Testing Conformance and Interoperability of BACnet™ Building Automation Products

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The BACnet standard defines classes of conformance and other collections of protocol functionality. Since a product need not support all of the capabilities of the protocol in order to conform to the standard, a manufacturer must select conformance classes and functional groups appropriate for the application the product is intended to meet. A system integrator must also understand these classifications in order to prepare procurement specifications. The standard does not contain test procedures for determining if a device conforms to the standard.

In 1993 the NIST BACnet Interoperability Testing Consortium was formed, in part to develop procedures and tools to test the conformance and interoperability of BACnet products. This paper describes BACnet conformance classification issues and the work of the NIST consortium in developing testing tools and applying them to test products made by member companies.

INTRODUCTION

BACnet™[1] is a standard communication protocol for *Building Automation and Control networks* developed by the American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc. (ASHRAE). BACnet provides a way to convey data including, but not limited to: hardware binary input and output values; hardware analog input and output values; software binary and analog values; schedule information; alarm and event information; files; and control logic [1]. In short, BACnet provides a comprehensive communications infrastructure for integrating a wide variety of building control products made by different manufacturers.

After nearly ten years in development and three public reviews that generated 741 comments from 12 countries, BACnet was approved as an ASHRAE standard in June, 1995. It became an American national standard in December, 1995. BACnet has also been selected as a European Community prestandard by Technical Committee 247 of the European Committee for Standardisation (CEN).

BACnet enables building owners to obtain competitive upgrades to building control systems and to integrate controllers that come packaged with HVAC equipment, such as chillers, with a control system made by a different vendor. BACnet will also make it possible to integrate building systems that are now stand-alone, e.g., fire detection and suppression systems, HVAC control systems, lighting control systems, and security systems. Integration of these systems can improve life-safety, increase comfort, and reduce operation and maintenance costs.

BACnet is an enabling technology that creates opportunities for development of new kinds of building system products that utilize the valuable information about the status of the building accessible through the BACnet protocol. Two examples are fault detection and diagnostic systems and elevators that can be safely used during a fire to evacuate high-rise buildings. BACnet also will

[1] BACnet is a registered trademark of the American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc.

permit greater interaction between building control systems and electrical utilities such as real-time price negotiation and load management.

BACnet PHILOSOPHY

The information that needs to be conveyed between devices in a BACnet network is abstracted from the implementation details through the use of standard objects. The mapping between standard objects and the underlying data and processes is left to the vendor. A rich and comprehensive set of services for accessing and manipulating this data is defined by the standard. Descriptions of the protocol details in the BACnet standard can be found elsewhere [2-5].

One of the first issues that was addressed by the ASHRAE committee that developed BACnet was to determine what kinds of building control devices should be integrated using a standard protocol. Some in the industry believed that the requirements for application specific or unitary controllers should be addressed first as a way to accelerate the development process. Others believed that the requirements of high level controllers should be addressed first so that products could be integrated at the top. Implicit in both of these approaches is the assumption that communication at various levels in a hierarchical control system is different in some significant way. But, this is not so. Analysis was done that showed the basic elements of communication between HVAC &R controllers are largely independent of the particular devices [6].

As a result, the BACnet protocol was designed to be general, in the sense that it could be applied to a very wide range of building automation and control products. BACnet can be used at any level in a distributed, hierarchical building control system. In fact, although BACnet accommodates a hierarchical control structure it does not impose one. One of the strengths of BACnet is that it does not impose a particular control philosophy. The presence or absence of hierarchical control structure and the way in which control functionality is distributed is dictated by the application needs.

One consequence of making the BACnet protocol general is that it contains more functionality than is necessary for any particular device. Other than a testing tool, it is very difficult to imagine any building control device that would need to implement *every* capability defined in BACnet. To account for the reality that devices do not need to support the full functionality of BACnet in order to perform their tasks, conformance requirements are divided into classes and other divisions called "functional groups." The guiding philosophy is that conformance requirements should be driven by the application functionality of the device.

BACnet CONFORMANCE CLASSES

BACnet defines six classes of conformance. Each class specifies a set of application services that must be supported and indicates for each service whether the device must be able to initiate the service (client) or execute the service request (server). Some conformance classes also require the support of specific BACnet standard objects. The conformance classes are numbered 1-6 and are hierarchical. Conformance to a class greater than one requires support of all of the requirements of the lower-numbered classes. The requirements of the BACnet conformance classes are summarized in *Table 1.*

Table 1. BACnet Conformance Classes

Class	Initiate Service Requirements	Execute Service Requirements	Example Devices
1	none	ReadProperty	smart sensor, workstation[1]
2	none	Class 1 + WriteProperty	smart actuator
3	I-Am, I-Have	Class 2 + ReadPropertyMultiple, WritePropertyMultiple, Who-Has, Who-Is	application specific controller
4	Class 3 + AddListElement, RemoveListElement, ReadProperty, ReadPropertyMultiple, WriteProperty, WritePropertyMultiple	Class 3 + AddListElement, RemoveListElement	application specific controller, field panel
5	Class 4 + Who-Has, Who-Is	Class 4 + CreateObject, DeleteObject, ReadPropertyConditional	field panel
6	Class 5 + Clock , PCWS, Event Initiation, Event Response, and Files functional groups.	Class 5 + Clock , PCWS, Event Initiation, Event Response, and Files functional groups.	field panel

[1] Workstation requirements also include the ability to initiate many BACnet services contained in one of the workstation functional groups.

BACnet conformance classes were assigned numbers instead of names in order to avoid constraining the design of a building control device or system. Past history indicates that the capability of control devices will change rapidly. It did not seem prudent to impose today's design ideas on products of the future. Thus, the standard does not define a specific conformance class for application-specific controllers, one for field panels, one for workstations, etc. Nevertheless, a very rough mapping of these kinds of control devices to BACnet conformance classes can be made based on current technology as shown in Table 1.

BACnet FUNCTIONAL GROUPS

In addition to conformance classes, BACnet defines something called "functional groups." The idea behind functional groups was to categorize BACnet communication capabilities in such a way that the requirements to meet a specific building control function would be represented, but to do so without imposing this control function on a particular class of controllers. For example, the Event Initiation Functional Group specifies the features of BACnet needed to detect the occurrence of an alarm or event and to notify one or more recipients that it has occurred. By making this a functional group instead of including it in a conformance class, the decision about which devices need to support this functionality is left up to vendors and building owners. Table 2 lists the BACnet functional groups.

Table 2. BACnet Functional Groups

Functional Group Name	Purpose
Clock	Maintain a local representation of time that can be synchronized over the network.
Hand Held Workstation (HHWS)	Provide the BACnet service initiation functions needed for a typical hand-held interface tool.
Personal Computer Workstation (PCWS)	Provide the BACnet service initiation functions needed for a typical operator workstation.
Event Initiation	Define alarms or other events, detect their occurrence, and notify one or more recipients when they occur.
Event Response	Acknowledge the receipt of alarm or event notifications.
COV Event Initiation	Detect changes of value and initiate notification messages to one or more recipients.
COV Event Response	Subscribe to and receive change of value notifications.
Files	Read, write, upload, and download files.
Reinitialize	Reset or restart a device over the network from a remote location.
Virtual Operator Interface	Provide the capabilities for the operator side of a virtual terminal session.
Virtual Terminal	Provide the capabilities for the server side of a virtual terminal session.
Device Communications	Provide the capability to disable network communications for a specified time period for troubleshooting purposes.
Time Master	Maintain the synchronization of clocks throughout the network.

SPECIFYING BACnet SYSTEMS

One of the key ideas behind creating classes of conformance and functional groups was to make life easier for the building owners and specifiers. It was an attempt to organize BACnet functionality in such a way that expertise in the application combined with a general understanding of the protocol would be sufficient to develop high quality specifications. For each device or group of devices in a control system, a specifier would choose a networking technology and a reasonable conformance class. Add the functional groups that are needed for the application and you have the necessary pieces. If the application needs just do not fit into the groupings defined in the standard, it is possible to spell out precisely which object-types and services must be supported, but this would require greater expertise in the fine points of BACnet.

Does this approach work? It is too soon to tell, but early experience suggests that there may need to be some fine tuning to the standard. For example, the ability to dynamically locate communication partners using the Who-Is and I-Am services has proven to be very popular even for simple controllers. The ability to initiate the Who_Is service does not appear in the conformance classes until Class 5. It probably makes sense to introduce this capability at a lower class. There is also some evidence that it would be appropriate to move some BACnet functionality to a higher class than is currently required. On the whole the concept seems to be sound. Additional field experience will help to identify the kind of changes that would make it easier to use this approach.

The best advice for people developing BACnet specifications today is to be sure that the specification clearly states the desired control functionality and that BACnet is to be used to provide that functionality. Clearly indicating the control requirements is paramount. Tables or some other way to indicate required BACnet conformance classes and functional groups should be used to supplement the functional specifications, not as a replacement.

One specification the author is familiar with used three tables in just this way. The first table indicated the conformance class for each kind of device mentioned in the specification. A second table contained a column for each kind of device and a row for each possible functional group. By checking the appropriate boxes in the matrix the functional groups become specified. The third table also contained a column for each kind of device. The rows indicated the possible application services. A code was used in each box of the matrix to indicate that the service was not required, the ability to initiate requests is required, the ability to execute service requests is required, or the ability to do both is required. There is some redundancy built into this approach but it has the virtue of being clear.

CERTIFICATION OF BACnet PRODUCTS

Although the BACnet standard defines conformance requirements it does not contain a test suite that can be used to determine if these requirements have been met. As a matter of policy ASHRAE does not certify products of any kind to ASHRAE standards. At the present time there is no recognized certification authority for BACnet. It is widely recognized that these are important omissions that need to be addressed. It is ASHRAE's policy to work to establish a certification program that would be administered by an, as yet undetermined, outside organization. Some discussions have been held with candidates but a final determination is not expected soon.

The main obstacle to establishing a certification program is the lack of a testing standard. ASHRAE has formed a Standing Standard Project Committee (SSPC) 135 for the purpose of addressing questions of interpretation and developing addenda to the standard. A very high priority is a conformance test suite addendum. Creating a test suite addendum through the standards process ensures that affected parties will have an opportunity to have their views heard and that opportunities will be provided for public review and comment.

One of the benefits of a standard test suite is that it could be the basis for recognizing certification authorities in different countries. BACnet systems are already installed and running in the United States, Central Europe and Scandinavia. It is reasonable that companies building BACnet products would prefer to have their products certified locally but be able to market them globally.

THE NIST BACnet INTEROPERABILITY TESTING CONSORTIUM

In 1993 the United States National Institute of Standards and Technology (NIST) formed the BACnet Interoperability Testing Consortium. This consortium is based upon a cooperative research and development agreement between NIST and the member companies. The consortium was formed to verify the technical soundness of the BACnet protocol before it became a standard, to assist control system manufacturers develop interoperable BACnet products, and to develop conformance testing tools and procedures. One of the main reasons for forming the NIST Consortium was to create an interim solution to the problems caused by the lack of a certification program. Even though NIST does not certify products, the consortium umbrella gives member companies the opportunity to test their products with the products of other member companies in order to identify any interoperability problems. The current membership in the consortium is shown in Table 3.

Table 3. BACnet Interoperability Testing Consortium Members

Alerton Technologies	McQuay International
Andover Controls	NIST
Auto Matrix	Orion Analysis Corporation
Cimetrics Technology	PolarSoft
Cornell University	Siebe Environmental Controls
Delta Controls	Staefa Control System
Honeywell, Inc.	Teletrol
Johnson Controls	The Trane Company
Landis & Gyr	United Technologies, Carrier

Thirteen of the BACnet Consortium members participated in a demonstration of interoperable BACnet products at the ASHRAE sponsored International Air-Conditioning, Heating, Refrigerating Exposition in February, 1996. The demonstration included a BACnet internetwork made up of all four BACnet LAN options (PTP communication was not demonstrated). The building control applications on display were a chiller system with thermal storage, a multi-zone variable air volume (VAV) system, a building lighting control system, and a laboratory fume hood control system. Four different BACnet workstations, made by different participants, illustrated the ability to access data from and control applications on any controller in the demonstration, without regard to the manufacturer of the controller. Peer-to-peer controller communication between products made by different vendors was also demonstrated.

BACnet TESTING TOOLS AND PROCEDURES

NIST has been working for several years to develop BACnet testing procedures and software tools. The BACnet Consortium has provided a rich opportunity to test ideas with a wide variety of BACnet devices. It is hoped that this experience can be channeled into the ASHRAE SSPC process to speed the development and acceptance of a test suite addendum to the BACnet standard.

NIST is developing a software tool called Visual Test Shell (VTS) for testing BACnet implementations. VTS runs on a personal computer and provides an easy to use graphical interface for conducting tests. A VTS user can manually generate any BACnet application layer or network layer message and transmit it to a recipient on a local or remote BACnet network. VTS provides packet trace windows that provide a plain language interpretation of messages transmitted or received. It can also execute test scripts and log the results of the test to a file. A text file format of a BACnet Protocol Implementation Conformance Statement (PICS) has been defined. VTS can read these files and establish a local database that matches the device described in the PICS. This is used by VTS to interpret the results of the executed tests in order to determine if the implementation has passed the tests.

The goal of the VTS project is to develop a reliable testing tool that can automate the testing process as much as possible but also provide a manual interface that will permit a skilled user to explore protocol implementation problems. The test scripts and testing procedures can be used as the basis for a BACnet testing addendum. Ultimately the VTS tool could be used by certification agencies to conduct conformance tests. NIST plans to make executable versions of the VTS software publicly available.

CONCLUSION

The BACnet protocol was designed to be used for a wide range of building automation and control products. It can be applied at any level of a hierarchical control system but does not impose a hierarchical structure. Because of this generality it was necessary to define conformance to BACnet in terms of selected groupings of protocol functionality. The standard defines six classes of conformance that are supplemented by functional groups. These conformance classifications provide tools for specifiers of BACnet systems to clearly indicate what BACnet functionality is required. They also provide a framework for comparing BACnet products to determine if they will work together.

Testing and certifying conformance to BACnet is still an open issue. NIST and the BACnet Interoperability Testing Consortium have been working to develop testing tools and procedures and apply them to real BACnet implementations. ASHRAE has formed a Standing Standard Project Committee to develop and approve addenda to the BACnet standard, including a test suite. These two activities are intended to complement each other and to shorten the time until a certification program is established.

ACKNOWLEDGMENTS

The author wishes to acknowledge the Federal Energy Management Program (FEMP) and the Office of Energy Efficiency and Renewable Energy of the US Department of Energy, and the US General Services Administration for providing financial support for NIST's contribution to the development of the BACnet protocol and tools to test BACnet implementations.

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