BACnet™ and LONWORKS®: Compared and Contrasted

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Introduction

Over the course of the past 20 years, building owners, managers and consulting/specifying engineers have become increasingly frustrated by incompatibilities and limited opportunities for the integration of building automation and control systems. Although the sophistication and flexibility of networking and communications technologies in general have been increasing geometrically, controls systems for buildings have carried forward a legacy of proprietary thinking which has impeded the natural migration of many of the benefits of open networking technology into building systems. The bottom line effect has been that, while many modern building automation and control systems incorporate some of the latest advances in networking technology, the benefits of interoperability, configuration flexibility, and performance-based pricing have yet to be realized by building owners and operators. Through accident or intent, building automation and controls systems have simply failed to embrace true open systems concepts effectively for building owners.

Several solutions have come into widespread use and are changing this situation permanently and dramatically.

One such solution is called BACnet™: The Building Automation and Controls Network. BACnet is an *international standard* for computers used in building automation and controls systems that was developed between 1987 and 1995 by ASHRAE. In December of 1995, BACnet was also adopted by ANSI, and is now an American National Standard (ANSI/ASHRAE 135-1995, ANSI/ASHRAE 135-2001, ANSI/ASHRAE 135-2004). In 2001, BACnet became an international standard (ISO 16484-5). Nearly every major vendor of building automation and controls systems in North America and many vendors in other countries have demonstrated support for BACnet in the form of new products. Today there are over 130 registered vendors and hundreds of BACnet products in daily use.

Another completely different solution is called LONWORKS® which was originally a proprietary communications technology marketed for several years by the Echelon Corporation in partnership with Motorola. Today, the underlying communications technology called LonTalk has become an ANSI standard (ANSI/EIA 709.1). This technology has been applied by a large number of vendors in many automation markets including Building Automation and Controls, although the total number of BAS vendors is only a subset of the much larger number of LONWORKS vendors.

This paper will explore both of these systems in some detail to help bring into focus the substantial differences between each approach. We will also focus on various popular myths in order to dispel some of the confusion and misinformation that has surfaced as these different solutions have been introduced to the marketplace. A key point to keep in mind is that BACnet and the family of technologies LonTalk, LONWORKS and LONMARK, are not designed to solve the same problems, although their areas of application have some overlap. It's important to be clear about the specific application when making comparisons.

BACnet and LonWorks: Summary

All of the technologies discussed here are fine technologies with clear strengths, clear weaknesses and clear areas of appropriate application. However, the reality is that buyers and specifiers of building automation and controls systems don't all want the same things. There is no "one size fits all" solution, and each available option has tradeoffs associated with it.

LONWORKS-based products have been applied to many kinds of automation problems. In fact, worldwide deployment of LONWORKS-based systems applied to BAS is extensive, particularly in terms of systems that have limited size, scope and interoperability requirements.

By comparison, since its introduction in 1995, deployment of BACnet-based systems has grown substantially both in terms of number of vendors and products, as well as number of installed devices. This trend has picked up a lot of momentum since BACnet became an international standard in 2001. A controversial study by the prestigious market research firm Frost & Sullivan in 2002 predicted flattening growth for LONWORKS products and geometric growth for BACnet going forward. While I won't try to debate the efficacy of the report's conclusions, it is interesting to note that the claims of the report's detractors that BACnet growth was overstated have been overshadowed by the reality that the actual growth of BACnet deployment has far exceeded the projection.

Perhaps we can explain the increasing popularity of BACnet by pointing to some of its principal benefits:

- Practical interoperability between building automation and controls systems from multiple vendors
- Real choices for scalability between cost, performance and size
- Systems based on ANSI and international standards
- Endorsement and adoption by nearly every major building automation and controls vendor in North America and in many other countries
- Capability for integration with and use of existing LANs and LAN infrastructure
- Highest performance and Lowest cost
- Robust internetworking including multiple LAN types and dial-up
- Easy and robust scalability from very small to enormous system sizes
- Unrestricted growth and the ability to add new innovations and new features anytime
- An open, transparent, no fee, consensus process for ongoing use and maintenance of the standard where every interested party has a voice

What is BACnet?

BACnet is both an American National Standard and an international standard. This is literally a book which describes in great detail how to create an automation and controls system which may *interoperate* with other BACnet systems. In BACnet terms, interoperate means that two or more BACnet-speaking computer systems may share the same communications networks, and ask each other to perform various functions on a *peer-to-peer* basis. Although BACnet does not require every system to have equal capabilities, it is possible for designers of system components at every level of complexity to have access to functions of other automation system peers. In the BACnet world, there is no class distinction between large controllers, small controllers, sensors, actuators and operator workstations or host computers, other than in terms of the number and kinds of interoperations they require of each other. There are two key concepts in BACnet that are critical to understand.

First, is the idea that BACnet is applicable to all types of building systems: HVAC and BAS, Security, Access Control, Fire, Vertical Transport, Maintenance, Waste Management, Lighting, and so forth. The same mechanism that gives BACnet this flexibility has two other important benefits: *vendor-independence* and *forward-compatibility* with future generations of systems. This is accomplished using an *object-oriented* approach for representing all information within each controller.

The second key idea is that BACnet uses any combination of six types of *local area network* or *LAN* technology for transporting BACnet application messages. These six types of LAN choices give the system designer or owner significant flexibility in choosing the best fit among price/performance options that suits each situation. All of the LAN options are ANSI or international (ISO) standards. Since BACnet is based on standards, it provides maximum benefits for both the vendor who designs BACnet systems, and the specifier or owner of those systems.

BACnet provides a sophisticated model for describing automation systems of all types. This model is based on the idea that for systems to be truly interoperable, there must be some agreement about various aspects of the overall operation and the individual systems themselves. BACnet organizes its model into these component parts:

- *Objects* to represent system information and databases, along with a uniform method for accessing both standardized and proprietary information, as well as a rich set of standardized object types.
- *Services* which allow BACnet devices to ask each other to perform various functions in standardized ways, including services suited to special applications requirements such as Life Safety.
- *LANs* which provide transport mechanisms for exchanging messages across various types of networks and communications media.
- *Internetworking* rules which permit the construction of large networks composed of different LAN types, again using standardized methods.
- *Conformance* rules which define standardized ways of describing systems in BACnet terms, and standardized forms for describing which optional features of BACnet a given system provides.
- A separate *Testing Standard* so that specific BACnet features and interoperations can be tested and compared in a known and standard way.

Each of these components delivers important benefits to purchasers and specifiers of BACnet systems. BACnet is not a guarantee that forces all systems to be the same, or even an assurance of interoperability since no one is required to use BACnet, or to implement all of the same BACnet features. BACnet does provide the mechanism to allow cooperating devices to interoperate if they choose to.

Objects

BACnet's object-oriented approach to accessing and organizing information provides a consistent method for controlling, examining, modifying and interoperating with different types of information in different types of devices, which is both vendor-independent and forward-compatible with future BACnet systems. BACnet defines standard *object types* that represent commonly used objects found in many existing automation systems. The 2004 standard includes 25 unique standard object types.

BACnet objects are collections of *properties* each representing some piece of information or parameter. Some properties may only be examined (read) while others may also be modified (written). BACnet defines not only what the properties of standard objects are, but also what types of behavior are to be expected from each property. Standard objects also have *optional* properties, which need not be implemented by every vendor, but if they are implemented then they must behave as the standard describes. These standard objects may also have *proprietary* properties that are added by vendors at their discretion to provide additional features. A BACnet device may also implement *proprietary object types* that can provide any type of feature or set of properties that the vendor chooses.

The key to the object mechanism is that every object and every property, whether standardized or proprietary, is accessible in the same manner. To use a proprietary object or property, you need only know of its existence and purpose. Of course, one vendor's system may not necessarily "know" about all possible proprietary objects and properties in another vendor's systems.

Services

BACnet services provide standard methods for one BACnet device to ask another BACnet device to do something, or to inform other BACnet devices that something has happened. For example, if one BACnet device needs to find out something, like a temperature, it can use the *ReadProperty* service to read a property of an object in the other device that represents the temperature. Similarly, the *WriteProperty* service can be used to make adjustments in another device, like changing a setpoint property. BACnet defines a comprehensive range of different services that cover access to objects and their properties, alarms and events, device and communications management, file transfer and virtual terminals. As with standard objects, not all devices are required to or will choose to implement all services. Vendors may also provide *Private Transfer* services to make new proprietary services available.

LANs

BACnet allows systems to use any of six types of Local Area Network, or LAN, technology. These different choices represent a range of different features, cost and performance, so no one technology is desirable or appropriate for all applications in automation systems. Each LAN type has unique benefits and liabilities that may make it preferable in one situation or another. We will talk about these issues in a later section. The LANs available to BACnet systems are:

- Ethernet 8802-3
- ARCNET
- MS/TP
- PTP
- LonTalk (Layers 1-4 as a transport)
- BACnet/IP over UDP

Internetworking

Real networks in real buildings need to interoperate together. The network that operates all of the VAV Terminal boxes on one floor of a building, needs to be accessible, not only to the air supply system for that floor, but to the building management as well. In a multi-building campus, or dial-up applications, the system must necessarily be composed of multiple separate networks that have intermittent reasons to interact between devices on two or more networks. Not all of these networks will use the same LAN technology, for reasons of cost and performance. Because there are multiple networks, we have several issues to confront:

- getting information from devices across multiple networks
- controlling and isolating unrelated message traffic between networks
- interfacing disparate LAN technologies and signaling
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Internetworking addresses each of these issues. One of BACnet's key strengths is the sophistication and flexibility of its internetworking that is achieved at only a modest cost to most BACnet devices. Typically internetworking is accomplished in BACnet using special devices called *routers* which couple two or more different networks together. Although BACnet routers can use the same LAN technology on each end of a router, more typically routers are used to couple different LAN types together. The important thing to keep in mind is that a BACnet router couples together two or more BACnet LANs.

It is also possible to have devices called *gateways* which couple a BACnet LAN to a non-BACnet LAN, perhaps using a proprietary communication scheme. Gateways are inherently more complex than routers because in addition to equalizing the differences between LAN types, gateways must also manage the usually vastly different *conceptual model* of one application protocol with another. This task may range from straightforward to very difficult or impossible in some cases.

Conformance

As a standard, BACnet describes mechanisms that, if properly applied, can result in systems from different vendors that may interoperate with each other. The big "if" is that each system must implement the features of BACnet that the other system(s) require. Having implemented a BACnet system, a vendor needs a method of telling others what has been implemented. To purchase or specify a BACnet system, one needs a method of describing which BACnet features are desired. BACnet addresses each of these requirements using standardized methods.

BACnet interoperability requirements have been widely misunderstood. Addendum D to the 1995 standard introduced a new scheme for describing the functional kinds of interoperation that BACnet devices may elect to implement. This scheme is based on a concept called "BACnet Interoperability Building Blocks" or BIBBs. BIBBs define a pair of interoperating devices and the BACnet features and expectations each one has when performing that particular role.

There are five areas of interoperability that closely relate to those defined in ASHRAE Guideline for Specifying DDC Systems GPC-13. Owners and specifiers may select the functionality desired from each of the interoperability areas that must be implemented for each kind of control device and write that into a performance specification by referencing specific BIBBs. Implementors of BACnet systems can publish the functionality that their devices can provide also in terms of BIBBs. BIBBs provide definitions for BACnet features that cover many different specific capabilities for Data Sharing, Alarm and Event Management, Scheduling, Trending and Device and Network Management.

Although interoperability requirements can be defined entirely using BIBBs, another useful concept in BACnet is called a device *profile*. A standard profile is simply a named collection of BIBBs that correspond to minimum interoperability features that are characteristic of a given class of device. BACnet defines a number of standard profiles that represent typical collections of interoperability features that might be expected to be useful in several classes of devices: Operator Workstations, Large Building Controllers, Small Application-Specific Controllers, more Advanced Application Controllers, Smart Actuators and Smart Sensors. But many other combinations are possible and in the end it's really BIBBs that define capabilities not profiles.

To facilitate the description of a BACnet implementation, BACnet defines the *Protocol Implementation Conformance Statement* or *PICS.* The PICS defines information that must be provided to identify all of the key features of a BACnet device. The PICS identifies the manufacturer, make and model, which BIBBs are supported, what minimum profile is indicated by the BIBBs supported, which standard objects are present, which optional properties of those objects are implemented, the acceptable range of values for writable properties, what type of LANs are supported with what types of media, etc.

Summary: What is BACnet?

BACnet is an International Standard as well as an ANSI Standard that defines methods for organizing applications and databases used within automation systems so that they may interoperate with each other across multiple types of LAN and media combinations. The standard further specifies standard mechanisms for describing typical types of objects and processes which may exist in automation systems, methods for extending this functionality into future and present proprietary systems, and methods for specifying and describing BACnet functions and features in standardized ways. There is also a companion Testing Standard for BACnet that defines standardized test procedures for evaluating different BACnet systems. BACnet systems are realized by sending and receiving messages across various types of transport mechanisms (LANs) using a common communications *protocol*.

Nearly every major vendor of building automation and controls systems in North America, and many other countries, has participated in the development of BACnet, and are actively selling BACnet-based controls today. BACnet has been widely implemented and its worldwide deployment is in the millions of nodes and growing rapidly.

What is LONWORKS?

LONWORKS is actually a family of products originally developed by the Echelon Corporation. At the core of this technology is a proprietary communications *protocol* called LonTalk. In this context, the term "proprietary" means that the technology was initially owned by a single proprietor, namely Echelon. Since its introduction, LonTalk has become an ANSI standard, ANSI/EIA 709.1-A-1999 and later ANSI/EIA/CEA-709.1-B-2002.

The LonTalk protocol uses some advanced ideas that are unique to Echelon and their products. Because of the complexity of some of these ideas, Echelon's designers decided to develop a special type of communications "chip" which was uniquely well suited to implementing LonTalk. Using this chip, and the appropriate software, much of the burden of implementing LonTalk could be absorbed completely by the communications chip, freeing the rest of the system for application tasks. This communications chip was called the *Neuron®*. Echelon eventually licensed the chip design to Motorola under a royalty agreement. Motorola became a substantial investor in Echelon. As is their standard practice for most chip designs, Motorola had a cross-licensing agreement with another chip manufacturer, Toshiba. Together, Motorola and Toshiba marketed the Neuron world-wide to various types of OEM developers who applied the LonTalk technology in different markets and applications.

Since its introduction several significant changes have occurred. Motorola backed-out of its involvement with the Neuron and no longer produces it. However, another chip company Cypress Semiconductor now also produces Neurons as well as Toshiba. In 1999, Echelon released a document describing a "reference implementation" of the Neuron functionality. This theoretically allowed other companies to develop their own implementations of the Neuron, or at least devices that could use 709.1 communications. Such implementations are required to enter into a patent licensing agreement with Echelon. The third significant change is the adoption of LonTalk as an ANSI standard as previously mentioned. Several companies, Loytec and TLON, are now marketing alternatives to the Neuron chip design. These developments add new dimension to the already complex LonTalk marketplace.

LonTalk has both a message *transport system* and an *application framework*. The LonTalk transport is like a very simple mailing system that provides system designers with some basic mechanisms for transporting messages between systems. In and of itself, LonTalk transport does not define what these messages contain. Like the U.S. Postal system, LonTalk transport merely provides a way to send a "message" to another recipient. Various options for sending may be used, but the "postal system" doesn't really care what the message says, or whether the recipient can even understand it.

For the message transport system of LonTalk to be useful in a given application, the sender and receiver need to agree on the *content* of these messages. Since Echelon's designers had a fairly good idea of some of the applications that the Neuron and LonTalk might be used for, they were able to develop an application framework that could be used to define the content of application messages. This "one size fits all" protocol represents the *session, presentation and application* layers of LonTalk and is often referred to as LONWORKS.

In this paper we will make the distinction between the lower transport layers of LonTalk and the upper application framework layers by consistently calling the upper layers "LONWORKS." Echelon and others also market tools for interacting with LONWORKS devices which are often called LONWORKS, but these tools are not the subject of this paper.

LONWORKS Interoperability Mechanisms

LONWORKS devices make use of several mechanisms for interoperation. Two key mechanisms are called *network variables* and *configuration properties*.

Network variables are individual data items that are shared amongst a group of cooperating devices. A network variable can be shared by repeatedly transmitting the value for any controller that cares to look at it, or through the use of a confirmed procedure that assures that each member of a group receives the value. The use of the confirmed procedure, what Echelon calls "end-to-end acknowledgement," limits the scope of sharing to 64 devices that must be members of the same group. There are at most 256 groups per LonTalk domain. Each LONWORKS device is configured to be a member of these groups through a process called *binding.*

The sharing of network variables allows devices to share information in a number of ways using a large collection of specialized datatypes. These packages of network variable data are called "Standard Network Variable Types" or SNVTs (pronounced "snivets"). The SNVT method is a different approach to defining data objects that requires a detailed knowledge on the part of the sender and receiver of what the structure of each SNVT is and is similar in some respects to BACnet context-driven base datatypes. SNVTs are identified by a code number that the receiving controller can use to determine how to interpret the information presented in each SNVT. Obviously it's important for all LONWORKS devices to have the same interpretation for the code number, hence the notion of "standardized" types. Early proprietary uses of these codes created a possibility for unintended interactions between proprietary LONWORKS implementations. The correct approach is to use "User-Defined Network Variable Types" or UNVTs, where at least the onus is on the receiver to scrutinize the proprietary source of the variable before using it.

The open-ended nature of network variables is both a strength and a liability. The liability comes from the fact that proprietary applications may unintentionally abuse network variable types so it is possible, and regrettably commonplace, for LONWORKS systems from different vendors to use the same network variables to mean different things. At best this causes confusion when these systems are coupled together, and at worst causes inappropriate actions to be mistakenly taken.

To help solve this problem, a consortium of Echelon vendors was formed to try to agree upon some rules for how LONWORKS should be used, and to agree on a common set of network variable codes and their associated meanings, as well as to determine common groupings of network variables that should be used for specific applications. This group is called The LONMARK® Consortium, and the documents that they have produced are also commonly referred to as LONMARK. In theory, controllers that only use the LONMARK subset of LONWORKS capabilities can be made to interoperate with each other, and at least not interfere with each other's proper operation. The LONMARK Consortium members must pay substantial membership fees for their on-going participation in LONMARK. Only the highest paying tiers of members may vote on extending LONMARK capabilities.

Among the usage standards that LONMARK has attempted to develop for its members, are definitions of object types that are in some ways similar to BACnet standardized objects. Each LONMARK object exchanges information with other LONMARK objects using only network variables. Most objects also require customization for a specific system application. The LONMARK guidelines specify data structures called *configuration properties* that provide standards for documentation and for the network message formats used to download the customization data to the device by network tools. The LONMARK Association defines a standard set of configuration property types; these are called "Standard Configuration Property Types" (SCPTs). Manufacturers may also define their own configuration property types; these are called "User-defined Configuration Property Types" (UCPTs). SCPTs are defined for a wide range of configuration properties used in many kinds of functional profiles, such as hysteresis bands, default values, minimum and maximum limits, gain settings, and delay times. SCPTs are to be used wherever applicable and are documented at www.LONMARK.org. In situations where there is not an appropriate SCPT available, manufacturers may define UCPTs for configuring their objects, but these must be documented in resource files according to the LONMARK standard resource file format.

While these are all good ideas, keep in mind that LONMARK is not a standards-making body. These conventions are created by the association members, not by an open consensus process. Also keep in mind that LONMARK conventions are not part of the ANSI standard 709.1.

LONWORKS Issues

Although LONWORKS has been applied in various markets for a long time, the application of LONWORKS in the building automation and controls market is less mature. In the context of building automation and controls applications, some vendors have used the innate ability of Neurons to contain applications in addition to communications, as a means of offering both the application and networking capabilities at a modest cost. The flexibility of using different media types with Neurons is realized with *transceiver* devices that plug on to a common foundation, making it possible, by design, to use different media types with the same device. So more capable transceivers can be plugged in to increase performance without changing anything else. Of course, more performance comes at a higher cost.

Initially, various vendors appeared in the marketplace with products implemented based on LONWORKS. Many had bought into the promise of automatic interoperability as a "free" consequence of using the Neuron and LONWORKS. As previously mentioned, this turned out to be problematic. The formation of LONMARK, though envisioned as a solution to this problem, has brought forward various new problems. While LONMARK has created an industry consortium to attempt to standardize on implementations of LONWORKS, there is still a lot of confusion and very little actual interoperability. Part of this comes from different expectations about what interoperability means.

Let's focus on several myths and misconceptions about LONMARK, LONWORKS, LonTalk and their relationship to BACnet.

One major problem is that LONMARK is not extensible without the agreement of "gold level" LONMARK members. So vendors who need to add functionality to their systems may not do so without violating their agreement to adhere to LONMARK (therefore losing the right to bear the LONMARK mark), or convincing the golden members to bless their extensions. For purchasers or specifiers, this restricts your choices to "gold member approved" features and functions (of course provided only by <u>their</u> companies). Since LONMARK is not a standards body, features may come and go as members elect, so no assurances of forward compatibility can be made in good faith by any LONMARK member, since future changes or enhancement may easily compromise backward compatibility.

A second problem is that not all systems are LONMARK systems. It is both possible and probable that LONWORKS will continue to be used by some vendors who do not wish to, or cannot afford to, buy in to the LONMARK consortium. Since the primary justification to applying LONWORKS is the alleged attraction to integrating communications with an application in the same device (i.e. Neuron) to *lower costs*, then development cost, manufactured cost and ongoing support cost are clearly important issues.

A third problem is compartmentalization. In the zeal to define LONMARK profiles for particular kinds of automation devices (which are good things) perhaps the LONMARK members have lost sight of the fact that low level device interactions are not the only interoperability requirements that exist. While it's nice that this LONMARK thermostat works with that LONMARK controller, how easily does that controller interact with other controllers, supervisory controllers and higher level components, especially as the system scales to larger sizes that are typical in so many building automation contexts?

BACnet LANs Revisited

This table briefly summarizes each technology. The *system cost per node* represents the cost of using this technology in a real system including issues like wiring costs, installation costs, the need for repeating devices etc.:

LAN	*system cost per node*	*speed*	*pros*	*cons*
Ethernet 8802-3	high	10-1000Mbps	international standard already in most buildings variety of media (UTP, coax, fiberoptic) very fast easy interface with PCs no special development tools	high infrastructure cost distance limitations non-deterministic
ARCNET	med	150K-7.5Mbps	ANSI standard deterministic response scaleable speed variety of media (UTP, coax, fiberoptic) very fast no special development tools high perf. for med cost	single source chip too costly for low end unitary controllers distance limitations
MS/TP	low	9.6K-76Kbps	ANSI standard low cost can be implemented in single chip microprocessor deterministic response	single media (EIA-485) limited speed
PTP	low	9.6K-56Kbps	only choice for dial-up specially designed for point-to-point applications accommodates modern modem standards (V.32bis, V.42)	point-to-point only limited speed
LonTalk	low-med	32K-1.25Mbps	variety of media (UTP, coax, RF, IR, fiberoptic) scaleable speed	non-deterministic distance limitations single source chip special development tools application size limited

Although it is misleading to generalize about the pros and cons of these LAN types, it is useful to point out some of their individual limitations and issues that affect their cost when applied in real situations for automation systems. Both Ethernet and LonTalk are *non-deterministic* technologies which means that because of the way they work, there is no way to guarantee how long it will take for a message to get from one node to another under any circumstances. LonTalk's approach improves on the Ethernet scheme by attempting to predict potential collisions thereby improving, so it is claimed, confidence in assuring delivery times. Both schemes suffer degraded performance when the network becomes busy, potentially interfering with automation functions as traffic increases. ARCNET and MS/TP use a *deterministic* scheme that makes it possible to determine the worst case performance of a particular network configuration, which may be desirable in some instances.

Although each LAN has distance limitations, Ethernet, ARCNET and LonTalk are potentially much more limited because they can employ higher communication speeds. Above about 156Kbps, the maximum distance of an unrepeated network segment for any of these LANs drops dramatically. For Ethernet, the maximum distances are about 1000' for thick wire (10Base5), 600' for thin wire (10Base2) and 300' for twisted pair (10BaseT). Similar restrictions apply to ARCNET and LonTalk, depending on the media used. ARCNET, LonTalk and MS/TP can employ EIA-485 baseband signaling at speeds below about 156Kbps over up to 4000' of twisted pair wiring.

ARCNET and LonTalk have the disadvantage that they require the use of a dedicated special communications chip from a limited number of manufacturers. In contrast, Ethernet chips are available from many different sources worldwide. This impacts the cost and supportability of end devices made with these technologies, and directly drives the cost and availability of third party devices such as repeaters, bridges and routers, not to mention diagnostic equipment.

Unlike ARCNET, LonTalk can be implemented in Neurons along with small applications. So in some instances it is possible to implement both the communications system and the application programs within the same chip. In these cases, the Neuron may provide an economical alternative to an ARCNET solution that would require an additional microprocessor chip to handle the application. In these same instances, a typical single chip microprocessor could be used without a Neuron to implement MS/TP for similar, if not lower, cost. When the size of the application becomes more demanding, the Neuron simply does not have enough resources to handle both jobs at the same time, therefore requiring the addition of a separate microprocessor. In these instances, the MS/TP approach is always more cost effective if you can live within the limits of MS/TP in terms of speed. The typical microprocessor solution would be hard pressed to provide MS/TP above about 76Kbps. For speeds in excess of 76Kbps, coupled with larger application requirements, either LonTalk or ARCNET become preferable. At 156Kbps, using baseband EIA-485, the cost is similar between LonTalk and ARCNET. At speeds above 1.25Mbps, or when deterministic response is needed, ARCNET is the clear choice. ARCNET chips are also available which include an additional 8031 microprocessor suitable for small applications, although the cost of these chips is slightly higher than Neurons.

The introduction of newer CPUs, such as the powerful ARM7 employed by Loytec and TLON implementations of 709.1, makes this evaluation more complex. Now, a lot more processing power can be brought to bear on the problem, with enough left over for additional application tasks. However, this extra power isn't free and lower cost CPUs that can take advantage of MS/TP are still the king in terms of lowest cost.

LonTalk has the unique distinction that it is the only LAN technology in this group that really requires special proprietary development tools. Developers who are in the business of making microprocessor-based controllers will already have all the development tools they require to create solutions using the other technologies. The proprietary development aspects of LonTalk have a direct impact on purchasers and specifiers, because these costs will be distributed to them in terms of higher product costs, or long term service fees, or both. While this is less of an issue now that there is a 709.1 standard, it's still a big barrier to using LonTalk as a transport for BACnet.

BACnet/IP

There is another LAN technology option that allows the use of BACnet over IP networks. The tight integration of IP with BACnet is a key strength, but also a complex topic. All of the other LAN types usable with BACnet make use of a transport technology that is essentially a media access or MAC layer. This is both good and bad. On the good side, MAC layer support in BACnet devices means efficient usage of the underlying transport technology. On the bad side, sometimes this creates an issue when another technology is sharing the same infrastructure.

The so-called Internet Protocol, or IP, is in widespread use and clearly is the dominant type of LAN technology in many buildings today. When we talk about an *IP-centric infrastructure* we mean a combination of LAN wiring and routers that support IP-based communications. Like BACnet's internetworking layer, IP is a network layer protocol for routing and transport applications. Although the most famous of the IP protocols is TCP/IP, there are actually a family of many different protocols that are typically carried over IP infrastructures. Like BACnet, IP uses routers to couple together LAN segments and to provide logical isolation of sub-networks or *subnets* from each other.

One of the common IP protocols is called the User Datagram Protocol or UDP. UDP messages basically contain a source and destination *port number* or *socket* and a payload of data that UDP doesn't understand the content of, but is responsible for delivering. BACnet/IP devices make use of a well-known UDP socket number to encapsulate BACnet messages in the payload of UDP datagrams. This may seem like an inefficient way of using your Ethernet, since the IP and UDP message itself is just overhead compared to sending a BACnet message directly using 8802-3. However, this turns out to be an advantage in some situations.

In a building with an IP-centric infrastructure, the Ethernet LAN will be typically partitioned into many separate segments, coupled together with IP routers. In some cases, IP routers that see 8802-3 messages that do not contain IP, either automatically repeat these messages (passing them transparently through the router) or they may be configured to allow this feature. If the IP infrastructure has these kinds of routers they are invisible to BACnet Ethernet 8802-3 devices. However, some kinds of popular IP routers specifically block all non-IP traffic. This can cause problems for BACnet devices on either side of this kind of router that may need to communicate with each other. One solution is to use a *tunnel router*, similar in concept to the CEA-852 routers used with LonTalk. However, if the BACnet devices themselves can use BACnet/IP, then the BACnet message itself is conveyed in a UDP message, which can pass easily through the IP-only router. So for any facility based on IP infrastructure, there are some advantages to having BACnet/IP devices.

Regrettably, there is still a problem that comes from IP routers. A number of BACnet's service depend on the ability to *broadcast* a message that many recipients can hear. While this is not a problem for the other LAN types, such as Ethernet 8802-3, it is a problem for IP routers. Most IP routers intentionally block broadcasts and restrict them to only devices in a particular subnet. As a result, if you have an IP infrastructure with multiple subnets (which is common) and you have BACnet/IP devices in different subnets that need to find out about each other, the routers get in the way. Fortunately, BACnet/IP solves this problem through the use of BACnet Broadcast Management Devices (BBMDs). BBMDs automatically forward broadcast messages to each other for redistribution on individual subnets.

Does LON Technology Cost Less Than BACnet?

There are really two issues here. First of all, let's ignore the long list of things you can do with a BACnet network which simply can't be done with a LONMARK network. Let's just focus on some application which is achievable by either approach. The first issue is whether a LONMARK-based device will be less costly than a BACnet-based device. The second issue is whether a "BACnet over LonTalk LAN" device will be less costly than a "BACnet over MS/TP LAN" or "BACnet over ARCNET LAN" device.

There are two possibilities for the first case. Either the application is small enough to fit into a Neuron along with LONMARK, or it isn't. If the application fits in a Neuron along with LONMARK, then the Neuron serves the same function that a single chip microprocessor in a "BACnet using MS/TP" device would. From a pricing standpoint, Neurons are not substantially less or more than average microprocessors, falling in the middle of the pricing pack. The alleged low price of Neurons is only available in very large quantities, where regular microprocessors are available at substantially more attractive discounts. The newer CPU designs (e.g. Loytec) are several times more expensive than Neurons and most small microprocessors, so they aren't even part of the "cost is everything" comparison.

If both solutions use baseband EIA-485 signaling below 156Kbps, the cost of transceivers or line drivers is the same. Current actual implementations of BACnet and MS/TP on real off-the-shelf systems show conclusively that the memory requirements in terms of RAM and ROM are similar. If the application doesn't fit in the extra space in the Neuron, you are forced into using an outboard microprocessor, and the cost comparison is clearly in favor of the BACnet approach. So if cost is the issue, LONMARK/LONWORKS/Neurons is not an advantage. If you factor the added costs of development systems and debugging tools into unit costs over, let's say, the first 100,000 units, BACnet is clearly the winner. LonTalk has some distinct advantages in terms of speeds higher than 156Kbps and media flexibility which were pointed out earlier, but cost isn't one of them.

The second issue deals with cost for BACnet devices only. The question is whether using LonTalk as a transport medium costs more or less than other alternatives such as MS/TP and ARCNET. This is a similar comparison to the one we just looked at above, but even more severe. In this case, we would be trying to fit LonTalk and a BACnet application layer and the application program into the confines of a Neuron. Again, since cost is the issue, we eliminate the newer Loytec-type implementations which have larger memory space. This can definitely be done. For example, Staefa (now part of Siemens Building Technologies) has developed BACnet devices that have been demonstrated with these capabilities. As in the previous example, once the application presses the limits of what can be managed within the Neuron, an outboard microprocessor (or a much more expensive core chip like the Loytec) is required and the cost war is over. Like the previous example, there is no cost advantage to using a Neuron with LonTalk over using a conventional microprocessor with MS/TP as a vehicle for BACnet. If speed is the issue, but cost is still a concern, then the roughly 76Kbps speed limit to MS/TP may rule out this option. In this case, ARCNET at 156Kbps using EIA-485 is a viable option to LonTalk. If the Neuron by itself cannot contain the application and BACnet and LonTalk and higher speed is required, then ARCNET is definitely an option since the cost of the ARCNET outboard chip is similar to the Neuron in equivalent quantities.

In any of these examples, the other costs are more or less equal. Whether you use Neurons or ARCNET or conventional microprocessors, EIA-485 circuitry costs the same amount. With or without magnetically and optically isolated power supplies, with or without transformer coupling, the signaling circuits have the same costs for each of these LANs (LonTalk, MS/TP, ARCNET) for the same media.

One comparison not often discussed is the issue of software costs. In the case of ARCNET, sample software to provide the transport function is available free from the manufacturer and numerous public domain examples exist, though none specifically targeted to BACnet (that I know of). Most of the functionality for ARCNET is inside the chip and not changeable anyway. There is no special licensing fee for using ARCNET. In the case of MS/TP, the developer must write their own software or purchase it from a third party, so the development costs must be amortized over some number of units, adding to the cost of that solution. In the case of LonTalk, while it is theoretically possible to implement your own chips to perform LonTalk functions that involves a considerable investment, as Loytec and TLON will attest. Typically Neurons are purchased and software is written to make the Neuron implement LonTalk. The developer may undertake this themselves or license this software from Echelon. In the Loytec case, 709.1 software is licensed from them directly. In either case, special development tools are required which may only be purchased from these vendors. Opinions will vary regarding the cost to develop communications software. However, for a vendor with a serious (10K-100K units) commitment to development, the difference in cost between developing your own BACnet software, such as MS/TP, and licensing LonTalk for the Neuron in those quantities is about 20 times less to make your own. If we factor in the added cost of special development tools the cost of LonTalk is much higher still.

LonMark: A Little System

Make no mistake about it, LONWORKS, and its intentionally restricted subset LONMARK, are little systems by design and intent. The capabilities of the Neuron, and performance limitations imposed by limited memory architecture within the Neuron chip and the design of LONWORKS, place practical limits on the size and scope of LONWORKS logical segments and the interactions which can take place. There are restrictive limits on the number of simultaneous *bindings* and network variables which can be accessed and shared on a given segment or across segments at one time. Remember that only 64 network variables can be shared within a group if end-to-end acknowledgement is desired. These limitations are not so onerous in the context of the small system concept for which LONWORKS was intended: 40 or 50 nodes within a radius of 100'. However, these limitations are simply unworkable in many building automation contexts today, and unthinkably limited in terms of growth. That's not to say that you can't make a large system built up out of LONWORKS, or even LONMARK, nodes. The questions is the degree of interoperability you will really be able to have between individual devices in these systems.

There are numerous examples of common everyday problems in building automation systems networking which historically have not been easily solved using LONWORKS or LONMARK devices by themselves. Let's discuss a few of these and look at how BACnet and LON-centric implementations typically solve the problems.

Remote dial-in and/or PBX coupling of LAN segments between buildings is a common building automation task. Using BACnet, this application is solved in both cases by a PTP half router. Many larger BACnet controllers already incorporate such features as built-in capabilities. Ask two such routers to dial each other, and you're done. Once the connection is established, the half-routers act like full BACnet routers and literally any BACnet function is allowed across the dialed connection.

Using LONMARK, there is no capability for dial-up routing, no capability for internetwork routing with session establishment, no capability for eliminating circular routes, etc. This type of function would have to be provided in some non-standardized way using proprietary dial-in gateways. What standard protocol would they use to resolve these problems? Just exactly how does a LONMARK device cause dialup to a remote LONMARK network to occur? Answer: it can't. The closest capability is the LONMARK profile for a Modem Controller. This simple object just allows a client to initiate (or try to initiate) a dialout connection based on the occurrence of an alarm, and places the burden on the client to know everything about the connection to be dialed.

Communication between two nodes across an existing Ethernet LAN is another common building automation task. Using BACnet, this application is solved using Ethernet routers, for example ARCNET to Ethernet or MS/TP to Ethernet (or LonTalk to Ethernet!). The coupling is automatic and invisible to nodes on either end. It is also very common for BACnet controllers to support Ethernet 8802-3 connections directly. The most ubiquitous BACnet routers are Ethernet to *X*. In the past, using LONMARK, there was simply no way to provide routing across Ethernet, since the LonTalk Network Layer does not provide the mechanisms necessary to make this happen. Several years ago, Cisco and Echelon introduced a *tunnel router* to provide this feature in a proprietary device. Since that time this tunneling technique has become a standard (CEA-852) and now several companies make tunnel routers that can be used to interconnect multiple 709.1 LonTalk networks across Ethernet, and in some cases across IP networks. This class of devices does a lot for allowing the construction of larger LonTalk-based networks, but again it is not part of LONMARK or an architectural component of LonTalk at all.

Given the ubiquitous presence of Ethernet LAN infrastructures in many buildings, and increasingly IP-centric infrastructures, it is also common to want building controllers and workstations to be able to interact freely across these infrastructures. With BACnet, which supports both Ethernet 8802-3 and BACnet over IP natively, this just isn't an issue. BACnet controllers are routinely connected to these LANs. However, device-to-device communications through tunneling routers such as the CEA-852 routers used with LonTalk can be problematic. At best, communication is slowed down by the inherent need for retransmission of the tunneled message which is unnecessary using BACnet Ethernet or BACnet/IP controllers. In this scenario, a typical controller-to-controller LonTalk implementation requires two tunnel routers to bridge the Ethernet or IP segments that separate the LonTalk networks, much like a scenario where two MS/TP devices on separate segments need BACnet routers to cross Ethernet. To be comparable to common BACnet Ethernet and BACnet/IP based controllers one needs to look at CEA-852 based controllers that also have 709.1 support since by itself CEA-852 does not provide the facilities for a general controller to act as a client or server.

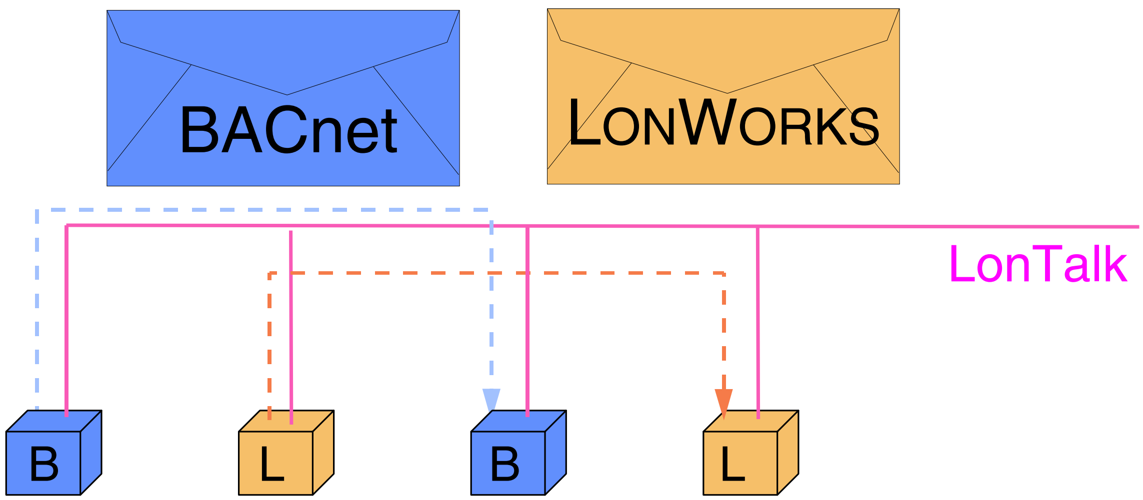
These, and many other examples, are due to the limited capabilities in the LonTalk strategy for internetworking, which never envisioned these types of application. BACnet, on the other hand, was designed from the start for this kind of scalable internetworking.

LonTalk: The Common Link?

A major problem has been the intentional misinformation espoused about the linkage between LONMARK/LONWORKS and BACnet. Many people have been mislead to believe that because LonTalk is a possible LAN for use with BACnet, that therefore LONMARK or LONWORKS systems are somehow *BACnet-compatible!*

LONMARK and/or LONWORKS devices cannot and do not interoperate with BACnet devices!

The technical reasons for this are simple. Even if a BACnet device uses LonTalk as its LAN, each message sent by that device in a LonTalk "envelope" will be expressed in BACnet "language." This BACnet language is totally different from and incomprehensible to a LONMARK or LONWORKS device which is expecting LonTalk envelopes containing "LONWORKS language."



As this drawing shows, the "B" boxes are sending BACnet messages over a LonTalk network to other "B" boxes. The "L" boxes are sending LONWORKS messages to other "L" boxes. Although these messages do not interfere with each other, the "L" boxes are not able to interoperate with the "B" boxes because the contents of the messages are incompatible.

The incompatibility arises from the fact that the application "languages" in the BACnet scheme are based on ideas and concepts that are very different from the LONWORKS scheme. Not only are the concepts different, but the method of encoding these concepts into numeric codes is also very different. If one wanted to have LONWORKS devices and BACnet devices interoperate, it would be necessary to have a *gateway* device between them which understood both schemes and had a method for converting from one to the other.

As it turns out, this is a fairly complex problem. Many of the ideas in BACnet, simply have no equivalent concept in LONWORKS. As a result, many of the capabilities which are expected of a BACnet device would have to be emulated by the gateway. Since BACnet devices may contain arbitrary extensions which are proprietary, and easily accessed by other BACnet devices, some or all of these extensions may have no equivalent in LONMARK. The consequences of these and other technical issues make the construction of any form of off-the-shelf BACnet-LONMARK gateway a practical difficulty. There are several companies that market gateways like this that make various trade-offs to bridge the significant philosophical differences between approaches.

It is certainly possible to build a device which could understand both LONWORKS and BACnet at the same time. Clearly such devices would require additional resources which would generally add significant extra cost to these traditionally cost-sensitive devices.

Fruit or Vegetables?

To ask "which is better?" is the wrong question. In terms of interoperability it's important to think about what kinds of interoperability you need, and how flexibility, performance, cost, choice, maintainability, operation, configuration and a host of other variables figure into your particular equation.

LON technology is available in many forms from a large number of vendors. Several different standards have grown out of the efforts to evolve this technology in various directions, not to mention the considerable efforts by the LONMARK trade association's members to define and adopt conventions for the use of some of the technologies themselves. Some of the manufacturers that market LON-related technologies have impressive and powerful products, including the products from the technology's creators at Echelon. Taken as a package, the marketplace has a range of interesting choices that can be effective for solving automation problems, and can deliver some of the interoperability promise.

But the LON technology marketplace is not a single standard, or even coordinated by a single organization. At best we can say that a loosely-coupled set of standards, products and trade association guidelines define the design space for LON-based products at this time.

BACnet comes from the hard forge of a consensus process with continuous maintenance and an open and transparent participation. Interested individuals, owners, specifiers, product developers, small companies and large, both domestic and international, may all participate with a balanced voice. The fruit of those efforts is a comprehensive and dynamic international standard that continues to grow in depth, and deployment, worldwide. New addenda have increased the scope and applicability of BACnet and that trend has no end in sight. Under the single umbrella of BACnet's well-honed process, the standard, and its revisions, and its internationalization, and industry deployment have proceeded at a comparatively rapid pace that few other standards can boast of.
