BACnet® Primer

Phoenix Controls

What is BACnet®?

Building Automation and Control Network (BACnet) is a true, non-proprietary open protocol communication standard created by the American Society of Heating, Refrigerating, and Air-Conditioning Engineers, Inc. (ASHRE). BACnet makes it possible for products made by different manufacturers to fully interoperate in a single building automated control system. These different products can talk to each other over a network as long as the standards/protocols of ANSI/ASHRE 135-2001 are met.

The BACnet protocol defines a model for building automation systems, describing the communication between devices and systems. The protocol model specifically defines:

- Data and control functions structured in an object-oriented manner
- Services that describe data requests and responses
- Network data link types
- A scalable and flexible internetwork and network architecture

BACnet Protocol

The BACnet protocol is based on devices, objects, properties and services. Communication between BACnet devices is achieved by using various Data Sharing Services for reading and writing the properties of particular objects and by the equally acceptable execution of other protocol services.

Devices: A BACnet device is typically a controller, gateway, or user interface. It is designed to understand and execute the various services using the BACnet protocol. The device contains a collection of information about the device called objects and properties.

Objects: A BACnet object is a collection of information within a device. Objects might represent logical groupings/collections of points or single physical/virtual points that perform a particular function, such as analog and digital inputs and outputs, control algorithms, specific applications, and calculations. The BACnet standard objects are:

Analog input	Group
Analog output	Life safety point
Analog value	Life safety zone
Averaging	Loop
Binary input	Multi-state input
Binary output	Multi-state output
Binary value	Multi-state value
Calendar	Notification class
Command	Program
Device	Schedule
Event enrollment	Trend log
File	

Every Object on a BACnet network is assigned an Object Identifier or Object ID which serves as its "address" on the network. Object identifiers are a 32-bit binary number containing a code for the object type and the object instance number.

Properties: Properties control and monitor objects. The properties present in a device are determined by the type of object and device in which the object resides. Properties let other BACnet devices read information about the object containing the property, and potentially command a different value to the property. BACnet specifies 123 properties of objects; three must be present in every object: Object-identifier/Name, Object-Value, and Object-type. Some properties allow writes, and others can only be read.

Services: Services are actions that a BACnet device takes to read or write to another BACnet device. Services are methods for establishing communications with other devices on the network and for accessing and managing properties of device objects. If a device wants to locate a server peer, it finds it by sending a Who-Is request system-wide, specifying the peer's device instance number. When the peer receives the Who-Is request, it replies by sending an I-Am response, either system-wide or on the originating network. When acknowledged, the I-Am request has the network address of the peer, along with other BACnet communications parameters. There are 35 basic services supported by BACnet and these are grouped into the following categories:

- Data Sharing
- Alarm and Event
- File Transfer
- Virtual Terminal
- Summary
- Device Management
- Object Access
- Security

The Read-property service is the only one that is required to be supported by all devices.

The Who-Is service request has an optional set of parameters used to limit the range of device instances.

Protocol Implementation and Conformance Statement (PICS):

The Protocol Implementation and Conformance Statement (PICS) is the most effective and useful tool for consulting engineers, vendors and customers to determine the BACnet implementation of a given device. PICS is generally presented in a format that is common among vendors. It is a valuable tool when comparing BACnet devices to determine functionality and interoperability between different vendors.

PICS discloses the following areas of information about a BACnet device:

- Product version, name and description
- Device profile to which the device conforms
  - B-OWS (BACnet Operator Workstation)
  - B-BC (BACnet Building Controller)
  - B-AAC (BACnet Advanced Application Controller)
  - B-ASC (BACnet Application Specific Controller)
  - B-SS (BACnet Smart Sensor)
  - B-SA (BACnet Smart Actuator)

Interoperability

BACnet Interoperability Building Blocks (BIBBs): BACnet provides functional capabilities known as "Interoperability Areas." These Interoperability Areas are aligned with the BACnet Interoperability Building Blocks (BIBBs).

BIBBs represent particular individual function blocks for data exchange between interoperable devices. They are designed to be a simplifying tool for engineers to be able to write concise specifications describing the interoperability requirements of the various devices comprising a BACnet system. BIBBs together with Interoperability Areas have been broken down into five categories:

Data Sharing
- Read/write property
- Read/write multiple properties
- Read property conditional
- COV (Change of Value)
- Unsolicited COV

Alarms and Event Management
- Alarm and event notification – internal/external
- Alarm acknowledgement
- Alarm and Alarm enrollment summary
- Alarm information
- Life safety alarm

Scheduling
- Scheduling – internal/external

Trending
- Viewing and modifying trends – internal/external
- Automated trend retrieval

Device and Network Management
- Device connection establishment
- Router configuration
- Device/Object binding - discovery and connection
- Device communication control
- Private transfer of message
- Text message
- Time synchronization
- Reinitialize device communications
- Backup and restore device database
- List manipulation
- Object creation and deletion
- Virtual terminal

The level of BACnet functionality each device on the network must support is determined by its Profile as defined in its PICS. Therefore, it is important to understand the Profile of devices you wish to integrate with and the supported Objects and Services.

Data Sharing

Data Sharing makes it possible for BACnet devices to exchange information. Interoperability allows data collection of reports, values between devices, change of set points, etc. In Data Sharing, a client device initiates a request for data from a server device and the server executes the request, it may also send commands to the server.

Alarms and Event Mangement

Events are predefined conditions that meet specific criteria that could result in alarm. There are different even types in BACnet:

- Change of Bi-string
- Change of State
- Change of Value
- Command Failure
- Floating Limit
- Out of Range

Scheduling

Allows adding and editing of schedules in BACnet devices so that control can be coordinated based on dates and times.

Trending

Enables trend collection and request trend data between BACnet devices.

Device and Network Management

Allows BACnet devices to discover other BACnet devices, discover objects within devices, establish and re-establish communications, synchronize time, and re-initialize a device's program.

BACnet Functional Levels

- Management, with data base and statistical functions
- Integration (Building level), with processing functions
- Field (floor level), with I/O functions
- Sensors/Actuators Level

Management Level Network

One of the major advantages of BACnet is that it focuses on integration at the management and integration levels. Workstations and servers are found on this level for managing and monitoring the different devices in the network. Even though it is possible to integrate to other manufacturers' controllers at a field-level, it is not very practical because of different I/O configurations, physical sizes and power requirements.

Integration Level Networking (Building Level)

Integrating external systems is achieved by allowing additional third-party building-automation networks to connect to the BACnet network. BMS controllers or master controllers are found at this level. The master controllers talk to the management level network and to field level network.

Field Controller and Sensor/Actuator Levels

Vendors can use optimized protocols at the field level providing better system communication performance and dependability. Integration with other BACnet network technologies (e.g. MS/TP, Ethernet, and ARCnet) or proprietary networks is provided using appropriate BACnet/IP routers or gateways.

The Field Level includes the instrumentation interfaced to the Integration Level DDC controllers such as the temperature, humidity, pressure sensors and switches etc.

The Sensor/Actuator Level includes the final control elements such as the valve and damper actuators and the control relays.

The control and monitoring signals between the Integration Level controllers and the Field Level components shall be via industry standard analog ranges, such as 0 to 5V, 0 to 10V, 4 to 20 mA, switched 0 and 5V, switched 0 and 10V, and so on. At some point the field level components send simple low voltage signals to the DDC.

A temperature sensor for example will send an analog signal relative to the temperature being measured (for example, from 0 to 10 volts). The signal is interpreted by the DDC control logic at the "Integration Level" as an Analog Input Object. This command or action will then be in the form of a BACnet Object. It is not necessary for the devices at the field level to understand the signals it is sending or receiving.

BACnet Networks

BACnet supports six different network types (LANs), which serve as the transport for BACnet messages. Messages in BACnet, to monitor or command information, are the same, no matter the physical or data link layer used. The supported networks are:

Ethernet

Runs from 10 Mbit/s to 10 Gbit/s, and on a variety of media-STP, coaxial cable, or fiber optics.

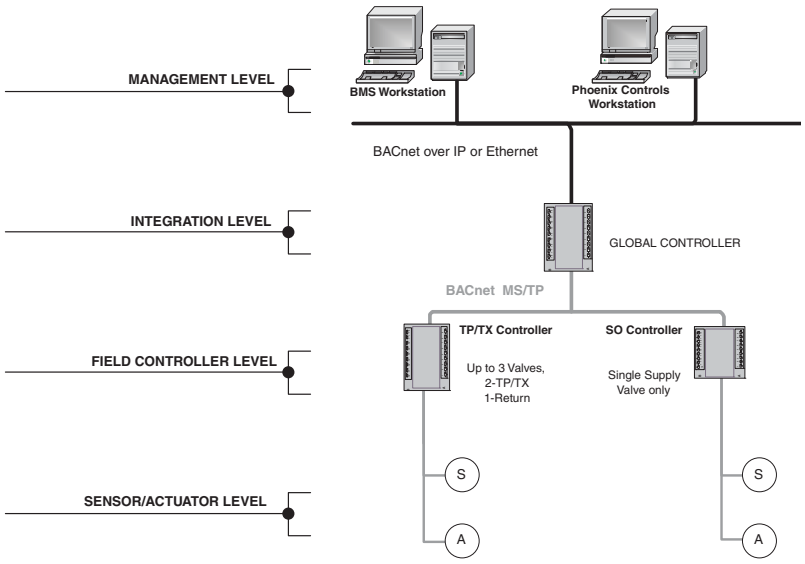
Some key characteristics of Ethernet are:

- CSMA/CD - Carrier Sense Multiple Access Device with Collision Detection
- Achieves orderly use of the medium by allowing a device to transmit when it determines that the medium is clear
- For lightly loaded networks, CSMA/CD yields excellent throughput

BACnet/IP (B/IP)*)*

A BACnet/IP is a standard BACnet message encapsulated within an IP packet. A BACnet/IP network

Figure 1. BACnet Functional Levels



is a group of one or more IP sub-networks (IP Domains) assigned with a single BACnet network number. A BACnet inter network is made up of two or more BACnet networks.

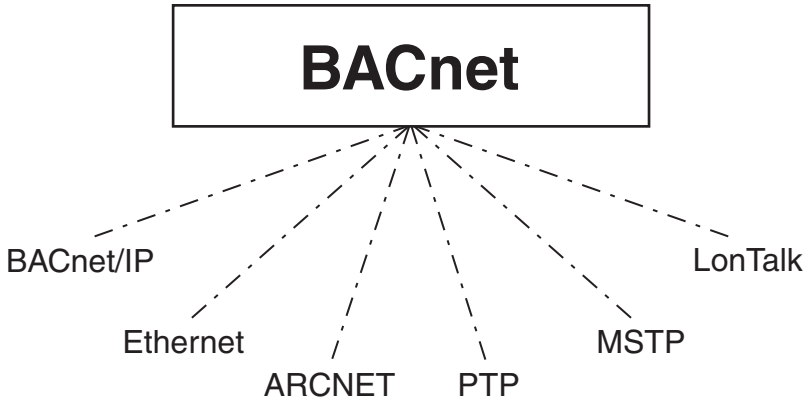
- BACnet/IP settings need correct Ethernet network settings and connections
- The address of a BACnet/IP device is the IP address and UDP Port Number
- BACnet/IP can send messages either IP/Point-to-Point or IP/Broadcast

BACnet/IP finds ways for BACnet messages to be broadcasted across IP networks in native IP formats. This is done by the BACnet Broadcast Management Device (BBMD).

Using BACnet/IP, a device such as a laptop can now connect anywhere in the enterprise and get BMS data from throughout the enterprise. This has established a level of flexibility and control for BAS architectures on enterprise networks.

BACnet/IP is also the best solution for facility managers and building owners because of its cost efficiency, interoperability and scalability. As the project grows, the enterprise network grows, and the BAS enjoys a pre-existing pipeline for data.

Figure 2. BACnet Networks



ARCNET

Token bus standard. Most devices that support it need single-source chips that handle the network communication. It runs from 150 kbit/s to up to 7.5 Mbit/s. ARCNET is very rarely used any longer as most device manufacturers opt for the higher speed Ethernet or IP.

Point-to-Point

Unique to BACnet and provides for internet-worked communications over modems. PTP accommodates current modem protocols and also supports direct cable connections. Speed from 9.6 kbit/s to 56.0 kbit/s.

LonTalk

A control networking protocol developed by Echelon. It's typically implemented in a Neuron 32 bit chip. LonTalk provides a cost-effective, easy-to-implement option for adding intelligent communication to many devices that couldn't otherwise carry the cost or technology overhead. Very few products use the LonTalk media to transfer BACnet messages.

"Native" BACnet

Means that the devices only speak and understand BACnet. Native BACnet devices provide BACnet communication directly, device to device.

MS/TP

Master slave/token passing is also unique to BACnet. It runs from 9.6 kbit/s to 76.8 kbit/s. MS/TP is low cost and convenient for the communication of a unitary controller.

BACnet/MSTP

Some key terms associated with the MS/TP network are: device, segment, master, slave, and unit load.

Device: A piece of equipment connected to the MS/TP LAN. This includes VMCs, repeaters, and other BACnet-compliant devices.

Segment: A segment is an uninterrupted cabling run of MS/TP LAN with no signal interference, like a repeater. A single MS/TP LAN can be composed of a number of segments. Segments are interconnected through the use of repeaters.

Master and slave: A master is any device on an MS/TP LAN with a conformance class of 3 or higher; a slave is any device on an MS/TP LAN with a conformance class of 2 or lower.

Unit load: A unit load is a measurement of the relative electrical load of a device on the MS/TP LAN. For example, a device can count as 1/4 unit load, 1/2 unit load, or one unit load.

The MS/TP LAN supports up to 255 devices overall, (masters and slaves), with a maximum of 128 master devices. An MS/TP LAN segment supports up 32 unit loads.

When designing the network, it is safer to assume that each device counts as one unit load unless stated otherwise by the manufacturer.

BACnet Routers

A BACnet Router can be used to connect multiple network types. The router passes BACnet messages among the different network types without altering the message content. Routers may be used to get BACnet MS/TP to BACnet IP or BACnet Arcnet to BACnet Ethernet. Routers may also be embedded in a Gateway which actually translates one protocol LON, N2, P1) to another BACnet IP.

BACnet Broadcast Management Device (BBMD) allows BACnet broadcast messages to go across IP routers. BBMDs make the IP network look like a single BACnet network to BACnet devices, and their setup is the key to communication across the IP network. BBMDs have to be able to communicate with one another, and operator workstations have to recognize at least one BBMD on the internetwork. In BACnet there are three types of broadcasts: local, global, and remote. A local broadcast is a broadcast only on the same network as the initiating device using the data link's broadcast MAC address. A global broadcast is intended for every network in the

BACnet system. A remote broadcast is a broadcast message intended to be broadcast on some specified network.

Each subnet in a system can only have one BBMD. There is a maximum of 32 BBMDs per a single IP virtual network. It is possible to have a greater number with a more complex network setup.

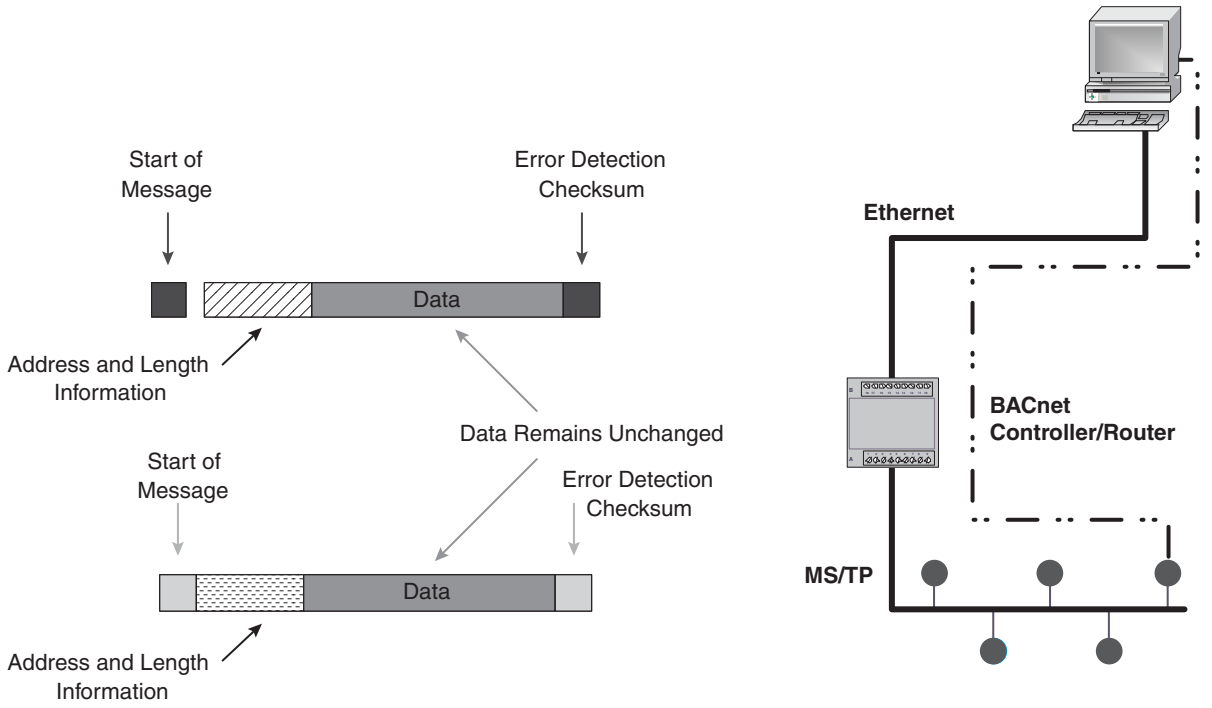
There are a many IP settings for the BBMD, a lot of them necessary for the BBMD to operate. Other default IP and networking settings rarely need to be changed.

The key IP setup parameters for the BBMD are:

- IP Address
- Subnet Mask
- Gateway Address
- UPD Port
- Virtual Network Number

In order for a BACnet device, like an operator workstation, to talk to non-BACnet devices like an existing direct digital control (DDC) system from "Y Controls," you will need an intervening gateway. A "gateway" is like a translator that can speak two languages. One side speaks BACnet, the other side the Y protocol of the legacy system. Logically the most apt source for such a gateway would be the Y Company and they may, or may not, chose to develop one.

Figure 3. BACnet Controller/Router



Device Address

When setting up or adding a BACnet network it is highly recommended to document the addressing scheme. There are three important addresses in all BACnet systems: Network number, MAC address and device instances. All BACnet devices all linked to these addresses. Even though all of these are called addresses they have different functions and are assigned differently.

Network Number: Identifies the network to which a BACnet device belongs to.

MAC Address: Controls how the device is recognized on the physical network to which it is attached. Each LAN type has its own MAC addressing scheme. Bridges maintain the integrity of the single MAC domain requirement and do not duplicate MAC addresses. A good example of a bridge is an Ethernet switch. Two devices can have the same MAC address as long as they are on different networks.

Device Instance: Identifies the device to the BACnet software and is the address most often encountered. The device instance is a shortcut to having to specify a MAC address and network number each time an operation is performed.

ISO Layers

The Organization for Standardization Open Systems Interconnection (ISO/OSI) seven layer model is a standardized method of breaking down network communications into more manageable levels. Each level of the ISO basic reference model targets a specific aspect of network systems and devices systematically address the problems of large networks.

The BACnet committee determined that not all layers of the ISO model were suitable for building automation controls networks. Some functions were already accounted for by other layers and would add unnecessary network overhead to operations. They determined which aspects of the ISO model were fitting for BACnet and implemented some of the most common and useful LAN standards to handle the physical and data link layers of a BACnet connection.

Command Priority Process

BACnet uses command priority to assign different levels of priorities to commanding entities throughout a system. This process was implemented to give priority to controls where conflicting control situations may occur.

Commandable Property

Objects that support command priorities have properties that are known as commandable properties. The value of these properties is controlled by the command priority process.

Priority Array

There are sixteen levels of priority in BACnet, known as the priority array, which consists of commands or NULLs, in an order of decreasing priority.

The active command is the one with the highest priority (lowest array priority level) with a non-Null value. If a priority level holds a value of NULL, then the next non-NULL object is assigned to the object.

Command Priority Levels

In the 16-level BACnet priority array there are 11 available levels that can be used in the future. The two top priority levels are associated to personnel safety and five priority levels already have a priority assigned. The 16 priority levels are:

1. Manual Life Safety
2. Automatic Life Safety
3. Priority 3, available
4. Priority 4, available
5. Critical Equipment Control
6. Minimum On Off
7. Priority 7, available
8. Manual Operator
9. Priority 9, Available
10. Priority 10, Available
11. Priority 11, Available
12. Priority 12, Available
13. Priority 13, Available
14. Priority 14, Available
15. Priority 15, Available
16. Priority 16, Available

If a priority level has not been specified when attempting to command a property, the priority level will default to the lowest priority, level 16. If there's an attempt to command a property that is not commandable with a specified priority level, the priority will be ignored.

Command Values and NULLs

A priority level in the priority array may have a commanded or a NULL value.

A NULL value means there is no existing command at that priority. An object constantly monitors the complete priority array to find the entry with the highest non-NULL value, and then sets the commandable property to this value.

Relinquish

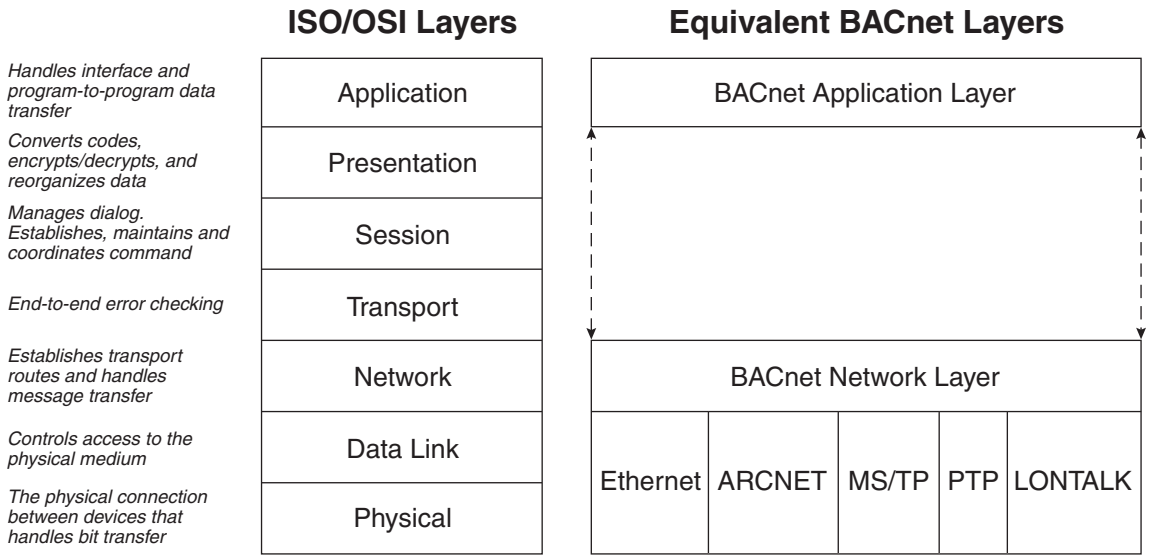
The value of the Relinquish Default is assigned to the commandable property when the priority levels in the priority array become NULL. The value of Relinquish Default is set when the BACnet object is configured.

Relinquishing a Command

A commanding entity could issue a command to an object's commandable property, or it may relinquish a command issued earlier. Relinquishing is a write operation, with the exception that the value of NULL is commanded. The Relinquishing command puts a NULL value in the priority array, corresponding to the right priority.

A commanded value can be relinquished or overridden.

Figure 4. ISO and Equivalent BACnet Layers



Valve Mounted Controllers (VMC)

VMCs communicate on the BACnet system over MS/TP network, which uses the RS-485 signaling standard. VMCs are master devices on the MS/TP network. Each VMC exerts 1/4 unit load on the MS/TP LAN. Some VMC network specs can be found on the table below.

Transmission speed	9.6, 19.2, 38.4, or 76.8Kbps (configured at global controller)
Layout	Bus
Cabling	BACnet specifies the following. Shielded, twisted-pair cabling with characteristic impedance between 100 and 130Ω. Distributed capacitance between conductors must be less than 30 pF/foot (100 pF/m). Distributed capacitance between conductor and shield must be less than 60 pF/foot (200 pF/m). Foil or braided shield acceptable.
Segment length	4000 ft. (1071 m) per segment using recommended wire
Maximum devices overall	Depends on classification of devices as master or slave. Maximum number of master devices is 128. Maximum number of slave devices or devices overall (mixed master and slave) is 255. This includes VMCs, global controllers (all are considered masters) and any other devices, regardless of their relative unit loads.
Maximum devices per segment	Depends on relative unit load of devices
Repeaters	Required when making runs longer than 4000 ft. (1071 m). Three repeaters maximum between any two devices.
Terminating resistors	Matched resistors required at each end of segment bus wired across (+) and (–). Use matched resistors rated 120 ohm1/4W ±5%.
Shield grounding	Ground shield drain wire at single point earth (panel) ground, not VMC ground. Tape off shield drain wire at other end. Tie shield drain wire through at each VMC.

The MAC address on VMCs is set by using DIP switches. Each VMC on an MS/TP LAN must have a unique MAC address in the range 0–127 (addresses 0 and 127 are often reserved for the global controller).

Celeris MicroServer and MacroServer Communication Protocols

MicroServer Communication Protocols

BMS Network Protocol	
BMS protocol	BACnet over Ethernet BACnet over IP
BMS network connection	RJ45
Implementation	Conformance Class 3 BIBBS—BBC (BACnet Building Controller)
Data transfer rates (points per second)	Read Requests/second: • 50 sustained • 100 peak Write commands/second: 30 maximum
Celeris Network Protocol	
Building network	ANSI 709.1-LonTalk protocol FTT-10 78 KB transceiver
Celeris network connection	22 AWG, Level IV, twisted-pair cable (no shield)

MacroServer Communication Protocols

BMS Network Protocol	
BMS protocol	BACnet over Ethernet BACnet over IP
BMS network connection	RJ45
Implementation	Conformance Class 3 BIBBS—ASC (Application Specific Controller)
Data transfer rates (points per second)	Read Requests/second: • 100 sustained • 300 peak Write commands/second: 30 maximum
Celeris Network Protocol	
Building network	ANSI 709.1-LonTalk protocol TP1250 transceiver
Celeris network connection	22 AWG, Level IV, twisted-pair cable (no shield)

BACnet Terminology

ANSI	American National Standards Institute.
Analog	A variable number used to measure a continuously varying entity, such as pressure or temperature.
APDU	Application Protocol Data Unit, a BACnet application-level message.
ASHRAE	American Society of Heating, Refrigeration, and Air Conditioning Engineers.
BACnet Testing Laboratories™ (BTL)	Responsible for testing building automation products and certify them as BACnet compliant.
BACnet Broadcast Management Device (BBMD)	A device that forwards BACnet broadcasts using UDP/IP.
BDT Broadcast Distribution Table	Used by BBMDs to forward broadcasts.
Bridge	Bridges maintain the integrity of the single MAC domain requirement and do not duplicate MAC addresses. A good example of a bridge is an Ethernet switch.
Building Blocks (BIBBs)	Interoperational capabilities of BACnet device. Certain BIBBs may also be predicated on the support of certain, otherwise optional, BACnet objects or properties.
BVLC BACnet Virtual Link Control	Commands and responses conveyed in BVLLs.
BVLL BACnet Virtual Link Layer	A header for messages conveyed over virtual networks (UDP/IP)..
COV Change Of Value	A notification that some data value has changed (by some amount).
Client	An application or device acting as a requestor or consumer of data. A client requests a server device for data resident in the server.
Datalink	The datalink layer as defined in the OSI (Open Systems Interconnection) model. The datalink encompasses the data structure.
Digital	Entities represented by two states, such as an on/off switch.
Ethernet	A high-speed LAN that runs on a variety of media-STP, coaxial cable, or fiber optics
FD Foreign Device	A device that has registered with a BBMD to receive (and send) broadcasts.
FDT Foreign Device Table	A BBMD's list of currently registered FDs
ID (Identifier)	An Object ID identifies an object's type and instance number. A Vendor ID defines the vendor who manufactured a device. A Property ID identifies a property by a code.
IP	Internet Protocol
ISO/OSI Reference Model	International Standards Organization/Open Systems Interconnection reference model.
Instance	A number that uniquely identifies an object within a device or a device on a BACnet internetwork.
Internetwork	A set of two or more networks interconnected by routers.

LAN	Local Area Network. A defined network providing the physical infrastructure for device communication.
Native Protocol	Protocol used by device, panel or workstation for network communication without the use of a gateway or translation interface.
Media Access Control (MAC)	The part of a network that handles access to the physical network (media). In BACnet, each device has a unique MAC Address/Network Number combination that identifies it on the BACnet internetwork.
MS/TP	Master-Slave/Token Passing.
National Institute of Standards and Technology (NIST)	An agency of the U.S. Department of Commerce's Technology Administration. NIST has played an integral role in the development of BACnet.
NPCI Network Protocol Control Information	The NPDU header.
NPDU Network Protocol Data Unit	An APDU with routing information, or network layer message.
Object	A piece of information in a BACnet system, described by its properties. An object might represent information about a physical input or output, or it may represent a logical grouping of points that perform some function, such as a setpoint.
Point-to-Point PTP	An EIA-232 communications protocol defined in BACnet.
Properties	The means by which objects are monitored and controlled. BACnet specifies 123 properties of objects. Three properties (Object-identifier, Object-name, and Object type) must be present in every object.
Protocol Implementation Conformance Statement (PICS)	A document that details the particular BACnet objects, services and capabilities supported by a type of BACnet device.
Repeater	BACnet segments are interconnected through the use of repeaters. Repeaters function at the physical layer since they control the symbols sent over the medium in the form of "1s and 0s". An example of a repeater would be an EIA-485 repeater that extends two MS/TP segments. The data link layer is in charge for organizing the transmission of data in the form of frames from one device to another.
Router	A device that connects two networks.
Server	An application or device acting as a provider of data, responding to a request from a client.
Services	How one BACnet device gets information from another device, commands a device to perform certain actions (through its objects and properties), or lets other devices know that something has happened.
TCP/IP	Transmission Control Protocol/Internet Protocol. TCP/IP is the de facto protocol standard used by the Internet. IP only deals with packet transmission, TCP enables two hosts to establish a connection and exchange streams of data. TCP handles delivery and order of data streams. TCP/IP also includes UDP (User Datagram Protocol). UDP is the connectionless transport mechanism upon which BACnet relies for message delivery on IP networks. By default, BACnet devices listen for incoming messages on UDP Port 47808.
UTC	Universal Time Coordinated (Greenwich Mean Time).
VT Virtual Terminal	A simulation of standard terminals (VT100, etc.) over BACnet.

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