ControlNet
ODVA

TECHNOLOGY OVERVIEW SERIES

CIP on CTDMA Technology

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ControlNet™ -
CIP on CTDMA Technology

ControlNet™ is a serial communication system for communication between devices that wish to exchange time-critical application information in a deterministic and predictable manner. ControlNet is a member of a family of networks that implements the Common Industrial Protocol (CIP™) at its upper layers. CIP encompasses a comprehensive suite of messages and services for a variety of manufacturing automation applications, including control, safety, synchronization, motion, configuration and information. As a truly media-independent protocol that is supported by hundreds of vendors around the world, CIP provides users with a unified communication architecture throughout the manufacturing enterprise.

With media independence comes the ability to choose the CIP Network best suited for each application. One of these possible choices is ControlNet, which adapts CIP to Concurrent Time Domain, Multiple Access (CTDMA) Technology. Why adapt CIP to CTDMA? CTDMA allows for users to achieve deterministic, high-speed transport of I/O and peer-to-peer interlocks in applications that are time-critical.

ControlNet offers several unique advantages for manufacturing automation applications:

- Comprehensive producer-consumer services let you simultaneously control, configure and collect data from intelligent devices over a single network;
- Deterministic, repeatable performance for both discrete and process applications;
- Flexible topology options, including trunkline-dropline, ring, star, tree and combinations there of using repeaters;
- Ability to remove and replace nodes under power at any point on the network;
- Intrinsically safe options available that meet various EU, CENELEC, UL and FM certifications for use in potentially explosive atmospheres;
- Duplicate Node ID detection;
- Multiple media types, including coaxial and fiber, including RG-6 quad shield cable, which is inexpensive and used widely in the cable TV industry;
- Optional media redundancy that transparently allows higher system availability; and
- Support for up to 99 nodes, and a bus speed of 5 Mbits per second.

Here's a more in-depth look at the technology behind every ControlNet-compliant product.

What is ControlNet?

ControlNet, like other CIP Networks, follows the Open Systems Interconnection (OSI) model, which defines a framework for implementing network protocols in seven layers: physical, data link, network, transport, session, presentation and application. Networks that follow this model define a suite of network functionality from the physical implementation through the application or user interface layer. As with all CIP Networks, ControlNet implements CIP at the Session layer and above while adapting CIP to the ControlNet technology at the Transport layer and below. This network architecture is shown in Figure 1.

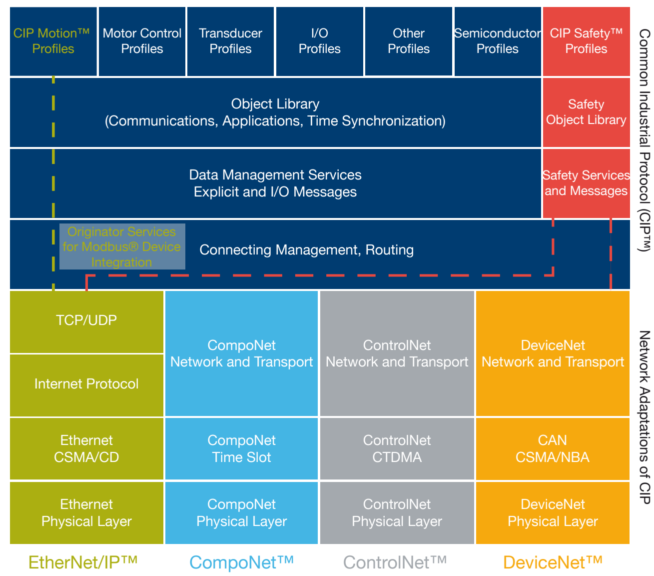

Figure 1: ControlNet as Part of the CIP OSI Model

ControlNet is a digital network that provides high-speed transport of time-critical I/O and messaging data - including upload/download of programming and configuration data and peer-to-peer messaging - on a physical media link. Each device and/or controller is a node on the network. The ControlNet network infrastructure is passive, making node functionality independent of physical location and the network inherently tolerant to node connections.

To further decrease complexity, ControlNet systems require a point of connection for both configuration and control. This is because ControlNet supports I/O (or implicit) messages—those that typically contain time-critical control data—and explicit messages—those in which the data field carries both protocol information and specific service requests. As a producer-consumer network that supports multiple communication hierarchies and message prioritization, ControlNet provides efficient use of bandwidth than a device network based on a source-destination model. ControlNet systems can be configured to operate either in a centralized or distributed control architecture using peer-to-peer communication. ControlNet's time-based message scheduling mechanism provides devices with deterministic and predictable access to the network while preventing network collisions. This scheduling mechanism allows time-critical data, which is required on a periodic, repeatable and predictable basis, to be produced on a predefined schedule without the loss of efficiency associated with continuously requesting, or "polling," for the required data.

The Physical Layer

ControlNet offers users a choice of network topologies and physical media. The variants in topology are shown in Figure 2. Multiple topologies and media types can be mixed within one system. End-to-end network length varies based on the number of nodes, type of media and use of repeaters, as shown in Table 1.

Media	2 Nodes	32 Nodes	48 Nodes	49-99 Nodes
Coax	1000 m (3280 ft)	500 m (1520 ft)	250 m (820 ft)	requires repeaters
Fiber	Depends on repeater capability, fiber and termination quality			
Coax or Fiber with Repeater	Depends on number of repeaters, repeater capability, fiber and termination quality			
Maximum Drop Length	1 m (3.3 ft)	1 m (3.3 ft)	1 m (3.3 ft)	1 m (3.3 ft)

Table 1: End-to-end network distance based on cable media

When a coax cable media is chosen, ControlNet uses RG-6 quad shield coax cable, the same standard cable that is used in the cable TV industry. This coax cable is inexpensive, readily available and has high noise immunity. Several types of outer jackets are available (plenum, high flex, armor) to meet any application or environmental requirement.

Connectors are standard BNC-type for IP20 applications and TNC-type for IP67 applications where dust, dirt and/or liquids are present. Two 75-W termination resistors are required: one on each end of the cable to limit the reflections from transmitted signals on the trunkline.

A passive tap is required for every permanent node on the network. Custom taps for ControlNet can be rail-mounted and easily connected to the ControlNet trunk cable. Taps are available in different styles, including straight, right angle and "Y." Although the taps must be installed while the network is powered-down, they allow devices to be added or removed while the network is powered. Taps may be installed anywhere along the ControlNet trunk cable, with no minimum separation distance. A 1m drop line from the tap to the device is standard. Transformer coupling is utilized in each node to provide electrical isolation.

When a fiber optic media is chosen, ControlNet incorporates a full-duplex, point-to-point fiber link using a transmitter and receiver at each end of a pair of fibers. The fiber characteristics are shown in Table 2.

Specification	Short Range (300 m)	Medium Range (3000 m)
Fiber Technology	Step index, hard clad silica (HCS)	Graded index, multi-mode
Core/Cladding	200/230 um	62.5/125 um
Numerical Aperture	0.5	0.275

Table 2: Fiber characteristics

Redundant cable media is a ControlNet option that allows all messages to be transmitted simultaneously on both cable paths. Each node evaluates signal quality, and the best quality signal is chosen dynamically.

In addition to its ControlNet port for control and information, each ControlNet node has a network access port that makes it possible for a computer or other support tool to plug into the network and communicate with any other device on the network. The network access port uses a standard 8-pin, RJ-45 connector.

Repeaters may be used to increase end-to-end network lengths and the number of nodes per segment. They may also be used to connect coax to fiber cables for increased noise immunity or greater distance. For a given system, the maximum number of repeaters will be limited by the propagation delay introduced by the repeater. When determining the maximum number of repeaters and/or the maximum distance capabilities of the system, the individual propagation delays (media, taps and repeaters) must total less than 120 microseconds between the two furthest points on the network.

Intrinsically safe options are available through vendor implementations of ControlNet products that meet various EU, CENELEC, UL and FM certifications for use in potentially explosive atmospheres.

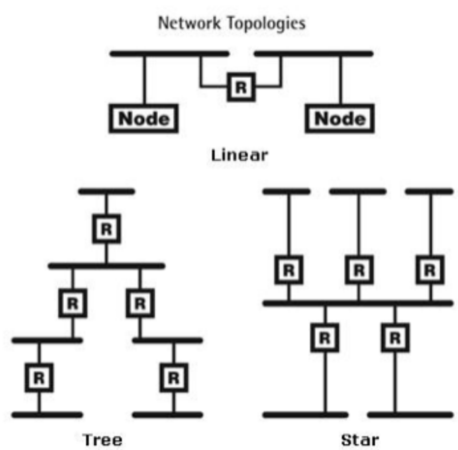

Figure 2: ControlNet Topology Options

The Data Link Layer

ControlNet uses a Concurrent Time Domain, Multiple Access (CTDMA) algorithm to ensure the precise time for message delivery. This protocol is based on a fixed, repetitive time cycle called a Network Update Time (NUT), as shown in Figure 3.

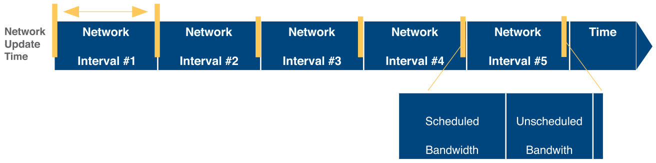

Figure 3: The CMDT algorithm´s NUT ensures precise time for message delivery.

The NUT can be configured for a duration ranging from 2 to 100 milliseconds. Each node contains its own timer synchronized to the NUT for the local link. Media access is determined by local subdivision of the NUT into access slots based on node number. Each NUT is divided into three major parts: scheduled, unscheduled and guardband, and this sequence is repeated in every NUT.

Users select NUT parameters with a network configuration tool. These parameters are distributed to all nodes via the moderator, which is the node with the lowest MAC ID on the link. The network parameters are broadcast during the guardband portion of the bandwidth. ControlNet's network synchronization method assures that no node will transmit on the medium with parameters that do not agree with those currently in use. Different links (joined by bridges) may have different NUT durations and network parameters, and will have their own moderators.

The Network and Transport Layers

ControlNet uses two forms of messaging:

- **Unconnected messaging** is used in the connection establishment process and for infrequent, low-priority messages. Unconnected messages always use the unscheduled bandwidth, and the unconnected resources in a device are referred to as the Unconnected Message Manager, or UCMM. To receive a Declaration of Conformity, ControlNet products are required to implement a UCMM to receive requests from other devices.

- **Connected messaging** on ControlNet utilizes resources within each node that are dedicated in advance to a particular purpose, such as frequent explicit message transactions or real-time I/O data transfers. Connection resources are reserved and configured using communications services available via the UCMM.

The process of opening a connection is called Connection Origination, and the node that initiates the connection establishment request is called a Connection Originator, or just an Originator. Conversely, the node that responds to the establishment request is called a Connection Target, or a Target.

ControlNet has two types of messaging connections: explicit and implicit (I/O data). Explicit messaging connections are point-to-point relationships that are established to facilitate request-response transactions between two nodes. These connections are general purpose in nature and can be used to reach any network-accessible items within a device. Explicit messaging connections utilize unscheduled services on ControlNet.

Implicit connections, on the other hand, are established to move application-specific I/O data at regular intervals. These connections are multicast in nature, and often are set up as one-to-many relationships in order to take full advantage of the producer/consumer model. Implicit connections utilize scheduled services on ControlNet, providing highly deterministic transfer of data.

ControlNet supports three device classes based on network communication capabilities: Messaging Class, Adapter Class and Scanner Class. Each class supports a basic set of communications services, but may provide other optional services too.

Messaging Class products support unscheduled explicit messaging (connected or unconnected) that is sent or received from all other classes of products. Messaging Class products are the targets of explicit message connection requests, and may also be an originator of these requests, but they cannot send or receive scheduled, real-time I/O data.

Examples of products in this class include:

- Computer interface cards for program upload and download to HMI products, robots and PLCs;
- Computer interface cards or other hardware that supports HMI applications that gather data from control systems (i.e., MIS);
- Software applications that do not require real-time I/O response; and
- Network configuration and diagnostic tools.

Adapter Class products are the targets of scheduled I/O data connection requests from Scanner Class products. They cannot send or receive scheduled real-time I/O data unless they are requested to do so by a scanner, and they do not store or originate the data transmit schedule. Adapter Class products receive unscheduled explicit message requests (connected or unconnected) from all other classes of products. They may also exchange (peer) data using unscheduled messages with any class of device, but they cannot originate such relationships.

Examples of products in this class include:

- I/O rack adapters producing and consuming scheduled real-time data;
- Weigh scales, welders, drives and robots sending and receiving real time scheduled data at the request of PLCs and other controllers;
- Weigh scales, welders, drives and robots sending and receiving unscheduled message data to and from computer interface cards, PLCs and each other; and HMI products sending and receiving scheduled and unscheduled data to PLCs.

Scanner Class products are the originators of scheduled I/O data connection requests to Adapter Class products, as well as to other Scanner Class products (i.e., scheduled peer-to-peer). These products may also be the originators or targets of unscheduled explicit connection requests to and from other classes of products, and they can also send or receive unscheduled messages to or from all other classes of products.

Examples of products in this class include:

- PLCs, controllers and robots sending and receiving real time scheduled data to I/O rack adapters, PLCs, robots, weigh scales, welders and MMI products;
- PLCs, controllers and robots sending and receiving unscheduled message data to other PLCs, robots, weigh scales, computer cards, welders and MMI products; and
- Computer interface cards used for PC-based control.

The Upper Layers

ControlNet uses the Common Industrial Protocol (CIP), a strictly object-oriented protocol, at the upper layers. Each CIP object has attributes (data), services (commands) and behaviors (reactions to events). CIP's producer-consumer communication model provides more efficient use of network resources than a source-destination model by allowing the exchange of application information between a sending device (e.g., the producer) and many receiving devices (e.g., the consumers) without requiring data to be transmitted multiple times by a single source to multiple destinations. In producer-consumer networks, a message is identified by its connection ID, not its destination address (as is the case with source-destination networks). CIP's message structure makes it possible for multiple nodes to consume data produced by a single source based solely on the connection ID to which the message refers. Thus, the producer-consumer model provides a clear advantage for users of CIP Networks by making efficient use of network resources in the following ways:

- If a node wants to receive data, it only needs to ask for it once to consume the data each time it is produced.
- If a second (third, fourth, etc.) node wants the same data, all it needs to know is the connection ID to receive the same data simultaneously with all other nodes.

CIP also includes "device types" for which there are "device profiles." For a given device type, the device profile will specify the set of CIP objects that must be implemented, configuration options and I/O data formats. This consistency in object implementation for a given device type provides another clear advantage for users of CIP Networks by promoting a common application interface for a given device type and interoperability in networks comprised of devices from multiple vendors. For applications where unique functionality is required, it is also possible for a ControlNet vendor to define additional vendor-specific objects in a ControlNet-compliant product in order to support the functional requirements of particular applications.

Seamless bridging and routing is perhaps the most significant advantage for users of CIP Networks for it is this mechanism that most protects the user's investment for the future. The ability to originate a message on one CIP Network, such as DeviceNet, and then pass it to another CIP Network, such as ControlNet, with no presentation at the Application Layer, means that users can incorporate incremental application improvements to existing installations and/or integrate automation systems with diagnostic, prognostic and/or IT applications. Seamless bridging and routing between both homogeneous and heterogeneous CIP Networks is enabled by a set of objects that defines routing mechanisms for a device to use when forwarding the contents of a message produced on one network port to another. This mechanism does not alter the contents of a message during the routing process. When using this mechanism, the user's only responsibility is to describe the path that a given message must follow. CIP ensures that the message is handled correctly, independent of the CIP Networks involved.

Management of the ControlNet Technology

ControlNet is managed by ODVA, an international association of the world's leading automation companies. ODVA's ControlNet management responsibilities include:

- Publishing The ControlNet Specification;
- Overseeing the process to incorporate new enhancements to The ControlNet Specification;
- Licensing the ControlNet Technology to companies desiring to make and/or sell ControlNet-compliant products;
- Promoting industry awareness of ControlNet and its benefits; and
- Helping to ensure compliance of ControlNet products with the specification through conformance testing and conformity reporting.

For more information about ControlNet, CIP or ODVA, visit ODVA at **www.odva.org**..

About ODVA

Founded in 1995, ODVA is a global association whose members comprise the world's leading automation companies. ODVA's mission is to advance open, interoperable information and communication technologies in industrial automation. ODVA recognizes its media independent network protocol, the Common Industrial Protocol or "CIP" – and the network adaptations of CIP – EtherNet/IP, DeviceNet, CompoNet and ControlNet – as its core technology and the primary common interest of its membership. ODVA's vision is to contribute to the sustainability and prosperity of the global community by transforming the model for information and communication technology in the industrial ecosystem. For future interoperability of production systems and the integration of the production systems with other systems, ODVA embraces the adoption of commercial-off-the-shelf (COTS) and standard, unmodified Internet and Ethernet technologies as a guiding principle wherever possible. This principle is exemplified by EtherNet/IP – the world's number one industrial Ethernet network. For more information about ODVA, visit odva.org.

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