow a user to commission their network with respect to a known Nodal Geography. To facilitate this, a new DeviceNet of Things Link Object and a new DeviceNet of Things Commissioning Object will be introduced into the DeviceNet specification. These new objects will control some system behaviors by using the Select line to throttle system level service delivery sequencing for the network. Select line system level service delivery will always be sequential from “Select Out” to “Select In” of the adjacent node (aka “left to right” as would be the delivery direction in Figure 1 above).

In Master/Slave DeviceNet of Things systems, it will be required to geographically place any network master as the “left-most” node on the wire as shown in Figure 3 below. Only a single network master will be allowed, and in Master Slave DeviceNet of Things systems, the network master’s MAC ID will be fixed at address 0.

Figure 3: Simple Master/Slave DeviceNet of Things Network



To capture the network geography, the leftmost node (the network master) initiates a Network Geographic Discovery sequence. The master tells the node to its right (position 1 on the network) to produce relevant information describing itself and its state on its CAN lines. This is done by sending a coded “Geography Request” service on the master’s “Select Out” pin. When the node to the master’s right (position 1) receives the coded request message, it produces the relevant information on its CAN lines, and sends the same Select line coded Geography Request command on its “Select Out” pin. The CAN message contents are consumed by the master and stored in an attribute of a new DeviceNet of Things Commissioning Object. This process continues until all nodes on the network have produced their relevant geography information messages on their CAN lines, and the DeviceNet of Things Commissioning Object has captured the Nodal Geography.

Relevant Nodal Geography information is reported by each network node in 2 new Group 5 CAN messages; Device Key messages and Offline Status messages. Figure 4 illustrates the DeviceNet of Things use of the CAN Identifier Fields and in particular the CAN Identifiers reserved for the new Group 5:

Figure 4: DeviceNet of Things Use of the CAN Identifier Fields – The New Group 5

IDENTIFIER BITS										HEX RANGE	IDENTITY USAGE	
10	9	8	7	6	5	4	3	2	1			0
0	Group 1 Message ID				Source MAC ID						000-3ff	Message Group 1
1	0	MAC ID						Group 2 Message ID			400-5ff	Message Group 2
1	1	Group 3 Message ID			Source MAC ID						600-7bf	Message Group 3
1	1	1	1	1	Group 4 Message ID (0 – 2f)						7c0-7ef	Message Group 4
1	1	1	1	1	1	1	0	Group 5 Message ID			7f0-7f7	Message Group 5
1	1	1	1	1	1	1	1	X	X	X	7f8-7ff	Invalid CAN Identifiers
10	9	8	7	6	5	4	3	2	1	0		

Production of the new Group 5 messages is allowed even when a device is in the “Communication Faulted” state, i.e. it has failed the Duplicate MAC ID test. This allows the user to place all nodes on the network in their “out of the box” configuration, and still determine the network Nodal Geography. The Group 5 messages, triggered by the reception of the Select line Geography Request service, are consumed by network masters or network commissioning tools that have implemented the DeviceNet of Things Commissioning Object as they are produced from left to right, allowing the master or commissioning tool to determine and report the nodal geography of the network.

Once the Nodal Geography has been identified, a network commissioning tool can present the user with numerous network commissioning options using the existing node commissioning services provided by traditional DeviceNet. These options could include (but are not limited to):

- Set all MAC ID addresses sequentially, starting at a specified MAC ID number.
- Specify a starting MAC ID address for a group of nodes.
- Specify the MAC ID address of each node individually.

Group 5 “Device Key” messages contain the following information:

Figure 5: Group 5 Device Key Message Format

Byte	7	6	5	4	3	2	1	0
0	Vendor ID (low byte)							
1	Vendor ID (high byte)							
2	Device Type (low byte)							
3	Device Type (high byte)							
4	Product Code (low byte)							
5	Product Code (high byte)							
6	Major Revision							
7	Minor Revision							

Group 5 “Offline Status” messages contain the following information:

Figure 6: Group 5 Offline Status Message Format

Byte	7	6	5	4	3	2	1	0
0	MAC ID							
1	Duplicate MAC ID Faulted Status							
2	Serial Number (low byte)							
3	Serial Number (byte 1)							
4	Serial Number (byte 2)							
5	Serial Number (high byte)							

Details on how the information in the above Group 5 messages is formatted, stored and reported in attributes of the DeviceNet of Things Commissioning Object are described in the description of the object later in this document.

Select Line Protocol Basics

All DeviceNet of Things devices shall support the Select line message protocol. Figure 1 shows how the Select line connections are made in a DoT system to facilitate “Select Out” to “Select In” message delivery.

At startup, immediately after initialization, DeviceNet of Things nodes set the “Select Out” pin low, indicating to the adjacent “Select In” partner node that no system level Select line service is currently being delivered. When a message is received on the “Select In” pin, the device services the messages, and after processing of the message is complete and any actions specified in the command have been executed, the Select line message is retransmitted on the “Select Out” pin of the device, relaying the message to the next node on the network.

The following generic packet format is transmitted in a bitwise serial fashion over the Select Out pin (with the Sync Bit transmitted first):

Figure 7: Select Line Packet Format

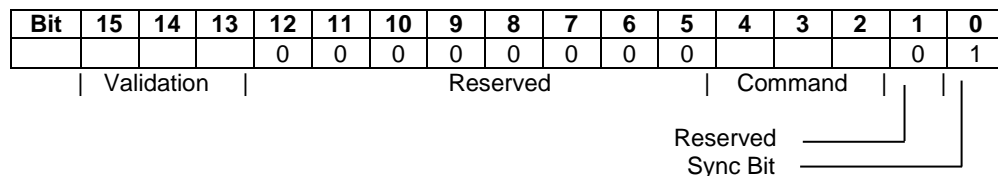
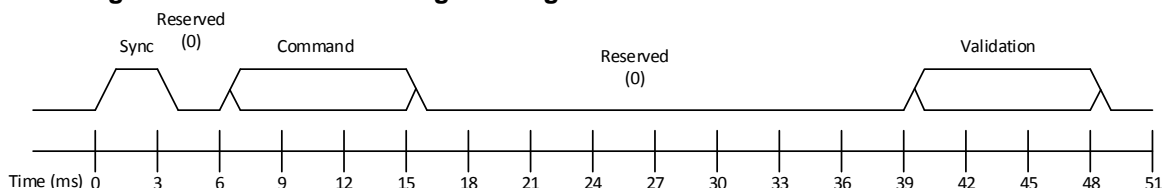


Figure 8: Select Line Packet Bit Fields

Bit	Field	Description
0	Sync Bit	This bit signals the neighboring node that a command is being transmitted.
1	Reserved	Reserved for future use and shall be 0
2 - 4	Command	Command issued.
5 - 12	Reserved	Reserved for future use and shall be 0
13 - 15	Validation	3-bit Validation = inverse of remainder of division of 12-bit quantity of Reserved/Command/Reserved fields (bits 1 – 12) by 8.

Bit timing for messages on the Select line is 3 ms per bit. Bits are left-shifted onto the wire by the transmitting node. The received (sampled) message is disqualified and ignored if it fails the Validation test.

Figure 9: Select Line Message Timing

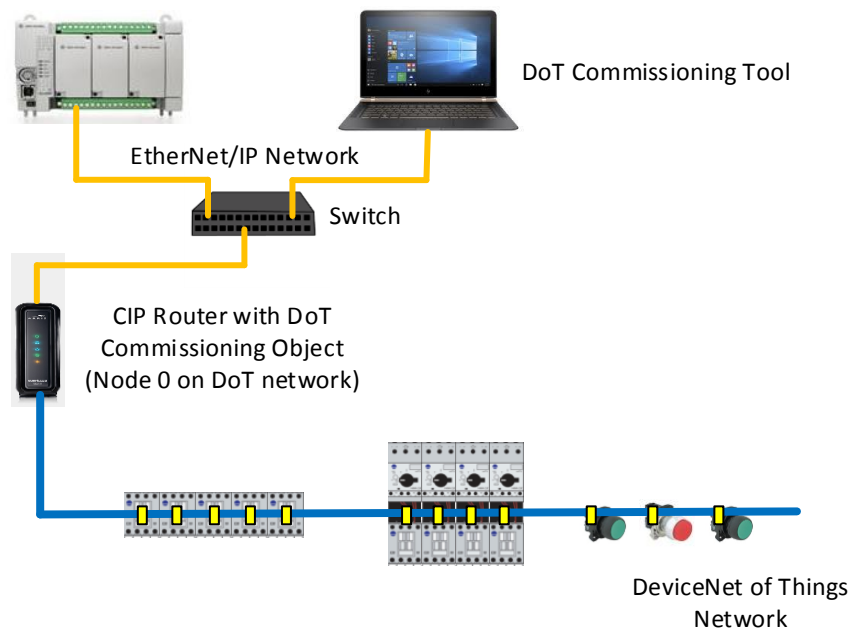


One way to easily support the Select line message transmission and reception is to use a 1ms timer interrupt within whose Interrupt Service Routine (ISR) any transmission or reception of bits via the Select Out and Select In line takes place. Since a node's timer ISR can be up to 1ms out of phase with its neighbor's, the following synchronization scheme can be used. Each bit is transmitted 3 times in the Interrupt Service Routine, resulting in each bit having 3ms on the wire. When a node first detects that a packet is being transmitted by its neighbor (by sensing a high level on the Select In pin), it waits for the next interrupt and then begins the process of storing 16 bits received every third interrupt. This guarantees that the value read will be within the middle third of each bit's transmission time. After all 16 bits have been sampled and stored, the Validation field is verified.

Three Typical DeviceNet of Things Deployment Models and the DeviceNet of Things Commissioning Object

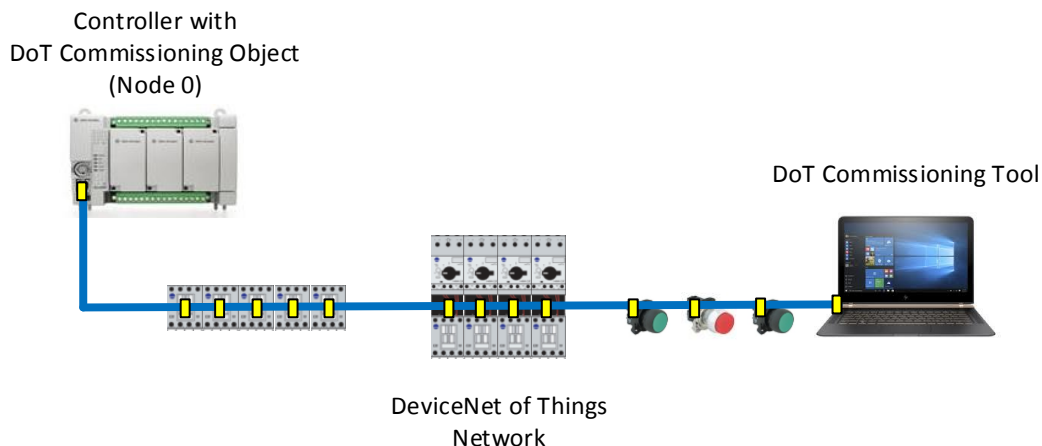
A new “DeviceNet of Things Commissioning Object” will be provided to initiate Select line services for a DeviceNet of Things network. It will also be used to capture, store and report the Nodal Geography of a network, and to facilitate node commissioning for a DeviceNet of Things network. Note that in a DoT network, “commissioning” is defined as the setting of MAC ID addresses for the nodes in a network. The DeviceNet of Things Commissioning Object may be implemented in a CIP Router device in a DeviceNet of Things subnet system to allow a commissioning tool to reside on the other side of the Router from the subnet. This configuration is shown in Figure 10 below.

Figure 10: DeviceNet of Things as a Subnet of EtherNet/IP



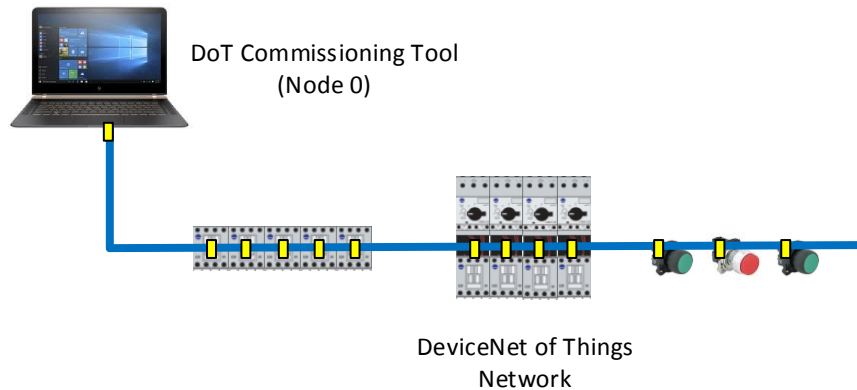
The DeviceNet of Things Commissioning Object may also be implemented in a controller that resides directly on a DeviceNet of Things network as shown in figure 11 below:

Figure 11: DeviceNet of Things in a Traditional Master/Slave Single Controller System



The DeviceNet of Things Commissioning Object may also be implemented in a commissioning tool that is meant to reside directly on a DeviceNet of Things Publish/Subscribe network as shown in figure 12 below:

Figure 12: DeviceNet of Things in a Pure Publish/Subscribe Network



The object contains instance attributes to capture and report an “Actual Nodal Geography” for the DeviceNet of Things network. In the case where the DoT Commissioning Object resides in a CIP router, the Actual Nodal Geography can be retrieved from the CIP router by a commissioning tool on the main network (for example, the EtherNet/IP network in figure 10 above). In the case where the DoT Commissioning Object resides in a controller, the Actual Nodal Geography can be retrieved from the controller by a commissioning tool on the DoT Network (as shown in figure 11 above). In the case where the DoT Commissioning Object resides in the commissioning tool, the Actual Nodal Geography can be discovered by the tool directly (as shown in figure 12).

The process of capturing an Actual Nodal Geography is requested by invoking the DoT Commissioning Object “Network_Geography_Request” service. This service triggers the object to use the Select line function to sequentially trigger the production of node identity, status and geography information (heretofore referred to as “geography information”) on the CAN lines of all DeviceNet of Things nodes. This information is consumed by the device that triggered the Select line service. The consumed Nodal Geography is then stored in the “Actual Geography” instance attributes of this object. The Actual Geography information is “read-only”.

The DoT Commissioning Object also contains instance attributes to store a “Reference” or “Desired” Nodal Geography for a DeviceNet of Things network. The “Reference Geography” information may be delivered to the “Reference Geography” attributes by writing the desired information to individual attributes explicitly. The “Reference Geography” may also be determined and stored by first invoking a “Network_Geography_Request” service to determine the Actual Nodal Geography, and then transferring the “Actual Geography” attribute data to the “Reference Geography” attributes by invoking the “Geography_Sync_Request” service. This service copies all of the information in the “Actual Geography” attributes into the “Reference Geography” attributes of this object. The Reference Geography information is stored non-volatily.

Figure 13 below summarizes the instance attributes of the DoT Commissioning Object.

Figure 13: DeviceNet of Things Commissioning Object Instance Attributes

Attribute ID	Need in Implementation	Access Rule	NV	Name	Data Type	Description of Attribute
1	Required	Get	V	Status	WORD	Status of the object Bit 0 = Reference Data Ready Bit 1 = Actual Data Ready Bit 2 = Geography Mismatch Bits 3-15 = Reserved
2	Required	Set	NV	Number of Nodes in Reference Geography	USINT	Number of nodes in the stored reference geography for the network
3	Required	Set	NV	Reference DoT Commissioning Object Node	STRUCT	Structure describing the identity of the expected device at MAC ID 0
4	Required	Set	NV	Reference First Position	STRUCT	Reference geography information for first node (position 1) on network
5	Required	Set	NV	Reference Second Position	STRUCT	Reference geography information for second node (position 2) on network
...						
66	Required	Set	NV	Reference Sixtythird Position	STRUCT	Reference Geography information for 63rd node (position 63) on network
99	Required	Set	NV	Auto Apply Reference Geography	BOOL	Enables the Auto-Commissioning of DoT network devices in a System based on the Reference Geography.
182	Required	Get	V	Actual Number of Network Nodes	UINT	Actual number of Nodes on the network
183	Required	Get	V	Actual This Node	UINT	Actual geography information for this node.
184	Required	Get	V	Actual First Position	STRUCT	Actual geography information for first node (position 1) on network
185	Required	Get	V	Actual Second Position	STRUCT	Actual geography information for second node (position 2) on network
...						
246	Required	Get	V	Actual Sixtythird Position	STRUCT	Actual geography information for 63rd node (position 63) on network

Attributes 2-66 are used to store Reference Geography information. Attributes 182-246 are used to store Actual Geography information.

Reference Geography Data

Attributes 3 through 66 each store a “Reference Node Attributes” data structure that describes a single node in the Reference Geography. Attribute 4 describes the expected first node to the right of the master (MAC ID 0), attribute 5 describes the node to the right of that, etc. The Reference Node Attributes data structure contains all of the information needed to describe a Reference Geography for a network. The data structure described in Figure 14 is used for each of these attributes.

Figure 14: Reference Node Attributes Data Structure Definition

Member ID	Name	Data Type	Description of Attribute	Semantics of Values
1	Vendor ID	UINT	Vendor ID of the Node	Identity Object Instance 1 Attribute 1 of the node. Default Value = 0
2	Device Type	UINT	Device Type of the Node	Identity Object Instance 1 Attribute 2 of the node Default Value = 0
3	Product Code	UINT	Product Code of the Node	Identity Object Instance 1 Attribute 3 of the node Default Value = 0
4	Revision	STRUCT of:		Identity Object Instance 1 Attribute 4 of the node Default Value = 0.0
		USINT	Major Revision	
		USINT	Minor Revision	
5	Serial Number	UDINT	Serial Number of the Node ¹	Identity Object Instance 1 Attribute 6 of the node Default Value = 0
6	MAC ID	UINT	MAC ID of the Node	0– 63 are valid MAC IDs Default Value = 0xFF (not configured)
7	Geography Match Keying Mask	WORD	Specifies the device keying criteria used to compare a Reference Node and an Actual Node to determine if they match	See Member 7 description below. Default = 0x17

¹. The reference node Serial Number may be set to the value consumed during a Network Geography Request operation. If a reference geography is delivered using the Set_Attribute services and an actual serial number is not known, then this attribute should be set to the Default Value of 0.

Individual Reference Numbered Position instance attribute values may be set with the Set_Attribute_Single, Set_Member or Set_Attribute_List services. This is typically done when a Commissioning Tool delivers a Reference Geography to a node with the DoT Commissioning Object at MAC ID 0.

The various Reference Numbered Position instance attribute values may also be set by a Geography_Sync_Request service which copies Actual Numbered Node attribute data to corresponding Reference Numbered Node attributes.

Member 7 “Geography Match Keying Mask” specifies the device identity criteria used to compare Reference Geography data with Actual Geography data for a node during geography compare operations. Each bit in the mask enables a comparison to be used:

- Bit 0 – Vendor ID Match: Identity Object Instance attribute 1
- Bit 1 – Device Type Match: Identity Object Instance attribute 2
- Bit 2 – Product Code Match: Identity Object Instance attribute 3
- Bit 3 – Major Revision Exact Match: Identity Object Instance attribute 4 (high byte)
- Bit 4 – Major Revision Match or Higher: Identity Object Instance attribute 4 (high byte) is <= Major Revision of the Actual Node Data
- Bit 5 – Minor Revision Exact Match: Identity Object Instance attribute 4 (low byte)
- Bit 6 – Minor Revision Match or Higher: Identity Object Instance attribute 4 (low byte) is <= Minor Revision of the Actual Node Data
- Bit 7 – Serial Number Exact Match: Identity Object Instance attribute 6
- Bits 8-15 – Reserved and shall be 0.

A bit value of 1 signifies that the match criteria for that bit should be used when comparing Reference Node Attribute data to Actual Node Attribute data for a numbered position. For example, the value 0x0F corresponds to the following bits being set:

- Bit 0 – Vendor ID Match = 1
- Bit 1 – Device Type Match = 1
- Bit 2 – Product Code Match = 1
- Bit 3 – Major Revision Exact Match = 1
- Bit 4 – Major Revision Match or Higher = 0
- Bit 5 – Minor Revision Exact Match = 0
- Bit 6 – Minor Revision Match or Higher = 0
- Bit 7 – Serial Number Exact Match = 0

When comparing Reference Node Attribute data to Actual Node Attribute data for a numbered position, a value of 0x0F means that Vendor ID, Device Type, Product Code and Major Revision of a Reference Node number must match the corresponding values in the corresponding Actual Node number.

Bit 3 and Bit 4 cannot be set at the same time. Bit 5 and Bit 6 cannot be set at the same time. If a Set service attempts to set both bits at the same time, the general status response 0x09 – “Invalid attribute value” is returned.

This member defaults to the value of 0x17.

Actual Geography Data

Attributes 183 through 246 each return an “Actual Node Attributes” data structure that describes a single node in the Actual Network Geography. Attribute 184 describes the first position to the right of the master (MAC ID 0), attribute 185 describes the node to the right of that, etc. The Actual Node Attributes data structure contains all of the information needed to describe an Actual Geography for a network. The data structure described in Figure 15 is used for each of these attributes.

Figure 15: Actual Node Attributes Data Structure Definition

Member ID	Name	Data Type	Description of Attribute	Semantics of Values
1	Vendor ID	UINT	Vendor ID of the Node	Identity Object Instance 1 Attribute 1 of the node Default Value = 0
2	Device Type	UINT	Device Type of the Node	Identity Object Instance 1 Attribute 2 of the node Default Value = 0
3	Product Code	UINT	Product Code of the Node	Identity Object Instance 1 Attribute 3 of the node Default Value = 0
4	Revision	STRUCT of:		Identity Object Instance 1 Attribute 4 of the node Default Value = 0.0
		USINT	Major Revision	
		USINT	Minor Revision	
5	Serial Number	UDINT	Serial Number of the Node	Identity Object Instance 1 Attribute 6 of the node Default Value = 0
6	MAC ID	UINT	MAC ID of the Node	0– 63 are valid MAC IDs Default Value = 0xFF (not present)
7	Duplicate MAC ID Fault Status	UINT	Duplicate MAC ID Fault Status of the Node	Network Access State Machine Communication Faulted State for the Device. 0 = Not Faulted (default) 1 = Faulted.

Automatically Applying a Reference Geography – Automatic Network Commissioning

Consider the use case where the system designer or panel builder wants to specify a network Nodal Geography, including the relative positions of each networked device in a panel and specify node addresses for each device, all before the actual network is built. Ideally, the system designer would be able to work “off-line” with a commissioning tool to design his network, and at a later time, “download” the network geography to a network master or CIP router, and have the network master or CIP router automatically check if the Actual Nodal Geography “matches” (is compatible with) the Reference Geography that was downloaded. Then if the Reference and Actual Geographies matched, automatically commission the entire network based on the information in the Reference Geography.

This use case will be supported in devices that implement the DoT Commissioning Object. Attribute 99 “Auto Apply Reference Geography” will enable the automatic invocation of the “Apply_Reference_Geography” service to the Actual network. This “Auto Apply” can effect behavior during an initial power up, after a new Reference Geography has been written to the Reference data attributes (attributes 2-66) or during a device replacement operation.

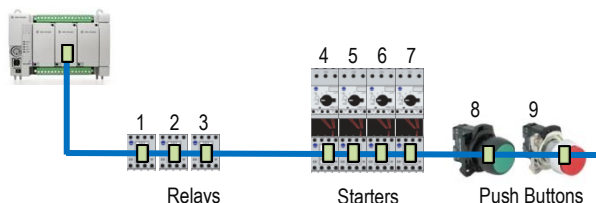
The “Auto Apply Reference Geography” operation works as follows:

After power up initialization has been completed, or after a new Reference Geography has been established, the following occurs if this attribute 99 “Auto Apply Reference Geography” is set to 1=Enabled:

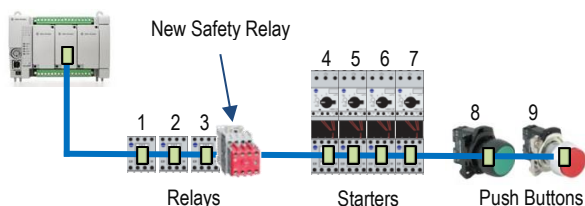
1. A Network_Geography_Request service is executed to determine the Actual Geography of the network. This service uses the Select line to trigger all devices on the wire to produce Group 5 device-identifying messages. The messages are consumed in the order that they are produced, which reflects the relative position of each device on the wire. The information is stored in DoT Commissioning Object attributes 2-66 to form the “Actual Geography” of the network.
2. The Actual Geography is compared to the Reference Geography specified in attributes 182-246 using the various Geography Match Keying Masks contained in the Reference Geography.
3. If the Actual and Reference Geographies match, the MAC IDs of all Actual Position nodes are commissioned to match the MAC IDs specified in their corresponding Reference Numbered Position attributes. For faulted nodes, this is done using the Group 4 Faulted Node Recovery protocol. For nodes that are not faulted, this is done by setting the MAC ID (attribute 1) of the DeviceNet Object.
4. After all nodes have been commissioned, the “Geography Mismatch” bit (bit 2) in the Attribute 1 (Status) is cleared

Flexible Addressing – Not Auto-Addressing

Traditional auto-addressing schemes limit address assignment to sequential addressing exclusively. In real applications it is quite common in the life cycle of a system to add a node to the network, but not want to affect the node addresses of the existing nodes in the cabinet. Consider the following system:

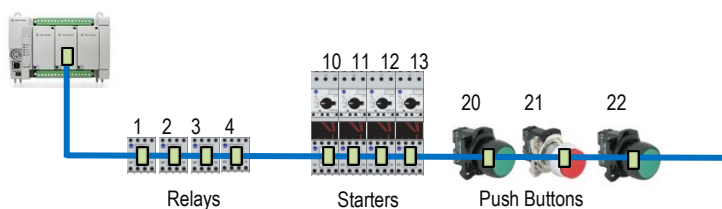


Suppose a new safety relay is be added to the cabinet as shown below.

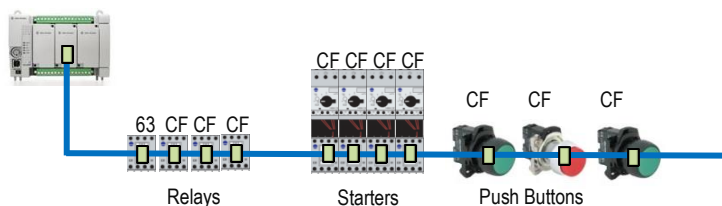


In this example, use of traditional sequential auto addressing is not desirable since it would bump the node addresses of all of the nodes to the right of the new safety relay (the starters and push buttons) and probably break the existing logic in the controller as a result. In this case, a traditional DeviceNet node addressing method (for example, writing to the MAC ID attribute of the DeviceNet Object), perhaps coupled with nodal geography discovery and display is more appropriate.

Now consider the case where a machine designer needs to incorporate varying numbers of each type of device in a “base system” but would also like to be able to add optional devices to the base design without affecting the basic machine design and controller logic. The example below shows such a system with all relays addressed left to right starting at MAC ID 1, all starters addressed left to right starting at MAC ID 10, and all push buttons addressed left to right starting at MAC ID 20. This way the machine designer could add an optional relay at MAC ID 5 without affecting the starter or push button device node addresses in his base system.



To accomplish this, the machine builder could connect all of the nodes in his system in their “out of the box” state (MAC ID 63). On initial power up, all but one of the nodes will fail the Duplicate MAC ID Check and enter the “Communication Faulted” state. The faulted nodes in the figure below are denoted by “CF”.



A DeviceNet of Things commissioning tool would initiate a network geography discovery operation and display the Actual Geography shown above. Since many of the nodes are in the “Communication Faulted” state, the commissioning tool would need to use the “Group 4 Offline Connection Set” described in Volume 3 Section 2-11 to recover and set the MAC IDs of the faulted nodes. Setting MAC IDs in Group 4 is done by connecting to nodes by specifying Vendor ID and Serial Number. This information is contained in the Group 5 “Offline Status” messages that are produced by each node during the node geography discovery sequence. These messages contain the Vendor ID, Communication Faulted Status and Serial Number for the network nodes.

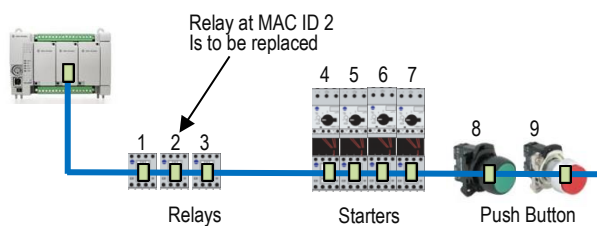
When the network geography discovery operation has run to completion, the commissioning tool has all of the information it needs to individually connect to and address each “Communication Faulted” node on the network individually using the Group 4 Offline Ownership protocol, and the Group 4 Communication Faulted protocol.

Automatic Device Replacement and Geographic Device Keying

It is common for system maintenance personnel to replace system components in a panel. Many DeviceNet systems today implement an “Auto Device Replacement” feature where the replacement of a removed device with a like device with compatible identity keys can be accomplished automatically. In these systems, the new replacement device is connected to the network at its default node address of 63. When the network master sees the replacement device at node 63 come on-line, it sets the replacement device’s MAC ID to that of the original device and downloads stored configuration data to the device so that no intervention is needed from the maintenance personnel to commission or configure the new device.

The replacement of a node with a compatible device on a DeviceNet of Things network will include the ability to check that the replacement device was placed on the network at the same geographic position as the original device before the “Auto Device Replacement” feature is triggered, effectively adding a new and important device keying criteria.

Consider the following system where the contacts in the relay at node address 2 weld closed, and the relay must be replaced.

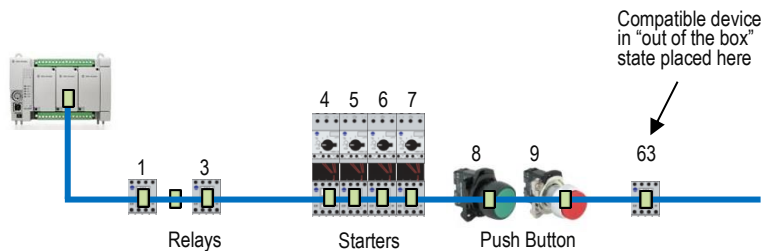


If “Auto Apply Reference Geography” is enabled in the DoT Commissioning Object in the network master device, the following sequence would be initiated”

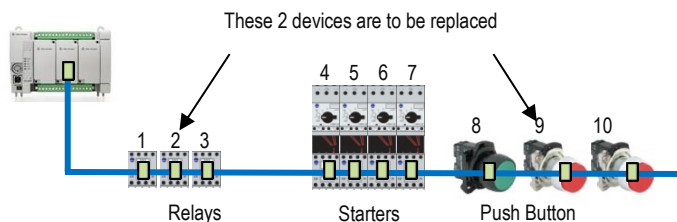
1. When the disappearance of a node specified in the Reference Geography is detected,
AND
2. A new node comes on-line, i.e. a Duplicate MAC ID Request message is detected on the network, a Network_Geography_Request service is executed to establish the new Actual Geography of the network.
3. If the newly detected node is found to be at the same geographic position as the node that dropped off the network, the Geography Match Keying Mask is used to determine if the newly detected node is compatible with the Reference Position node. If it is, the MAC ID of the new node is set to the Reference Position MAC ID. If the new node is found to be incompatible, no action is taken.

4. Optionally, the master device could automatically download a complete saved device configuration to the new device. All of this could be done without any user intervention.

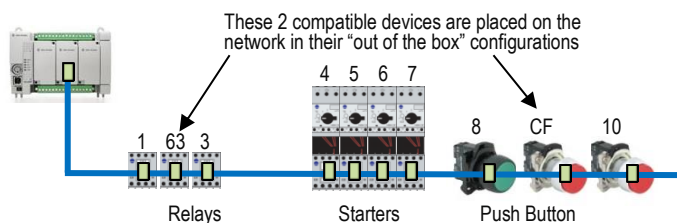
But if the user removes node 2 and places a compatible relay to the right of the push button at MAC ID 9, a Nodal Geography Discovery operation would point out that a compatible node that was installed on the network is geographically located at a different position on the wire than the original device at MAC ID 2. If the Auto Device Replace operation requires a geographic location match and a compatible device keying match, it would do nothing. If, however, the compatible relay had been placed on the network between MAC ID 1 and MAC ID 3, then an Auto Device Replace operation would be performed.



An extension of the device replacement use case would be to consider a system where multiple nodes at various network locations are to be replaced at the same time. Consider the following system where the relay at MAC ID 2 and the push button at MAC ID 9 need to be replaced.

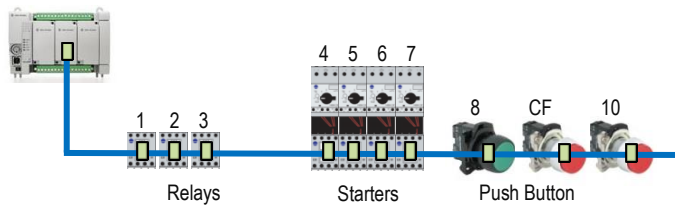


The user could first replace the 2 devices on the network with 2 compatible devices and locate them in the same geographic position that they were originally in.

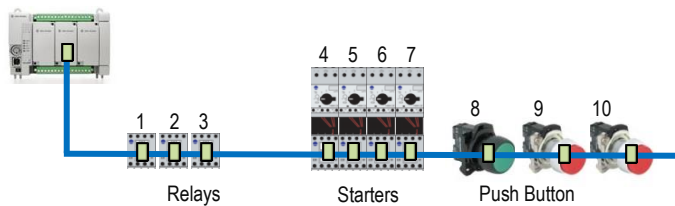


A "Discovery of Nodal Geography" operation would reveal that a compatible relay had been placed on the network between nodes 1 and 3 at MAC ID 63, and that a node has been placed between nodes 8 and 10, but in this example the node would enter the Communication Faulted state since the new relay would defend MAC ID 63 when the new push button broadcasts its Duplicate MAC ID Request message on power up.

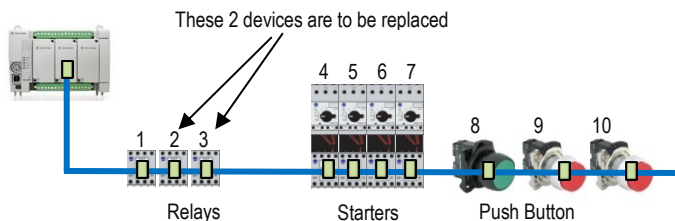
The master device could first perform an “Auto Device Replace” operation on the relay located between MAC IDs 1 and 3 resulting in the following network nodal geography:



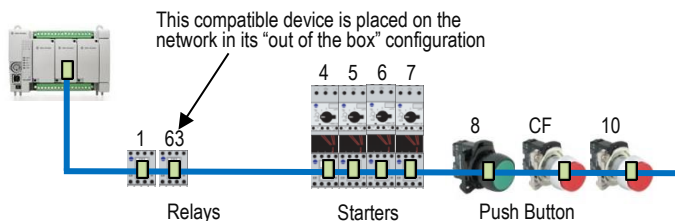
Then the master could use the Group 4 faulted node recovery protocol to set the faulted pushbutton's node address to 9. Finally, the master device could complete the “Auto Device Replace” operation on the push button located between MAC IDs 8 and 10 resulting in the following network nodal geography:



Now consider the following system where the relays at MAC IDs 2 and 3, which have the same device keying, are to be replaced.

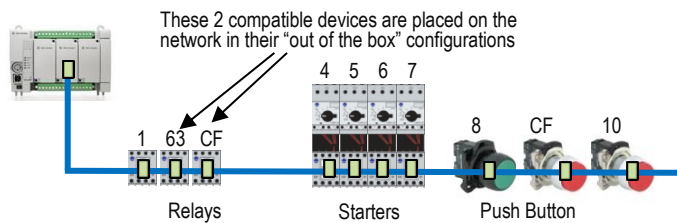


The user places a single new relay devices on the network with compatible device keying and locates it to the right of node 1.

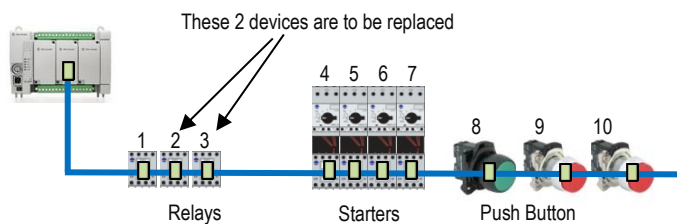


A discovery of nodal geography operation would reveal that a compatible relay had been placed on the network between nodes 1 and 4 at MAC ID 63. But there is no way to determine if this new node should replace the old node 2 or 3, thus no Auto Device Replace operation would be initiated.

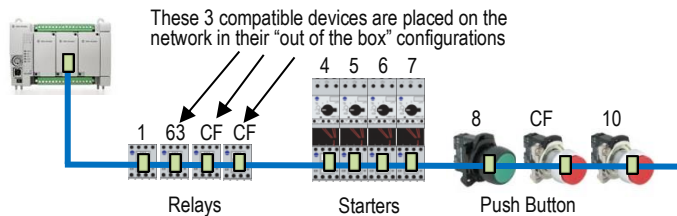
But if the user replaces the 2 devices on the network with 2 compatible devices and locates them in the same geographic position that they were originally in, there is nothing that would prevent the system from automatically replacing both devices.



Finally, consider the following system where the relays at MAC IDs 2 and 3, which have the same device keying, are to be replaced.



The user replaces the 2 devices on the network with 3 compatible devices and locate them geographically between nodes 1 and 4.

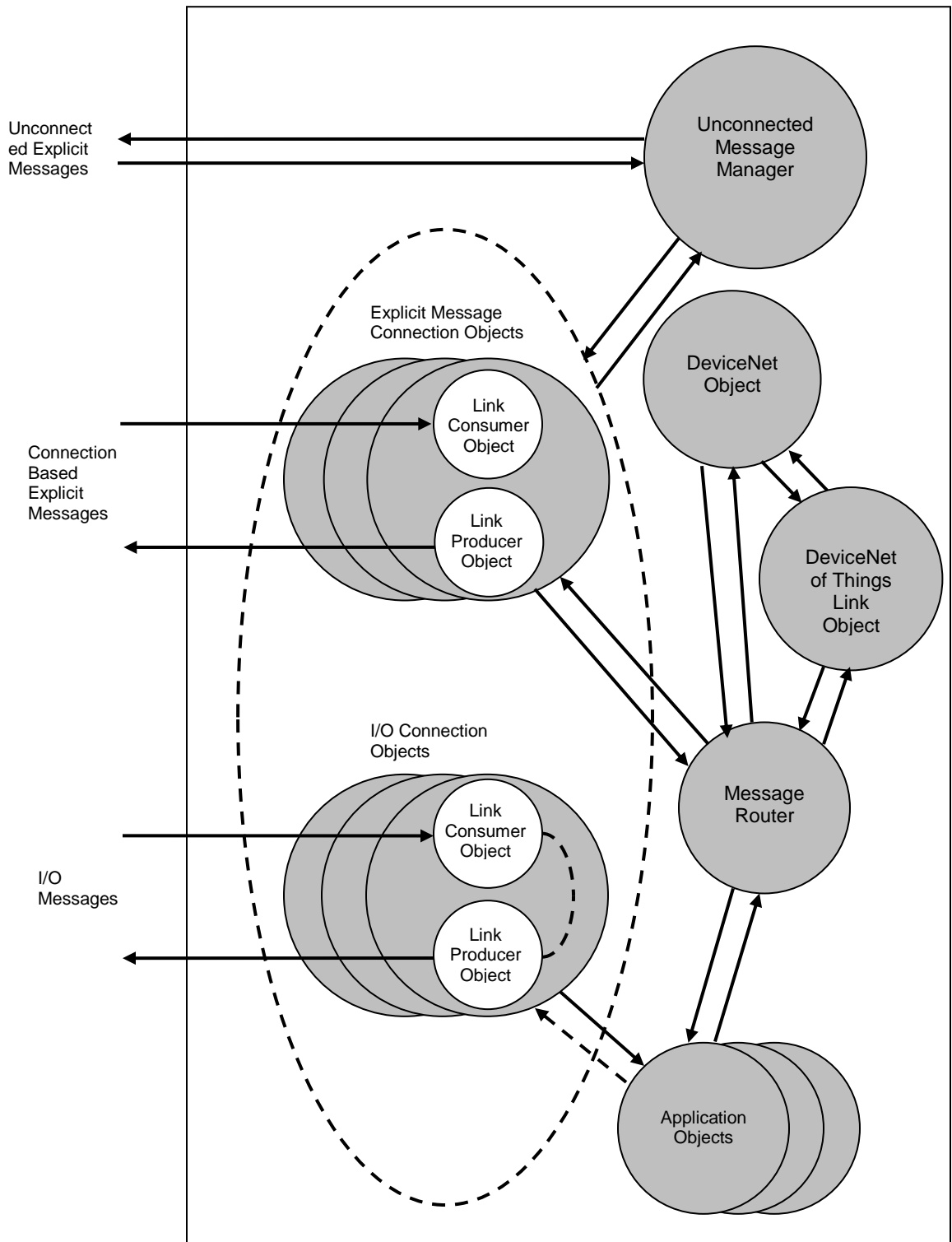


A discovery of nodal geography operation would reveal that 3 compatible relays had been placed on the network between nodes 1 and 4. But there is no way to determine which of these 3 nodes should replace the old node 2 or 3, thus no Auto Device Replace operation would be initiated.

DeviceNet of Things Object Model

The following figure illustrates the abstract object model of a DeviceNet of Things product. All components of the DeviceNet object model are present, and a DeviceNet of Things Link Object is added to the model to indicate that the Select line sequential service delivery feature for DeviceNet of Things devices is supported. The inclusion of an instance of the DeviceNet of Things Link Object in a device is what classifies it as a DeviceNet of Things device and not a traditional DeviceNet device.

Figure 16: DeviceNet of Things Device Object Model



DeviceNet of Things Power Architecture

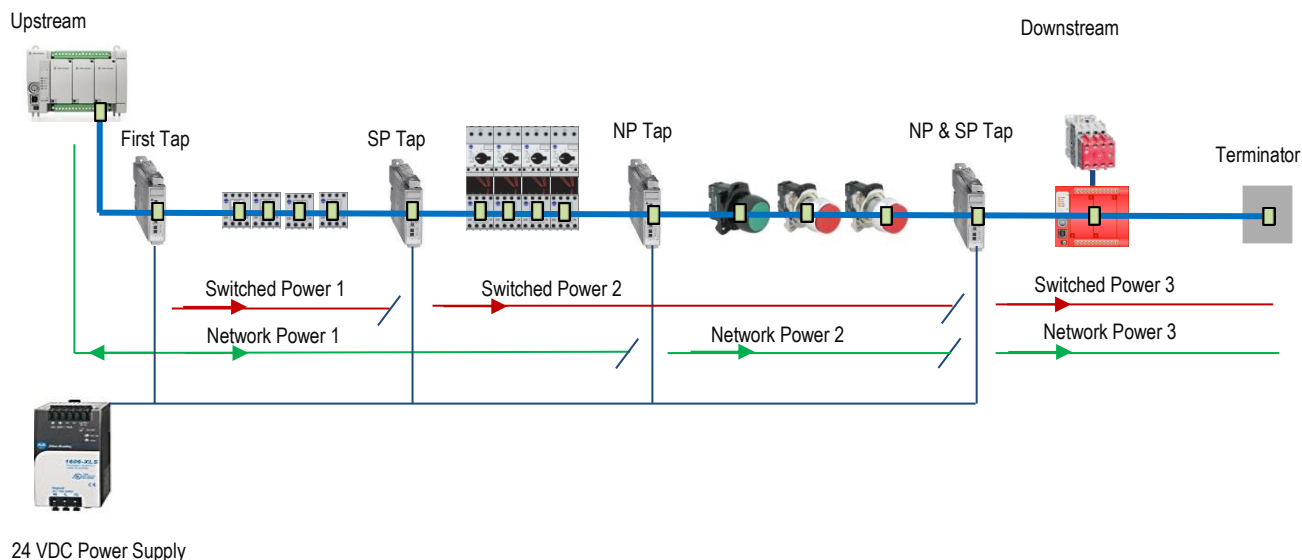
Three key requirements drive the DeviceNet of Things power architecture design:

1. Commercially available “off-the-shelf” power supplies must be allowed.
2. Both Network and Switched power must be delivered.
3. It must be possible to size a single power supply for a system and use “Power Taps” to distribute power for the network.

The DeviceNet of Things media will be rated for 4Amps. In many systems, the number of devices on the network would cause the 4 Amp limit on Network and/or Switched power to be exceeded. For example, the high inrush current needed to actuate many commercially available contactor coils might limit the number of motor starters that can be placed on the wire before the 4 Amp limit is reached. To address this problem, a Power Tap architecture with four types of power taps has been defined. The Power Taps will serve to segment the power delivered to the network media. Figure 17 illustrates the four possible types of Power Taps that would be needed for DoT networks:

1. A First Tap (the leftmost Tap in Figure 17)
2. A Switched Power Tap (SP Tap in Figure 17)
3. A Network Power Tap (NP Tap in Figure 17)
4. A Network and Switched Power Tap (NP & SP Tap in Figure 17)

Figure 17: DeviceNet of Things Power Tap Types



The First Tap will generally be the first device downstream from Node 0 (the Master or CIP Router). It will need to inject Network Power both upstream (to power the Master or CIP Router) and downstream (Network Power segment 1 in Figure 17). The First tap will also need to inject Switched Power downstream (Switched Power segment 1 in Figure 17). Generally, the Master or CIP Router will not need Switched Power delivery.

A Switched Power Tap (SP Tap) will allow Network Power to be continuous through the tap, but will break the Switched Power + conductor allowing fresh 24 VDC power to be injected, forming a new Switched Power segment (Switched Power segment 2 in Figure 17).

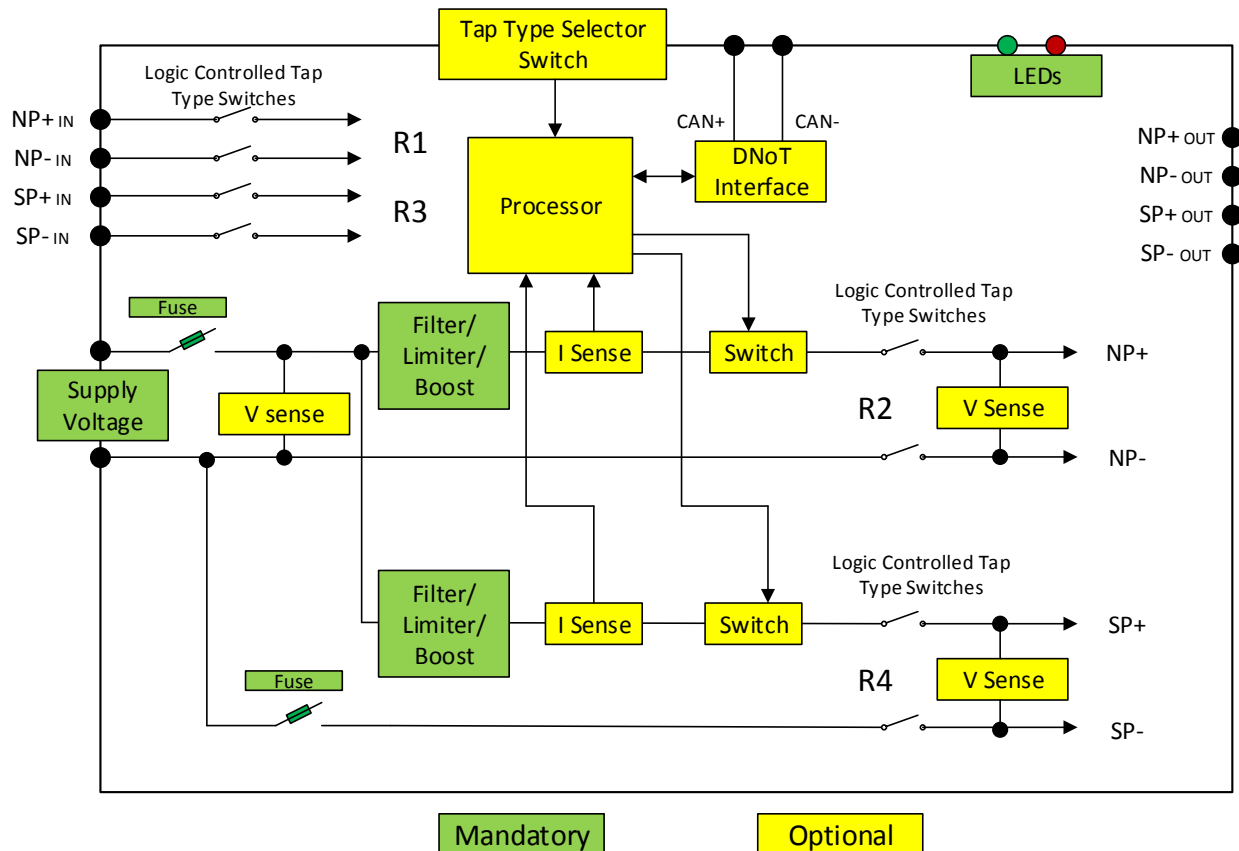
A Network Power Tap (NP Tap) will allow Switched Power to be continuous through the tap, but will break the Network Power + conductor allowing fresh 24 VDC power to be injected, forming a new Network Power segment (Network Power segment 2 in Figure 17).

A Network and Switched Power Tap (NP & SP Tap) will break both the Network Power + conductor and the Switched Power + conductor allowing fresh 24 VDC power to be injected, forming a new Network Power segment (Network Power segment 3 in Figure 17) and a new Switched Power segment (Switched Power segment 3 in Figure 17).

Adjustable Smart Power Taps

Rather than offer separate catalog numbers for the 4 Power Tap types, an Adjustable Smart Power Tap design can be considered. Figure 18 shows a block diagram for such a tap.

Figure 18: Adjustable Smart Power Tap Types



The tap would include 4 sets of switches (R1 – R4 in Figure 18) to either inject new power from the Supply Voltage to create a new power segment, or bypass the Supply Voltage to allow continuous power through the tap. The R1 – R4 switch settings are controlled by a “Tap Type Selector Switch” to determine the tap type. Figure 19 summarizes how the switches would operate.

Figure 19: Adjustable Smart Tap Configuration

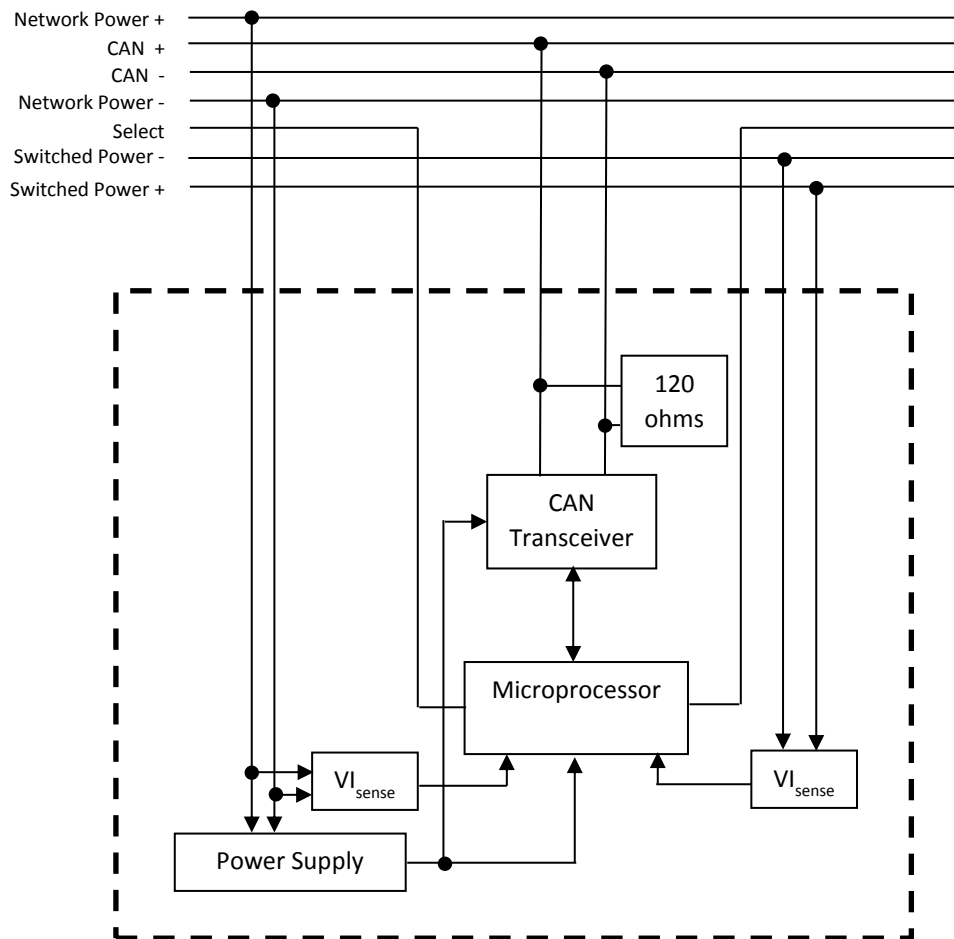
Switch	First Tap	SP Tap	NP Tap	SP & NP Tap	Description
R1 (NP Bypass)	On	On	-	-	Connects NP _{IN} to NP _{OUT}
R2 (NP Inject)	On	-	On	On	Connects Voltage Supply to NP _{OUT}
R3 (SP Bypass)	-	-	On		Connects SP _{IN} to SP _{OUT}
R4 (SP Inject)	On	On	-	On	Connects Voltage Supply to NP _{OUT}

Smart Taps, Smart Terminators and Network Infrastructure Diagnostics

Many common field problems encountered when deploying traditional DeviceNet are related to Network Power supply sizing problems and improper network termination. The introduction of “smart” networked components that have traditionally been passive (non-networked) in nature can provide useful network diagnostic data to the user. Referring back to Figure 18, the smart power tap includes a microprocessor and a DeviceNet of Things network interface. This allows the power tap to report diagnostic information such as CIP energy data for each power segment. This information can be used to inform the user when the current being drawn by the devices in a power segment is nearing or exceeds the current rating of the network media. At a system level, smart tools can be developed that know the current and power draw of the individual devices on a network and suggest to the user how to segment the Network and Switched Power for his system. Since smart power taps can participate in the discovery of the Actual Network Geography, the user can be informed of potential problems with his power segmentation in an actual system.

The improper termination of DeviceNet network media is a common problem in the field. Since the cost of implementing a simple DeviceNet of Things node will be small (Cortex M0+ microprocessors with ample on-board Flash, RAM, CAN and other peripherals are available for less than \$1 and the cost of the physical layer interface will be reduced for DoT), it makes sense to provide “Smart Terminators”. Figure 20 illustrates a block diagram for a DoT Smart Terminator. Since Smart Terminators can participate in the discovery of the Actual Nodal Geography, the user can be informed when his network is not terminated properly. Note that in the network depicted in Figure 17, only 1 terminator is shown. This is because the DeviceNet of Things will require devices that implement the DeviceNet of Things Commissioning Object to include a 120 ohm terminating resister in the device. This can be done because these devices must be placed as the first device on the network at MAC ID 0.

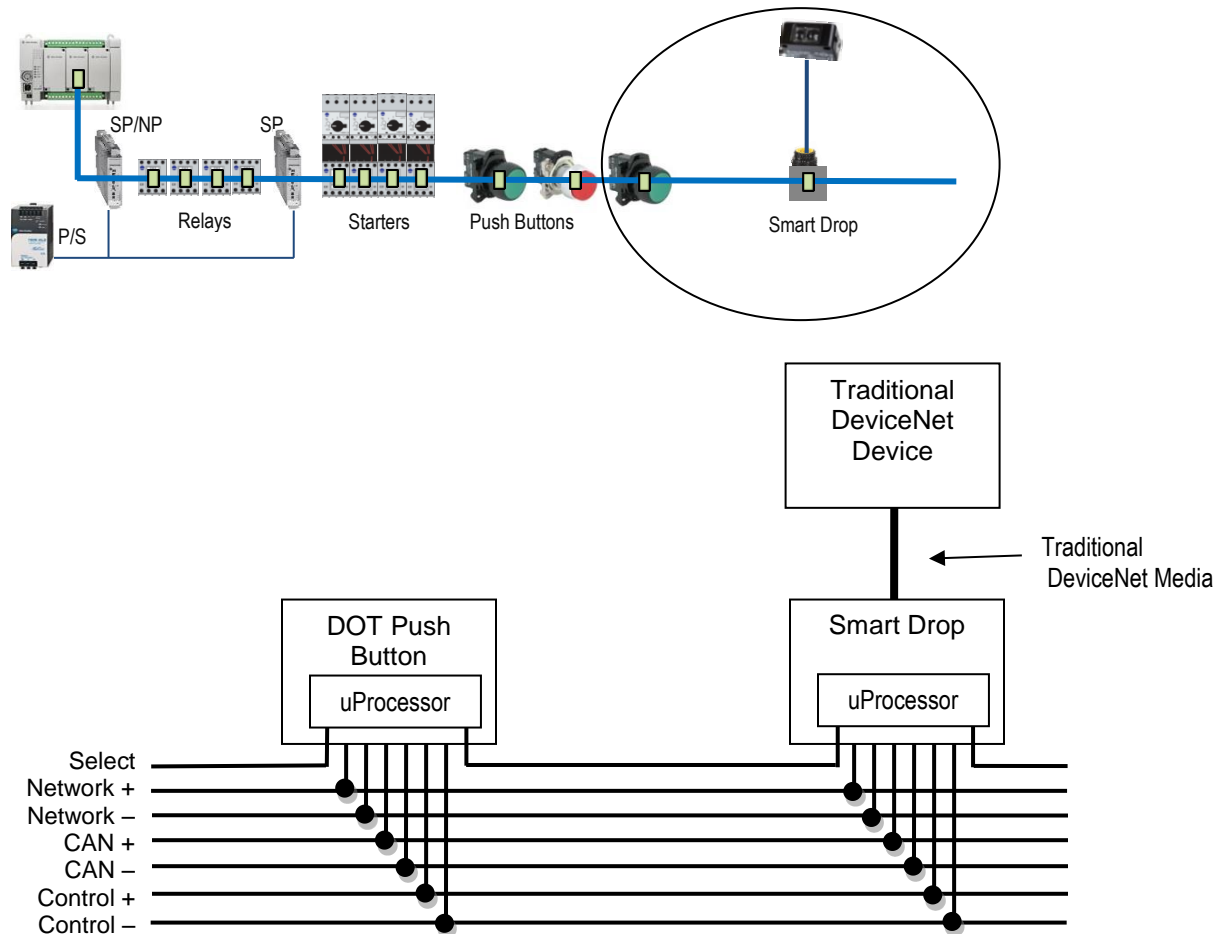
Figure 20: Smart Terminator



Smart Drops – Extending DeviceNet of Things Functionality to Existing DeviceNet Devices

DeviceNet is a mature network with a large number of devices available from a variety of vendors. In order to protect the investment that vendors have made and offer a simple path to extending the functionality of the existing product portfolio, a “Smart Drop” device could be developed. The Smart Drop would allow traditional devices to participate in DeviceNet of Things Select line and Group 5 messaging. A Smart Drop would mainly act as simple DeviceNet to DeviceNet router. The DeviceNet of Things side of the router would occupy a node address on the DeviceNet of Things network and would be able to participate in Select line services and produce Group 5 messages. Messages to be routed to and from the traditional DeviceNet device would be passed through the Smart Drop and be readdressed with the appropriate MAC ID as needed. If no traditional DeviceNet device is connected to the Smart Drop it would participate on the network as a node of type “Network Adaptor” and report its own Identity Object keys. Figure 21 below depicts such a device.

Figure 21: Smart Drop



This approach would not affect the DeviceNet of Things media length budget since the drop to the traditional device is a separate point to point DeviceNet network.

The DoT SIG and Specification Enhancement Status

The ODVA DeviceNet or Things SIG mission statement states the following:

The Special Interest Group for DeviceNet of Things ("SIG") seeks to expand the adoption of DeviceNet to low cost, simple industrial devices that today typically are hardwired in the command-control and communication architecture found in today's automated plant. In the long term, this will help to accelerate the adoption of Ethernet/IP by expanding the application of the Common Industrial Protocol to new devices that, for the foreseeable future would not otherwise be able to be included in the Ethernet/IP architecture, because the cost of Ethernet connectivity remains too high. The result will be the availability of a complete and seamless CIP network architecture from the simplest low cost devices to the higher level supervisory systems and that reduces the user's total cost of owner for the automation architecture.

In support of this mission, the SIG has approved the following specification enhancements and forwarded them to the System Architecture SIG for review:

- DSE 0001-115 DeviceNet of Things Overview including:
 - An overview of work items for the SIG
 - Additions to Volume 3 Chapter 1 DeviceNet Adaptation of CIP.Feedback from the System SIG is pending.
- DSE 0001-114 DeviceNet of Things Objects including:
 - Volume 3 Chapter 2 protocol updates related to Group 5 and Select Line messaging
 - Volume 3 Chapter 5 updates to the DeviceNet Object
 - Volume 3 Chapter 5 additions to define the DeviceNet of Things Link Object and the DeviceNet of Things Commissioning Object.
 - Volume 3 Chapter 7 EDS file definition updatesFeedback from the System SIG has been received, updates are complete, forwarded back to the System SIG for further review.
- CIPSE 0001-252 DeviceNet of Things Hooks including:
 - Volume 1 Chapter 5 and Chapter 7 tweaks in support of the DeviceNet of Things.Feedback from the System SIG has been received, updates are complete, forwarded back to the System SIG for further review.
- CIPSE 0001-256 Pushbutton Portfolio Profile
 - Adds a new device profile to support Pushbuttons, Selector Switches and Pilot Light indicators to Volume 1 Chapter 6Feedback from the System SIG is pending.

Also in support of our mission, the DoT SIG has engaged the DeviceNet Physical Layer SIG to define the needed specification enhancements to support the new media, connector and power supply requirements. The following specification enhancement is being prepared:

- DSE 0798-001 DeviceNet of Things Physical Layer

Further related specification enhancement work to support new low-end devices for the DeviceNet of Things is being done in the ODVA Motor Control and Circuit Breaker SIG, most notably:

- CIPSE 0001-257 Circuit Breaker Profile
 - Adds a new device profile to support Circuit Breakers to Volume 1, Chapter 6
- CIPSE 0001-258 Circuit Breaker Objects
 - Adds a new Circuit Breaker Supervisor Object definition to Volume 1, Chapter 5
- Various other CIPSEs to better support component based motor starters and other devices in the ODVA Hierarchy of Motor Control Devices.

The DeviceNet of Things SIG will continue its work as follows:

- Define a Power Tap device profile.
- Define a Smart Terminator profile.
- Look into the development of other new device profiles as needed.
- Produce a DeviceNet of Things Conformance Test Specification.

References

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2. ODVA, THE CIP NETWORKS LIBRARY, Volume 3, DeviceNet Adaptation of CIP, Edition 1.14, November 2013
3. Rockwell Automation, Auto device replacement (ADR) –1769-SDN Compact I/O DeviceNet Scanner Module User Manual – Publication 1769-UM009E-EN-P, August 2009
4. John Harmon, 6 DeviceNet Sins Not to Repeat with EtherNet/IP, Sensortech, May 19, 2010

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