Integrating Building Automation and Control Products Using the BACnet™ Protocol

By H. Michael Newman
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BACnet™ is a data communication protocol for building automation and control networks developed by the American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE). BACnet is currently an American national standard and CEN prestandard. The BACnet protocol can be used to integrate building automation and control products made by different manufacturers into a single, cohesive system.

This paper describes the main features of BACnet, the motivation for developing the protocol, and the impact the protocol will have on manufacturers and users of building automation products.

Brief History of BACnet

It would be hard to believe that the yearning for a common protocol, useable by all building automation and control systems, originated in a single heart. In reality the frustration was felt by many, but undoubtedly most acutely by those that had some degree of inside knowledge of the inner workings of computer communication technologies as they existed in the early 1980s.

I, for example, noticed that all the direct digital control (DDC) systems that were being offered in those early days used the same type of communications - serial, asynchronous, byte-oriented. Only the format of the messages differed, there being little difference in the content and purpose of the messages.

Consequently, with a knowledge of each protocol it was possible to write fairly straightforward software that could communicate with each type of equipment and could be run on a single, central minicomputer. (Remember that personal computers hadn't been invented yet!) But it was clearly a burdensome nuisance. If only the vendors could cooperate to the extent necessary to develop a standard for data communication...

BACnet, of course, did not spring from the earth fully formed. On the contrary it was the result of nearly 81/2 years of toil, sweat, and tears on the part of a dedicated group of about 20 ASHRAE volunteers who had been assembled into a Standard Project Committee known as SPC 135P. These volunteers came from all segments of the building controls industry including universities, controls manufacturers, government agencies, and consulting firms. Their task was to do what the common wisdom held to be impossible: adopt or develop a standard method by which all computers used in building automation and control could exchange information.

Among the primary reasons why it could not be done were that it was too complicated a task and that the vendors would never cooperate with each other to the extent required. As is often the case, the common wisdom was wrong. What was needed was simply a little vision and a lot of tenacity. Fortunately, these qualities were present in abundance on the SPC.

Why did it take 8 ½ years to produce BACnet? There are two basic reasons. The first is that a consensus developed over time that it was better to do the job *right* than to do it *quickly*. Time will tell if this objective was achieved. The second reason is that it was required by ASHRAE procedures that the standard be developed in the full glare of public scrutiny.

This resulted, in the course of three formal public reviews, in 741 comments. The response to each comment had to be deliberated by the SPC, drafted by an SPC member, the draft approved by the SPC, and the response sent to the commenter.

The commenter then had an opportunity to approve or reject the response. In the case of rejected responses, the SPC was forced to begin the process again until, finally, each of the 741 comments was either resolved to the satisfaction of the commenter or formally unresolved.

In the end, there remained only a scant 11 "continuing objections" but this

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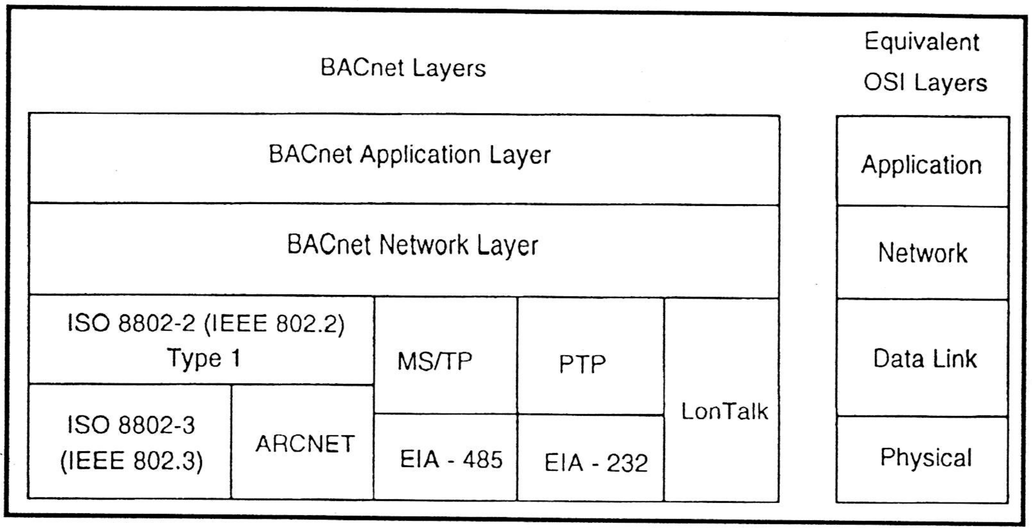

Figure 1. BACnet uses a "collapsed" OSI architecture consisting of the four layers shown at the left. Other lower layer protocols could be added in the future should a consensus develop to do so.

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painstaking process literally took years to complete.

Was it worth it? Almost certainly. The majority of comments represented thoughtful consideration of the draft standard and frequently pointed out areas that needed to be clarified, if not changed.

Even when it was decided to reject a commenter's suggestion, the discussions among the SPC members resulted in a greater sense of conviction about why certain provisions had been written as they had. This made it easier for each member of the SPC to go home and argue that the SPC was clearly doing the right things and that his parent company should ultimately support and implement the standard.

BACnet's Basic Concepts

BACnet is a data communication *protocol* for building automation and control networks. A protocol is simply a set of hardware and software *rules* that govern how computers talk to each other.

These rules address such issues as the characteristics of the electrical (or optical) signaling used on the selected communications medium; how each computer is identified or "addressed"; the method used to arbitrate when and how each computer may use the network; error checking; data compression and encryption; and the specific format of each computer message. Since there is a multitude of ways to address each of these issues, and others that I haven't even mentioned, you can see that the odds of two data communication schemes fortuitously using the exact same selection of options range from infinitesimally low to nil. Hence, the need for standards.

But how does one develop a standard for a particular application area?

Fortunately, this problem was tackled by the International Organization for Standardization (ISO), beginning in the early 1980s. The result of their work was the Open Systems Interconnection (OSI) Basic Reference Model, ISO 7498 [2].

The model represents an effort to make the communication problem manageable by breaking it down into a series of smaller problems, each of which can then be tackled independently of the others. This has been done by defining a hierarchy of functions arranged one on top of the other in seven "layers" where each layer deals with one or more of the issues cited in the previous paragraph.

For example, the bottom two layers of the stack are the "physical" and "data link" layers. According to the OSI model, these layers concern the type of physical interconnection of computers, the electrical signaling, addressing, error detection scheme, and medium access method. The selection of these characteristics, taken together, constitute what today is commonly referred to as a "local area network" or LAN.

The next layer up is called the "network" layer and describes the characteristics of protocols designed to allow multiple LANs to be connected together. Above it are the "transport," "session," and "presentation" layers, each of which deals with communication characteristics most often associated with wide area, as opposed to local area, networks.

Finally, at the top of the stack, is the "application" layer which addresses the communication requirements of specific applications, for example, building automation and control (BAC). An application layer protocol defines the specific format and content of the messages that two or more computers, each cooperating in a particular application, will use in conversing about their common activities.

In summary, the task of a protocol developer is to identify the specific communication features (OSI layers) required for a particular application and then select or develop the protocols to implement those functions.

In terms of the OSI model, therefore, BACnet is a four-layer protocol stack consisting of an application layer protocol, a network layer protocol, and several data link and physical layer protocols. See *Figure 1*.

In other words, BACnet specifies a model for representing the functions of BAC equipment and the messages to discuss them plus a protocol for interconnecting two or more LANs + several LAN protocols with various cost and performance characteristics. Let's take a closer look at each of these elements of the standard.

BACnet Model

The challenge underlying the BACnet model was to find a way to represent the internal functioning of disparate BAC devices in such a way that it could be the subject of a computer-to-computer dialog over a network. To accomplish this, the SPC

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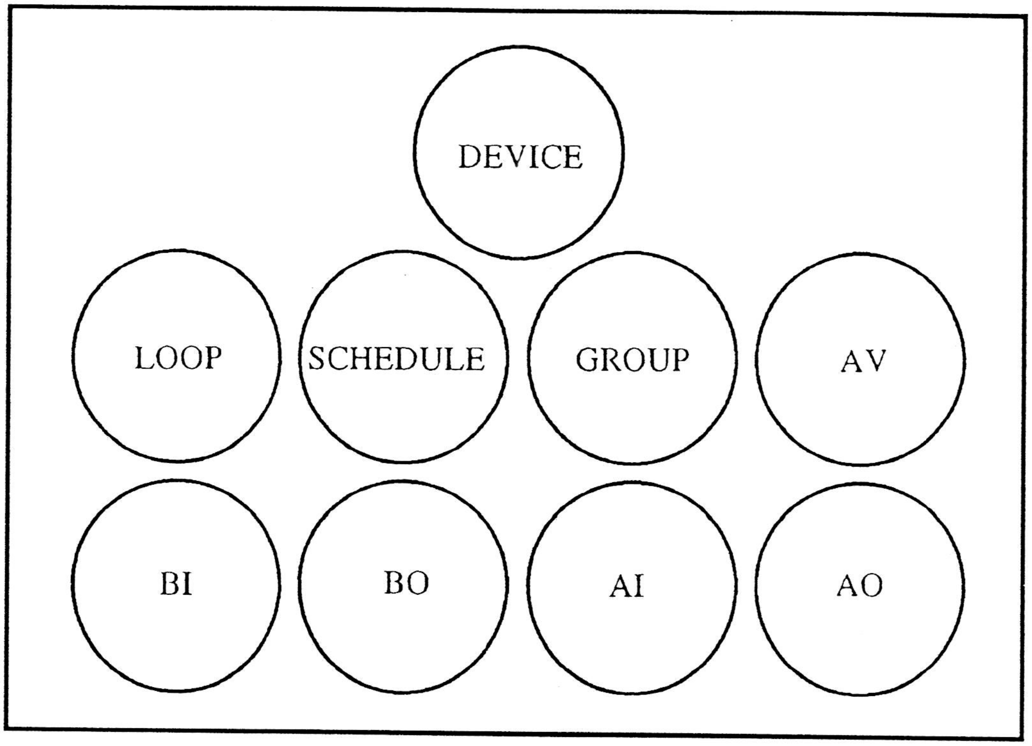

Figure 2. A BACnet device consists of a collection of objects that represent the functions of the underlying, physical device that are to be made "network visible." A real device, unlike this example, would typically have as many instances of each object type as required to represent its actual hardware and software configuration.

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looked initially at DDC devices. We reasoned that most such devices perform very similar tasks even though their internal software data structures are likely to be significantly different. The trick would therefore be to "map" the internal data structures to common, well-defined abstract data structures that we decided to call "objects."

The idea behind an object is that it is a collection of data elements, all of which relate to a particular function. The individual data elements are called the "properties" of the object. While the internal design and configuration of building automation devices will most likely continue to be proprietary and therefore different for each vendor, the properties of objects provide a means of identifying and accessing information without requiring any knowledge of the details of a device's internal design.

The communication software in the device can interpret requests for information about these abstract objects in such a way as to obtain the information from the real data structures inside the device. These objects collectively provide a "network-visible" representation of the building automation device and constitute what we call a "BACnet device."

BACnet defines 18 standard object types. Although these types, such as analog and binary inputs, control loops, schedules, and so on, are particularly suited to modeling DDC systems, additional object types may be easily added to facilitate communications about non-DDC devices that deal with other building automation functions such as fire, security, and lighting control. See *Figure 2.*

BACnet Services

While objects provide an abstract representation of the "network-visible" portion of a building automation device, BACnet "services" provide messages for

BACnet Won't Become Obsolete

The real benefit of using the Open Systems Interconnection (OSI) protocol development model is that it shields BACnet from obsolescence with respect to networking technologies.

While the standard currently specifies certain connectivity options, others can be added because BACnet simply sends its messages over whatever network is used.

One final point about LonTalk because there seems to be considerable confusion in the marketplace. BACnet sends its messages over LonTalk networks in precisely the same way it sends its messages over Ethernet, ARCNET, or MS/TP networks.

The confusion stems from the fact that Echelon, LonTalk's inventor, also has its own set of messages which can be used by devices set up to do so. These messages have nothing to do with BACnet and do not make such devices "BACnet compatible." In fact, even devices using Echelon's language are not interoperable without some agreement between implementors as to the meaning of specific messages.

The main objective of the various LonMark committees is to agree on these message conventions on an industry-by-industry basis. Of course, someone could build BACnet-message-to-LonMark-message gateways but this is conceptually no different than building BACnet gateways to other proprietary, legacy protocols.

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accessing and manipulating this information as well as providing additional functions. BACnet currently defines 35 services which are grouped into 6 categories including alarm and event, file access, object access, remote device management, virtual terminal, and security.

The format of these messages is represented using the rules prescribed by the ISO standard Abstract Syntax Notation One, ISO 8824 [3]. The messages are then encoded into the ones and zeros required for network transmission using rules defined in the BACnet standard itself.

BACnet Networks

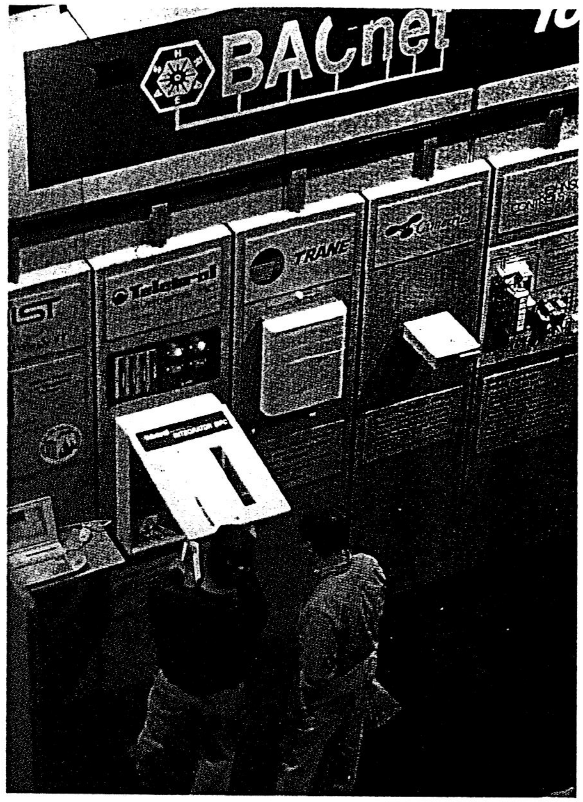
Once encoded, BACnet messages may be conveyed using any one of five different networking technologies. The reason the SPC chose to allow for more than one is that there are actually many different speed and throughput requirements, depending on the specifics of the application. A couple of controllers, for example, that want to share an outside air temperature sensor reading every five minutes or so clearly have a less demanding throughput requirement than a system with hundreds of controllers and thousands of sensor points, many of which are to be shared or whose values are to be logged or displayed on real-time graphics.

Apart from the BACnet Point-to-Point protocol, intended primarily to allow dial-up telephone access to a network, BACnet allows for the use of 4 true LAN technologies including Ethernet (ISO 8802-3) [4], ARCNET (ANSI/ATA 878.1) [5], a Master-Slave/Token-Passing (MS/TP) network defined by BACnet, and LonTalk™ [6], a proprietary network developed by the Echelon Corporation.

Although these networks differ in speed, topology options, and cost, they may be joined together to form a BACnet "internetwork," if an application so requires, through the use of BACnet routers. The characteristics of such routers is defined in the standard.

Relating BACnet to Realworld Applications

The key to properly specifying a BACnet network is to understand the communication requirements of the application and how these requirements relate to BACnet's capabilities [7]. To facilitate this, BACnet defines a set of "conformance classes" and "functional groups." The conformance classes are numbered 1 - 6 and are hierarchical in nature. Each class consists of one or more services that must be supported along with, possibly, certain standard object types.



BACnet's "coming out party" took place in February, 1996 at the International Air-Conditioning, Heating, Refrigerating Exposition (AHR Expo) in Atlanta. The 13 BACnet implementing companies showed their wares for the first time. The reaction of the attendees was enthusiastic.

The classes were chosen with the capabilities of some typical BAC devices in mind.

Conformance Class 1, for example, corresponds to the communication requirements of a device designed to be "read-only" such as a "smart sensor" (a sensor with the ability to transmit its value digitally on a network).

Conformance Class 2 adds the ability to accept output commands and thus might correspond directly to a "smart actuator".

Conformance Class 3 maps to the capabilities associated with application specific, or unitary, controllers such as are used to control VAV boxes, fan coil units, rooftop air conditioners, and so on.

Although conformance classes can be useful to confirm that a certain core group of communication capabilities is present, functional groups are an attempt to facilitate the specification of capabilities by operational function.

The BACnet functional groups include: Clock, Hand-held Workstation, Personal Computer Workstation, Event Initiation, Event Response, Change of Value Event Initiation, Change of Value Event Response, Files, Reinitialize, Virtual Operator Interface, Virtual Terminal, Device Communication, and Time Master.

For each group, BACnet defines a set of objects and services that must be provided.

Suppose, for example, you wish to design a control system that is to perform time-of-day based start/stop functions. You would then specify that the controllers, regardless of conformance class, support the Clock functional group and that somewhere in the system one of the devices, probably an operator workstation, support the Time Master functional group.

Together these specifications would provide controllers with the ability to communicate about time and date along with the ability to synchronize their time-related activities through the exchange of BACnet time synchronization messages.

Future of BACnet

BACnet's "coming out" party took place in February, 1996, at the International Air-Conditioning, Heating, Refrigerating Exposition (AHR Expo) in Atlanta. The 13 BACnet implementers showed their wares for the first time. The reaction of the attendees was enthusiastic. So it appears that BACnet has been successfully launched.

Still, much work remains to be done to ensure the long-term viability of the standard.

The first order of business is the formation of a standing standard project committee, within ASHRAE, that will oversee BACnet on a continuing basis. This committee will be known as SSPC 135.

While the general charge to the committee is to interpret, clarify, and extend the standard where needed, there is already a full agenda of specific items demanding attention.

• **Conformance testing and certification**. At the present time, no formal certification program for BACnet exists. As one of its first tasks, the SSPC will work on an addendum to BACnet that will set forth a set of conformance tests that can be used by a certification agency to verify a device's compliance with the standard. Preliminary work toward this end has already been published and, at the very least, will provide a starting point for this work. [8, 9, 10]

• **Enhanced routing using the Internet Protocol (IP)**. Although Annex H of the standard already prescribes a way that BACnet messages may be conveyed using IP and Novell's IPX protocol, many feel that more efficient mechanisms can be developed. This would facilitate the use of BACnet at sites where an IP-based infrastructure already exists such as most university campuses and many large industrial facilities.

• **File formats for trend and event logs**. Although BACnet currently provides services to send and receive files, there is no definition within the standard of their internal formats. Trend and event log files have been suggested as candidates for standardization, and there may well be others.

• **Definition of macro objects**. Many application specific controllers use a large number of related analog and binary parameters to carry out their functions. These parameters could be considered the properties of a large scale object that would generally correspond to the ASC's function. Thus the SSPC could define, for example, a "unit ventilator controller object" whose properties would have the values of the parameters necessary to carry out the control algorithm. This would avoid the overhead associated with mapping each parameter to one of the currently defined BACnet objects, such as the Analog Value object, which has a significant number of properties that must be supported in addition to its present value.

• **Fine tuning the conformance classes and functional groups**. The existing conformance classes and functional groups provide a jumping-off point for specifying BACnet systems although systems can be specified without their use. Some people, however, believe that the conformance classes would be more useful if they were client-server oriented with separate conformance class profiles for each. There is also some sentiment for adding additional functional groups and perhaps fine tuning the existing ones.

Conclusion

With the flurry of commercial activity aimed at bringing BACnet products to market and the ongoing efforts of the SSPC to refine and enhance the standard, the next several years promise to be exciting ones for those people who have long hoped for the advent of a viable interoperability standard for building automation and control systems. ■

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