Direct Digital Control (DDC) Networks
By Greg Jourdan
Wenatchee Valley College
May 7th, 2014 (1:25 - 2:20 p.m.)
Agenda

• HVAC DDC system architecture
• Open system interconnection architecture models
• DDC topologies
• Open Protocols—BACnet, Lon, Modbus and Niagara/Tridium networks
• Common solutions to upgrade existing HVAC DDC systems and how to integrate controls.
• Advantages and disadvantages of open systems
Why Use Open DDC Systems?
Because Open DDC Systems Integrate
The DDC Manufacturer’s Controls
Modern DDC Controls Have
Four Level Architecture—What are they?

Courtesy Alerton Controls
Four Level Architecture
Level One “Sensors”
Four Level Architecture
Level Two “Field Controllers”

Courtesy Alerton Controls
Four Level Architecture
Level 3 “Integration & Open Systems”
Four Level Architecture
Level 4 “Management Integration”
Thus, Modern DDC Controls Have Four Level Architecture
DDC Networks and Architecture
LAN Configurations

Peer-to-Peer LAN Diagram

Polling LAN Diagram

S = Sensor
C = Controller
O = Outputs

Courtesy DDC-Online Org
DDC Networks and Architecture
LAN Configurations

Courtesy DDC-Online Org
DDC Networks and Architecture
Large Systems

Multiple-Subnet Works System Architecture

C = Controller
CI = Communications Interface
I = Interface
LAN = Local Area Network
S = Sensor
O = Outputs
WAN = Wide Area Network

Courtesy DDC-Online Org
DDC Topologies
There are three basic configurations used to connect DDC Computer Controls, what are they?
DDC
NETWORK TOPOLOGIES

There are three basic configurations used to connect DDC Computer Controls. They are:

1. Bus
2. Ring
3. Star
Bus topology

- This type of network was widely used in the 1980’s.
- In this configuration every computer (node) shares the networks total bus capacities.
- In this configuration adding more DDC panels will reduce the access speed on the network.
- Each computer communicates to other computers on the network independently this is referred to as PEER-TO-PEER networking.
Problems with Bus Technology

- One of the main problems with this type of network is that it is not very fault tolerant, a break or defect in the bus would affect the whole network
Ring Topology

- In Ring topology each node is connected to the two nearest nodes so the entire network forms a circle
- Data only travels in one direction on a Ring network
How Ring Topology works

- A node has information to send to another computer on the network so it sends the information out on the network.
- This method of repeating the data helps keep the integrity of the data readable by other computers.
Star topology

- In a Star topology every node is connected through a central device such as a Hub, Switch or Router.

- Compared to a Ring or Bus topology a Star topology requires that more thought be put into its setup.
The Good and Bad of a Star Network

- The upside of a star network is that if any one cable fails then only the node connected on that cable would be affected.
- Another positive point to this type of network is that it is very simple to join two star networks together by connecting their central devices to each other.
What are Some Open Protocols?
Open Protocols

- BACnet
- Lon
- Modbus

- Tridium
  - Not really an Open Protocol
What is a Protocol?

A protocol is?
Protocol Inner Workings

A protocol is a set of rules defining the format of data transmission between two or more devices.

The protocol defines:
- Data format and composition
- Addressing
- Error checking
- Data compression
- Send/receive message notification

For communications to work effectively between two or more devices, the rules covering the required functionality must be interpreted and implemented exactly the same way.

The OSI Model explains the basics.
Open Protocol Forces DDC Manufacturer’s to do What?
Open Protocol Forces DDC Manufacturer’s to Integrate and Share Data
Open Communication Standards Software Integration (BACnet, LON, Modbus, Tridium)

Automation systems allow communication with multiple vendors including:
- HVAC Equipment
- Fire alarm, security
- Lighting, fan units
- PLCs (Programmable Logic Controllers)
- Boilers and chillers
BACnet Software is the DDC Standard Protocol

• BACnet, was developed by ASHRAE

• True, Non-proprietary, Open Protocol

• Industry Standardized

• Multiple Vendor Controllers
BACnet Connects Various Manufacturers of DDC Controls
The Principles of How BACnet Works

- Representing Information
- Making Requests and Interoperating
- Transport System
- Application Language
  - Objects
  - Services
  - LANs
  - Internetworking

Source: David Fisher, PolarSoft
Typical BACNet System View

Management Level

Integration Level

Field Controller Level

Application Level

BACnet-enabled Applications & other apps
BACnet—the standard
What is BACnet?
What is BACnet?

- A book
- An open standard
- A data communications protocol
- An acronym: Building Automation and Control Networks
- A means of integrating building systems
- A way of life!
So . . .

- BACnet is a data communications protocol and an agreed-upon set of rules for creating interoperable networks of building systems.
Encompassing . . .

- Building Automation Systems (BAS)
- HVAC Central Plant (Chillers, Boilers, Large Air Handlers)
- Lighting
- Perimeter and Object Security
- Fire and Life Safety
- Elevators
- The integration of all of the above.
Who Started this BACNet Thing?
Who Started this BACNet Thing?

- A working group (standard project committee) of the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE).
- Began work in 1987 under tremendous opposition (some said it would NEVER be done).
- Published as a standard in 1995.
- Supported and maintained by ASHRAE Standing Standard Project Committee 135.
What the Standard Defines

• In essence, the standard defines the messages that devices exchange and how they are delivered.
Further . . .

- The rules of the protocol apply to
  - Electrical signaling
  - Addressing
  - Network access (master/slave, peer-to-peer)
  - Error checking
  - Flow control
  - Message sequencing, segmentation, check pointing
  - Presentation format (compression, encryption)
  - Message format

Source: Mike Newman, BACnet pioneer
BACNet Pyramid

- The protocol can be viewed as a matrix of layers.
Properties

• The nucleus to the BACnet atom—the smallest piece of BACnet information.
• Properties can be read and written.
• Properties can provide command control.
• They consist of names and values.
Properties

• Example: high_limit = 78.0

• The standard requires some properties; other properties are optional; still others can be proprietary.

• Required properties must be implemented for each object type.

• Optional properties do not have to be implemented, but if they are, they must conform to the specification.
Objects

• Objects are the fundamental building blocks (atoms) of the standard.

• Objects represent data that originates in physical inputs, physical outputs, or software processes.

• Each BACnet Object possesses a number of properties.
Object Types

- The standard specifies 25 types of objects:

<table>
<thead>
<tr>
<th>Binary Input</th>
<th>Binary Output</th>
<th>Binary Value</th>
<th>Analog Input</th>
<th>Analog Output</th>
</tr>
</thead>
<tbody>
<tr>
<td>Analog Value</td>
<td>Multi-state Input</td>
<td>Multi-state Output</td>
<td>Multi-state Value</td>
<td>Averaging</td>
</tr>
<tr>
<td>PID Loop</td>
<td>Trend Log</td>
<td>Command</td>
<td>Calendar</td>
<td>Schedule</td>
</tr>
<tr>
<td>Life Safety Zone</td>
<td>Life Safety Point</td>
<td>Notification Class</td>
<td>Event Enrollment</td>
<td>Program</td>
</tr>
<tr>
<td>File</td>
<td>Group</td>
<td>Device</td>
<td>Pulse Converter</td>
<td>Accumulator</td>
</tr>
</tbody>
</table>
Objects

• Vendors can implement proprietary object types.
• When they do so, they use standard data types to promote interoperability.
Object IDs

- Numerical identifier that combines object type and instance number.
- Object types 0 – 127 are reserved to identify standard BACnet objects.
- Object types 128 – 1023 are used to identify proprietary objects.
Object IDs

- BACnet devices will support any mixture of object types up to a limit of \(4,194,303\) instances.
- Object IDs are typically referred to in this manner:

  *Analog Input, 5*
Objects—Summary

- Objects standardize the organization of data to facilitate the exchange of data between different vendors’ products.
Devices

• There are six device types or profiles specified by the standard:
  – Operator Workstation (B-OWS)
  – Building Controller (B-BC)
  – Advanced Application Controller (B-AAC)
  – Application Specific Controller (B-ASC)
  – Smart Actuator (B-SA)
  – Smart Sensor (B-SS)
Services

• Think of BACnet services as the messages that BACnet devices send to each other.
• Some services read and write properties of one or more objects.
• Other services send notification of alarms or special events.
• Still other services read and write files.
Services

• BACnet services follow a Client-Server model.
  – A BACnet client is a device that requests a service
  – A BACnet server is a device that performs a service
Categories of Services

• Alarm and Event
  – Routing & event notification

• File Access
  – Accessing & manipulating files contained in devices

• Object Access
  – Read and write properties
  – Create and delete objects
  – Manipulate lists of data

• Remote Device Management
  – Remote monitoring and control of devices

• Virtual Terminal
  – Used by a client user to establish a connection to an application program server in another BACnet device.
Services—Read Property

We wish to read the present value for an analog input called “SPACE_TEMP”

Service= Read Property
‘Object Identifier’ = (Analog Input, Instance 5)
‘Property Identifier’ = Present_Value

Assuming the target machine can locate the object with this ID and the requested properties, the result would be:

Service= Read Property
‘Object Identifier’ = (Analog Input, Instance 5)
‘Property Identifier’ = Present_Value
‘Value’ = 72.3

The result indicates that the present value of “SPACE_TEMP” is 72.3

What is BIBBS?
BIBBS is:

- BACnet Interoperability Building Blocks
- BIBBS are collections of services
- BIBBS define 5 areas of interoperability:
  - Data Sharing
  - Alarm and Event Management
  - Scheduling
  - Trending
  - Device and Network Management
Example of Scheduling & Trending BIBBS

<table>
<thead>
<tr>
<th>Description</th>
<th>B-OWS</th>
<th>B-BC</th>
<th>B-AAC</th>
<th>B-ASC</th>
<th>B-SA</th>
<th>B-SS</th>
</tr>
</thead>
<tbody>
<tr>
<td>SCHED-A</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SCHED-I-B (internal)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SCHED-E-B (external)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

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<th>Description</th>
<th>B-OWS</th>
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<th>B-ASC</th>
<th>B-SA</th>
<th>B-SS</th>
</tr>
</thead>
<tbody>
<tr>
<td>T-VMT-A (viewing &amp; modifying)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>T-VMT-I-B</td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>T-VMT-E-B</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>T-ATR-A (automated trend retrieval)</td>
<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>T-ATR-B</td>
<td></td>
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</tr>
</tbody>
</table>
BACNet Transport Options

- BACnet IP
- BACnet Ethernet (8802-3)
- Master Slave/Token Passing (MSTP)
- LonTalk
- Point-To-Point (PTP)
## Transport Comparison

<table>
<thead>
<tr>
<th></th>
<th>Description</th>
<th>Issues</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Use BBMD or PAD router to get across an IP router.</td>
<td></td>
</tr>
<tr>
<td>BACnet 8802-3</td>
<td>Popular, fast. No real performance difference between this and IP.</td>
<td>Cannot get across IP routers.</td>
</tr>
<tr>
<td>MSTP</td>
<td>Very popular, especially as a low-level bus technology for AACs and ASCs. Uses EIA-485 signaling over twisted pair wiring.</td>
<td>Lower performance.</td>
</tr>
</tbody>
</table>
BACnet Layers vs OSI Layers

Standard OSI Reference Model

<table>
<thead>
<tr>
<th>Application</th>
<th>Presentation</th>
<th>Session</th>
<th>Transport</th>
<th>Network</th>
<th>Data Link</th>
<th>Physical</th>
</tr>
</thead>
</table>

BACnet Layers

- **BACnet Application Layer**
- **BACnet Network Layer**

<table>
<thead>
<tr>
<th>ISO8802-2 (IEEE 8802.3) Type 1</th>
<th>MS/TP</th>
<th>PTP</th>
<th>LonTalk</th>
</tr>
</thead>
<tbody>
<tr>
<td>ISO8802-3 (IEEE 802.3) ARCNET</td>
<td>EIA-485</td>
<td>EIA-232</td>
<td></td>
</tr>
</tbody>
</table>

Equivalent OSI Layer

- Application
- Network
- Data Link
- Physical

## BACnet is the Preferred and Fastest Growing Network Standard

<table>
<thead>
<tr>
<th>Year</th>
<th>Units (1000s)</th>
<th>Revenue (mill $)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>BACnet</td>
<td>ECHELON</td>
</tr>
<tr>
<td>1998</td>
<td>145</td>
<td>44</td>
</tr>
<tr>
<td>2001</td>
<td>183</td>
<td>58</td>
</tr>
<tr>
<td>2008</td>
<td>747</td>
<td>90</td>
</tr>
</tbody>
</table>

* Units sold and revenue for BACnet, LonWorks, and proprietary systems in the building automation industry, 1998-2008
BACnet Adoption

BACnet vs. LonWorks Revenue

($1000s)

1998

2001

2008 (Projected)

Year

The LON Protocol

What Company Owns LON?
LonTalk and the Neuron Chip is a Product of the Echelon Corporation
LonWorks - Overview

• Owned and Developed by Echelon Corp.
• LonWorks
  – Overall technology, includes chips, transceivers, protocol and tools
  – Neuron
    • Chips with LonTalk protocol
    • Application space for device mfgr.
• LonMark Association
  – Promote the use of LonWorks
  – Provides testing and certification of products
    • 442 certified products as of 3/16/06
  – Over 300 companies in a variety of industries; HVAC, lighting, home, etc.
LonWorks Platform Integration
(Open Protocol)
Integration Using LonTalk

LonTalk – Overview

- LonWorks Technology is from Echelon Corp.
- LonWorks is a suite of products
  - LonMaker Integration Tool
  - LNS network operating system
  - Lon IP router and Internet Server
  - LonTalk protocol
  - Neuron Chip
Integration Using LonTalk

LonTalk – Pros

• LonTalk is the standard protocol
  – ANSI/EIA/CEA 709.1 A 1999
• LonTalk is an effective device level protocol standard
• Product selection impressive
  – HVAC and BAS devices
  – Lighting control
• LonMark controllers adhering to LonMark profiles are cost effective and standard
• Neuron chip provides unique address out of factory
Integration Using LonTalk

LonTalk – Challenges

- LonTalk standard does not define important applications
  - Scheduling, Trending, Alarming, Programming, etc.
- LonMark profiles provide few mandatory network variables, leading to many variances in vendor implementations
- LonMark programmable controllers do not conform to LonMark profiles
The MODBus Protocol

Who Developed It?
Integration Using Modbus

Modbus - Overview

- Developed by Modicon (Schneider Electric)
- Considered a *de facto* standard
- Register based protocol
  - Digital data
  - Analog data
- Master/Slave or Client/Server based architecture
- Several types of Modbus:
  - **Modbus RTU**
  - Modbus ASCII
  - Modbus Plus
  - **Modbus TCP**
Integration Using Modbus

Modbus - Pros

- Simple data protocol means simple development
- Extensive implementation in many building systems:
  - Process controls
  - Power meters
  - Power and Lighting control
  - Chillers
  - Boilers
  - BAS
- Leverage existing driver development and integration expertise
Integration Using Modbus

Modbus - Challenges

• Simple protocol means functionality limited
  • No high level application standardization
  • No time stamping
  • Information limited to simple register data implemented by vendor
• Vendors may not implement the standard consistently
• Mapping is project specific
What is the Niagara AX Framework?
What is the Niagara AX Framework?

- Niagara Framework software is a **graphical user interface** with two main advantages of all other GUIs previously mentioned.
  - First, it can accessed through a standard Internet browser.
  - Second, the Niagara Framework is designed to integrate data from many types of control systems, LON, BACnet, and Modbus.
DDC Networks Have Lot of Connections And Don’t Always Communicate between the Various Vendors

Application A  Application B  Application C

Diverse Systems & Data
Niagara Normalizes All Systems

BACNet or LON Network

Application A  Application B  Application C

Common Object Model

Diverse Systems & Data
A Solution to Connectivity Problems is to standardize the Internet Enterprise with NiagaraAX

- A Comprehensive software platform
- Internet-enabled products and device-to-enterprise apps
Niagara’s Advantages

• Easy browser access
  – The Internet is a comfortable environment, people know how to use it and are familiar with it
  – Customers can access their system from anywhere

• Lower cost
  – Cost advantage over traditional client/server applications
    • Niagara’s thin clients = $0
    • Competitor’s heavyweight clients = $1500 - $3000
  – Advantage gets better as more clients are needed
Niagara’s Advantages

• True integration platform
  – Niagara’s architecture is designed to be hardware independent
  – With Niagara, you get LON and BACnet “out of the box”
  – Modbus, legacy, DDE, and third party drivers enhance integrated solution capabilities
Niagara’s Advantages

• Flexibility
  – The Niagara framework is designed to integrate data
    • Connectivity with multiple protocols and devices
    • Enterprise data connectivity for integrating control system data with enterprise applications
    • Applications can be developed to satisfy virtually any requirement
  – Uses industry standards for enterprise level information sharing
    • Protocols - TCP/IP, HTTP
    • Languages - HTML, XML
    • Data access - ODBC, JDBC
Niagara’s Advantages

• Storage of critical data.
  – Able to store data and retrieve on-line - energy, etc.
  – Long term storage only limited by Disk Space.

• Customer service tool.
  – Occupant complaints can be investigated because system is always collecting the data.

• Compare performance
  – Year/year, month/month, building/building, etc.
NiagaraAX and Web Based DDC Controllers Can be Factory Specific

- 250 MHz PowerPC CPU
- 64 mB RAM, 64 mB Flash (s/n < 8454)
- LON, RS232, RS485
or Controllers Can be Built on a OEM & Partner Platforms
NiagaraAX Controllers are Available from Most Manufacturer’s
A NiagaraAX Internet-DDC Architecture
NiagaraAX – Key Features

• Alarm Framework
• Alarm APIs
  – Alarm model
  – Grouping via classes
  – Routing via the recipients
  – Storage via history data
• Pre-built recipients to Niagara stations, email, IM, printers
• Desktop and web enabled alarm consoles
Niagara\textsuperscript{AX} – Key Features
is Easy to Program and Build
Tridium’s Workbench can be used to program while running in the BAS Remote.
NiagaraAX Looks and Feels Like any other DDC System
NiagaraAX and Web Based DDC Controllers Can be Factory Specific

- 250 MHz PowerPC CPU
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or Controllers Can be Built on a OEM & Partner Platform
NiagaraAX Controllers are Available from Most Manufacturer’s
Niagara\textsuperscript{AX} – Key Features
is Easy to Program and Build
Start Using the Graphics to Troubleshoot but Commissioning the Graphics is Key
Use Dynamic Graphics
Start Billing Tenants via Control Panels
Use Real-time Meter Logs
Utilize Intelligent Scheduling
Interpret Data Collection

Tridium Logs

OATNovLows and OATNovHighs and OATNovAvgLows and OATNovAvgHighs

Graphs showing data trends over time.
Learn the Application Logic Language
Start Using Energy Dash Boards

- They give real time data
- Provide actual savings or losses each month
- Are relatively simple to use
- Can show the total energy plant
- Steam, Electric, Water, etc.
Energy Dash Boards Make Sense
Common solutions to upgrade existing HVAC DDC systems
DDC Software and Hardware is Integrated into Building Systems to Allow Multiple Vendor Integration

Boilers, Chillers, Fire Alarm, Security, Lighting, AHU’s, RTU’s
Solutions - Integration is the Key with DDC Controls
Open Protocol and Levels of Interoperability Issues

• Co-Existence
  – Systems don’t interfere nor they cooperate

• Solution Specific
  – Requires Joint development & Engineering

• Plug & Play
  – Effortless integration of various manufacturing

• Components
  – Interchangeability
  – Products are functionally identical
Integration is possible using the BACnet Software Standard Protocol

• BACnet, Developed by ASHRAE
• True, Non-proprietary, Open Protocol (Industry Standardized)
• Multiple Vendor Controllers
Connectivity is the Main Challenge with DDC Controls
What Customers Want

Systems
- Security
- Energy
- Lighting
- Fire
- HVAC
- And More

Enterprise
- CFO
- Facility Management
- Maintenance
- XML
- SQL
- HTTP
- HTML
- ODBC
- SNMP
- JDBC
- FTP
- SMTP
- WAP

From Boiler Room to Board Room – Bringing Value To The Operation
Open Systems - Warnings

• Have Options – **But Options add complexity**
  – Free to choose “best-of-breed” devices, software and services to suit applications - **Free choice requires more effort in design and selection**
  – Not locked to a single supplier - **Can not rely on a single supplier**
  – Opens up the procurement process for sub-systems - **Each sub-system may have limited sources**
Open Protocol and Levels of Interoperability Issues

• Co-Existence
  – Systems don’t interfere nor they cooperate

• Solution Specific
  – Requires Joint development & Engineering

• Plug & Play
  – Effortless integration of various manufacturing

• Components
  – Interchangeability
  – Products are functionally identical
What are The Challenges of DDC Controls?
The Challenges of DDC Controls

- **Current DDC Controls use embedded systems.**
  - Highly fragmented, Limited Interoperability.
  - Increasing complexity of systems and smart devices.
- **Multiple standards compete in an expanding market.**
  - No single technology dominates the marketplace.
  - Numerous protocols must be addressed.
- **The Internet, The Enterprise is The Future.**
  - Emerging technologies and specialties have filled the gaps: service bureaus, asset managers, wireless, cellular, etc.
  - True “Convergence” is now Realistic with Internet Integration
Connectivity and Customer Training is the Main Challenge with DDC Control Networks and Building Owners

System Sophistication Requires Advanced Training

Invest in TRAINING, TRAINING, TRAINING
DDC Networks
Wrap-Up & Summary

• HVAC DDC systems use a common architecture
• Interconnect on the Open system
• DDC topologies vary, plan on redundancy
• Open Protocols Include-BACnet, LonWorks, Modbus and Niagara/Tridium networks
• Common solutions to upgrade existing HVAC DDC systems is to integrate
• Advantages and disadvantages of open systems is integration and training
Further Resources

BACNet.org
Tridium.com
Lonworks.com
Modbus.com
DDC-Online.org
(DDC) Networks
Any Questions?
(DDC) Networks
By Greg Jourdan
Wenatchee Valley College
May 7th, 2014
THANK YOU