Title
Trends in Energy Management Technology: BCS Integration Technologies - Open Communications
Networking

Author
Webster, Tom

Publication Date
2002-09-18

New Technology Demonstration Program

Technology Focus

FEMP

Federal Energy Management Program

Trends in Energy Management Technology:

BCS Integration Technologies – Open Communications Networking

Tom Webster, P.E.

Center for the Built Environment
University of California, Berkeley CA

Lawrence Berkeley National Laboratory
Berkeley, CA

LBNL - 47358

Introduction and Background

Note: Please refer to Appendix A for a complete listing of all acronyms and their definitions.

Introduction

Our overall purpose in writing this series of articles is to provide Federal energy managers some basic informational tools to assist their decision making process relative to energy management systems design, specification, procurement, and energy savings potential. Since Federal buildings rely on energy management systems more than their commercial counterparts (see [1]), it is important for energy practitioners to have a high level of knowledge and understanding of these complex systems.

This is the second article in a series and will focus on building control system (BCS) networking fundamentals and an assessment of current approaches to open communications protocols. This is important because networking is a complex subject and the networks form the basic infrastructure for energy management functions and for integrating a wide variety of OEM equipment into a complete EMCIS. The first article [1] covered enabling technologies for emerging energy management systems. Future topics will concentrate on more practical aspects including applications software, product offerings, networking strategies, and case studies of actual installations. Please refer to the first article for a more complete overview of the purpose and background for this series.

BCS Communications Networks

There are two primary driving forces behind the vast changes that are occurring in BCS communications networking technology: 1) technological change, and 2) the open systems movement. Since we have discussed technological change in our companion paper we will focus the following discussion on open systems.

In general open systems embrace three major concepts: open source software, open communications protocols, and open data exchange. Open data exchange includes standardization of databases, data objects, and data presentation software (e.g., browsers). While a major driver for open systems derives from the user's desire for simplification, interoperability, and low cost, one of the strongest drivers comes from the Internet and the move to "web-enable" virtually all applications. While all of these categories of open systems will have an impact on BCS development, we will focus here on open protocols and open data exchange. Furthermore, since a discussion of open systems cannot be divorced from a discussion of standards, standards issues will be interwoven into the open systems discussions.

The central focus of open protocol efforts in the BCS industry is the standardization efforts by BACnet and LonMark, and the corresponding changes the BCS vendors are making in their proprietary offerings to accommodate openness. A similar process is occurring in other industries, most notably industrial process control and information systems (IS), which will also affect BCS development.

In assembling this assessment we have relied heavily upon building control system experts, product literature, white papers, technical papers, and news and journal articles. Our intent is to provide as impartial and accurate a portrayal of the state of practice with emphasis on evolutionary trends and emerging technologies.

Networking Fundamentals

Introduction

We begin our discussion with an overview of networking since it is essential to have a grasp of basic concepts to be able to clearly understand issues as well as to interpret information being provided by vendors and consultants. We will discuss (1) network architectures as they apply to the BCS industry, (2) networking fundamentals, including a short primer on protocols, and (3) the contending approaches to open protocols.

Network Architectures

Although product and technical literature contain descriptions of various BCS network architectures, it is the evolution of these architectures and how they fit into a broader perspective that we focus on here. This is important because of the on-going convergence of technologies (voice, data, video) and the increasing internetworking of communications infrastructures that is the hallmark of the information age.

Figure 1 shows a generalized view of the interrelationship between network types and how BCS networks relate to others. This diagram illustrates the most common arrangements being developed today but does not indicate the vast array of legacy systems that make up the bulk of the installed base.

Networks can be broken down into two fundamental types:

1) Point-to-point - store and forward, or switched WANs that pass messages through a network node by node, and
2) Broadcast - multiple access or multi-drop LANs that (typically) use baseband[1] signaling with various access methods to share a single channel; i.e., each node sees packets sent to other nodes. [2]

BCSs can be characterized by the four-level architecture shown in Figure 1. While this hierarchical structure predominates in the buildings industry, it is being "flattened" by merging levels together as the technology evolves; e.g., sensor and terminal bus' merged together so sensors and terminal controllers co-exist on the same sub-network, or field panels and terminal unit controllers on the same bus.[2] However, in general, the sensor bus is not yet implemented as a discrete layer, although it is being developed in the industrial process industry. For BCS networks the trend is toward more internetworking just as it is for IS networks. In addition, as IS protocols become more standardized, and components less expensive, they are migrating further down the network hierarchy (see discussion below about Opto 22). One reason this is important is because of the impact it is having on the development of EMCIS standards.

As indicated in Figure 1, the *sensor bus*, connects sensors and actuators together and interfaces to the *terminal bus* level (referring to HVAC terminal equipment unit controllers such as VAV boxes, fan coils, etc.), which in turn connects to field panels at the *BCS backbone* level. Above the backbone level are various levels of EIS networks that ultimately connect to WANs. Typically EISs are client-server based, which distinguishes them from real-time peer-to-peer control networks. Client-server functions are contained in a set of protocols that sit on top of the networking protocols that are most familiar to the building control industry. Integration with the EIS is important in distributing control system information to higher level EIS applications. This is in fact one of the major drivers for change in BCS technology, the ability to port control system information into the EIS environment and thus service a much more diverse set of enterprise information needs than previously was possible.

Table 1 is a "roadmap" showing the relationship between the typical BCS network architecture and the various protocols used. This list includes common protocols that are or will be candidates for the architectural level shown. These are included to provide the reader with a basic framework for tracking the evolution of protocol development efforts that affect the BCS industry.

[1] Baseband refers to digital signaling whereas broadband refers to analog signaling. LANs and WANs use both of these techniques.

[2] In actual practice flattening depends more on the functions of system, its size, and the desire to segregate communications traffic than on technology availability. Merging these networks lowers costs and allows more direct integration with enterprise wide applications and WAN access and is changing the administration of these infrastructures away from the facility departments to the MIS departments.

Figure 1: Network Architectures

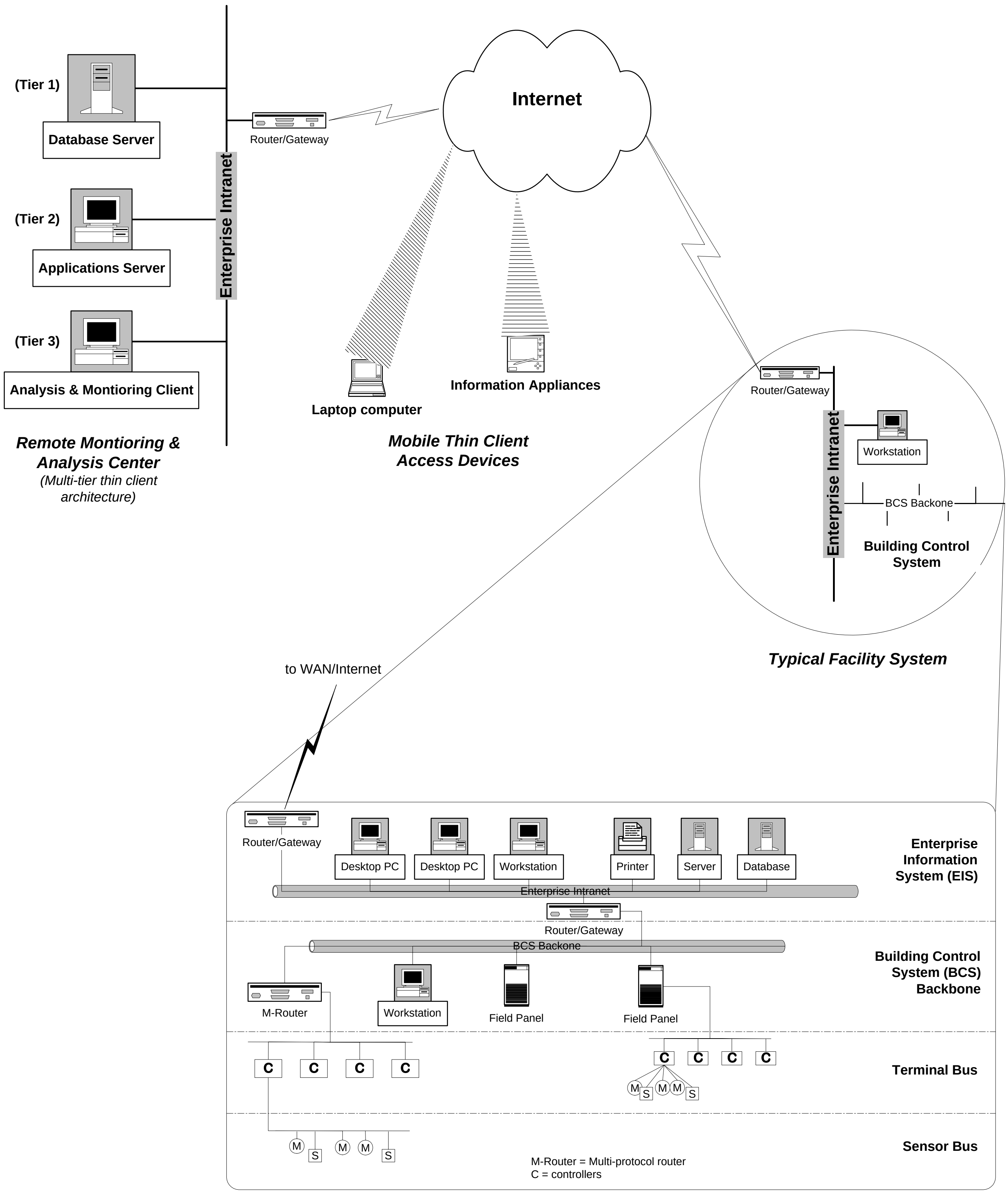

Table 1: Roadmap of Networking Protocol Options*

Network Level	Protocol Suite Options* Note: / indicates 'on top of" or 'over' data link/physical layers.	Standard or Specification Sponsor**	Remarks
Enterprise/ Intranet	CORBA IIOP	OMG	Client-server object standards via consortium//SIG of 800 companies
	COM,DCOM DDE OLE,ActiveX,OPC	Microsoft	Microsoft's client-server object model specifications that compete with CORBA. OPC is the initiative to adapt ActiveX to industrial real-time control.
	Java RMI	Sun	Java based C-S object model that competes with COM and CORBA
	TCP-IP/Ethernet	Internet Society RFCs/ IEEE 803.2	
	Novell IPX SNA	Novell IBM	Two examples of early computer networking technologies developed by Novel and IBM that still have large installed bases
BCS Backbone - Field panels (Control)	TCP,UDP-IP/Ethernet	Internet Society RFCs/ IEEE 803.2	Protocol suite of choice for intranet LANs
	Proprietary/Ethernet, ARCNET	Various control and HVAC OEMs	
	BACnet® /Ethernet, ARCNET BACnet-IP/Ethernet	ANSI/ASHRAE –135-1995, IEEE-803.2	
Terminal bus - unit controllers (Fieldbus)	Proprietary/EIA-485	Various control and HVAC OEMs	Typically proprietary master-slave or token passing low speed, low cost protocols used ubiquitously by BCS vendors since 1980's.
	Proprietary/Ethernet, ARCNET	Various control and HVAC OEMs	
	BACnet MS,TP/EIA-485	ANSI/ASHRAE –135-1995, IEEE-803.2	
	LonTalk/TP, PLC, RF	ANSI/EIA-709.1 and 709.2,.3	Adoption of Echelon's LonTalk. Requires a license from Echelon. Twisted pair, RF, and powerline carrier standards for are contained in EIA-709.2,.3
	Profibus	EN 50 170	European fieldbus bus standard
	DeviceNet	Allen Bradley	Short distance industrial sensor bus derivative of CAN that competes with other field & sensor buses. Uses CSMA.
	Modbus/Modbus+//TCP//IP	Modicon	Token passing industrial process protocol for PLCs now supported by several BCS vendors
Sensor Bus – sensors & actuators	DeviceNet, ControlNet	Allen Bradley, Rockwell	Short distance industrial sensor bus derivative of CAN that competes with other sensor buses. Uses CSMA.
	LonTalk/TP, PLC, RF	EIA-709.1	
Others (Emerging protocols to watch)	Bluetooth	Bluetooth SIG	Short-range self-configuring wireless networking protocol for information appliances (e.g., PDAs, etc.) being developed under auspices of 1200 member Bluetooth SIG
	Wireless Ethernet	IEEE 803.11	Wireless Ethernet LAN protocols being developed by IEEE.
	Firewire	IEEE 1394	High speed data bus primarily for PC peripherals
	Fieldbus	Fieldbus Foundation	Fieldbus Foundation works to implement the ISA SP50 specifications to develop an interoperable sensor bus for distributed process control.
	IEEE 1451	IEEE 1451.1-.4	Industrial process sensor/actuator interoperable interface standards.

* We do not attempt to distinguish individual OSI layers here, only indicate the various protocol suites that are used or under development for the particular architecture level shown. Parentheses indicate typical industrial process level designations.

** In this table we include both *de jure* standards as well as “specifications” being developed by SIGs and private companies.

Networking Protocols & Standards, Basic Concepts

Protocol – A protocol is a detailed, structured method of communicating certain types of information. When we use the term "protocol" in reality we are referring to a "protocol stack," i.e., a series of protocols that are used to send messages between devices (nodes) on a network or between different networks. When discussing protocols it is useful to use the OSI multi-layer model for a

Table 2: OSI Protocol Model

An easy way to conceptualize protocols is by using a layered model. Each layer performs specific functions and interfaces to the layers above and below. While the generalized model used by ISO (called the OSI model) consists of 7 layers, most HVAC protocols utilize only 3-5 layers (typically Layers 1-3,4 and 7).

Layer	Description	Function	Examples
Layer 7	Application	Interface to applications logic; data object interfaces	HTTP (HTML/XML web pages); SMTP, SNMP (email), Telnet, FTP BACnet
Layer 6	Presentation		
Layer 5	Session		
Layer 4	Transport	End to end security; assembly and ordering of message fragments	TCP UDP
Layer 3	Network	Addressing and Routing	IP BACnet LonTalk
Layer 2*	Data Link (LLC+MAC**)	Contention resolution, medium access, channel allocation	TDM FDM WDM (DWDM) ATM CDMA (wireless) CSMA (Ethernet) PPP,SLIP (for IP protocols) Token passing (ARCNET) Master/Slave
Layer 1*	Physical	Signaling, topology and media	EIA 232,485 10,100BaseT SONET (fiber) RF,FHSS, DSSS (wireless) ISDN

*Note that many LAN standards combine these two layers into one specification; i.e, Layer 2 and Layer 1 are not necessarily "mix and match."
** The MAC sub-layer is a very important component that specifies the packet structure and the rules for how a device accesses the network.

protocol stack that was created by ISO and is outlined in Table 2. The message, or packet, consists of various headers that are significant to the services being performed at each layer as well as for interfacing between the layers (i.e., addressing, contention resolution, etc.), and a data element that contains the application information. The lower four layers are considered "connectivity" layers, and the upper three "application" layers. For BCS applications, only the top application layer is generally used.

The workhorse protocol for WANs has been the TCP/IP stack that was originally developed for the Internet but now is used routinely for Intranets (LANs within enterprises) as well. Of course there are many other protocols being used in various types of LANs and WANs but there appears to be a steady migration in newer LANs towards the TCP/IP/Ethernet[3] standards. Although this makes internetworking easier it still does not make it possible to connect LANs and WANs together without some sort of interface device. For TCP/IP Intranets it is usually a "multi-protocol router" since the signaling protocols for the two networks are different (see discussion below about networking protocols). All of the networks can be classified under the terms "distributed processing" or "distributed intelligence" networks, as opposed to the central processing systems of old.

Standard – More care should be exercised in the industry when this term is used. We reserve this term for "true" or *de jure* standards, i.e., those promulgated by recognized standards organizations such as ANSI, ASHRAE, IEEE, EIA, ISO, and ITU. To apply this term to proprietary or *de facto* protocols tends to confuse and mislead and usually results from overzealous marketing efforts. Just as important as standardization is the availability of multiple suppliers; a standard that does not capture enough of a market to warrant multiple suppliers fails to achieve one of the primary goals of standardization – low cost from competition and thus easy access to a uniform implementation.

Even worse is the overuse of the designation "open system." Open can have just about any meaning one wants to put on it. As generally applied in the BCS industry, "open system" usually refers to those systems that allow connection by alternative protocols used by competing vendors. This definition has little to do with standards, proprietary systems can be interconnected by virtue of an agreement between two parties (see discussion below). "Open" implies the willingness to cooperate but the devil is in the details. For example, when a license is required to use a protocol, it represents a barrier to use and may compromise the concept of "free and open access to any and all parties." The author believes that a protocol cannot be truly "open" unless it is a standard as defined here. The process of standardization makes the specifications available to all comers without restriction or preconditions at virtually no cost. Even this definition is not completely adequate, since for example, implementing ANSI/EIA-

[3] The slashes between acronyms is synonymous with "over" and denotes the hierarchical relationship of the OSI model; i.e., TCP/IP means TCP (Layer 4) over IP (Layer 3).

709.1[4] requires a license from Echelon Corp.[5]

LAN Characteristics and Performance – A detailed discussion of networking technology is beyond the scope of this paper but a basic understanding of some key characteristics of LANs typically used in BCSs is important to frame the following discussions about BACnet and LonMark. There are three data link protocol technologies that are important to BCS networking: Master-slave (M-S), token passing (TP), and carrier sense multiple access (CSMA).

The master-slave protocol has been the most popular choice for lower levels in the network due to its simplicity and flexibility. This technique relies on a master node to orchestrate traffic on the network; the master initiates all transactions usually by polling the slaves. Although this is not technically a peer-to-peer solution, in practice it can be made to work like one.

Token passing schemes are "multi-master" and operate by passing a token from node to node. Only when a node holds the token can it transmit a message.

CSMA is the technique used in Ethernet (IEEE 802.3) and LonTalk. CSMA methods are fundamentally different than the two above. M-S and TP are orderly non-contention schemes while CSMA is a contention method where each node begins to transmit a message at will unless it detects[6] a collision with message being sent at the same time by another node. Various types of probabilistic backoff algorithms schedule retries.

Each of these has advantages and drawbacks, there is no perfect solution, and each was invented to solve certain problems and/or to overcome limitations from previous developments. The pros and cons can be evaluated to some extent from the following key factors:[7]

- Efficiency – ratio of message data bits to total bits in a packet; accounts for overhead in the protocol.
- Throughput – ratio of actual packet transmission rate relative to line speed signaling rate; depends on how efficiently network traffic is managed.
- Response time – the time it takes to respond to a request for data; important for time critical operations.
- Determinacy – the consistency in delivery of message packets; are there varying or known delays.[8]
- Peer-to-peer – the ability of nodes to talk directly to one another without a master being involved.
- Signaling method – baseband vs. broadband; i.e., digital vs. analog signaling; also determines cost of implementation.

[4] ANSI/EIA-709.1-A-1999 is the ANSI/EIA standard that incorporates Echelon's LonTalk protocol. [3]

[5] When a license is required there is another critical concern - who determines interoperability. To preserve openness, a separate, independent certification organization is required to allow competing vendors a certification method that does not require the "blessing" of the company granting the license.

[6] Technically this protocol is called CSMA,CD where the CD denotes collision detection..

[7] Most of these factors result from the MAC and physical layer specifications, but upper layers also will have an affect.

[8] This issue is being overcome for CSMA schemes by advances in the technology; see the discussion under the BACnet section.

- Data rate – raw signaling rate, i.e., bandwidth.
- Complexity – relates to difficulty of implementation in terms of initial cost, memory size, and maintenance.
- Topology – the geometric layout of the nodes and wiring. Bus, star, and ring are the configurations of most importance to BCS networks.
- Bus length and number of nodes – the combination of length of wire and number of nodes that can be supported without repeaters.

All of these factors influence one another in determining overall performance. For example, for CSMA networks, speed and bus length determines contention slot timing and therefore the minimum packet size required. Bus length is inversely proportional to speed; lower the speed the longer the bus can be. Table 3 provides an overview of the three data link protocols of interest in terms of these key factors.

When considering the pros and cons it is good to bear in mind Tannenbaum's view. He points out that numerous studies of these different access schemes have been conducted and have not identified any clear winner in terms of performance (i.e., throughput, efficiency, etc); they all work reasonably well so frequently factors other than performance drive the choice of one over the other. [4]

Interoperability – This is a complex subject that we intend to treat in more depth in the future. For our present purposes we assume that the Holy Grail of interoperability is "plug and play" – the ability to substitute devices of equivalent *functionality* for one another without special tools and configuration. This allows end users to enjoy the benefits of easily interchanging devices from multiple vendors that work the same way as one another.

Communications connectivity (meaning the lower four layers of the protocol stack) is assumed to be compatible within this concept. However, compatible connectivity itself is no assurance of interoperability. Interoperability is facilitated by the adherence to standards in the upper layers, primarily the application layer (Layer 7). Object standards, are application level methods for facilitating interoperability. Interoperability requires that all disparate applications adhere to the same object standards. Furthermore, use of these objects may be necessary for interoperability, but in and of themselves they do not guarantee equivalent *functionality* which is in the domain of the control logic.

Integration - Closely allied with interoperability, integration connotes the interfacing of multiple systems of distinct functionality such as HVAC, lighting, security, access, fire and life safety. While interoperability is useful to accomplish system integration it is not sufficient; many other issues must be resolved for these complex system to interact in a seamless and synergistic way. For example, deciding which data to exchange between the systems and what an appropriate system response should be to data input from other systems.

Table 3: Data Link Protocol Comparison

	CSMA	TP	M/S
Peer-to-peer	Yes	Yes	No
Complexity (relative)	Medium	Medium -High	Low
Signaling method (typical for BCS industry)	Baseband IEEE 802.3, EIA-485 (and derivatives)	Baseband IEEE 802.4,5 or EIA-485	Baseband EIA-485
Data rates (typical bandwidths for BCS)	39 kps – 100 Mbps	19.4 Kbps – 10 Mbps	9.6 kps – 78 Kbps
Determinate	No	Yes	Yes
Efficiency	Decreases with speed increase since minimum packet size increases. Low (10-15%) for short messages due to minimum packet size.	Medium to high - Increases with load and message size	Medium to high - Increases with message size
Throughput	Excellent at low to medium loads, saturates at high loads due to increase in number of collisions	Excellent at high load	Low to medium
Response time	Fast for low traffic loads, degrades with load	Slow relative to CSMA for low loads due to token passing time, but no degradation for high loads	Slow
Topology	Star, bus	Bus, Ring, Star	Bus
Bus Length	500 m – 2.5 km	~600 m	~1200 m
Other	Variations in implementation have potential to improve on determinacy and performance	Susceptible to lost token which complicates protocol	Requires a master node which makes the network susceptible to its failure and compromises response time and throughput.

Networking Components

Gateway, Routers, Bridges and Repeaters – There is much confusion (as well as marketing hype) generated around these concepts. In an attempt to avoid being bogged down in technical nuances inherent in these concepts, we believe HVAC practitioners and energy managers will benefit from using the conceptual framework illustrated in Table 4. All of the devices listed in Table 4 are considered at minimum two-port devices that support interfacing functions between two message streams. Remember that there is a "protocol" associated with each layer of the OSI "protocol stack" and a message (or packet) uses all of the available layers. The five component types listed in Table 4 perform a service (action or "translation") of some kind between the two message streams at the protocol layer(s) indicated.[9] It is only the gateway, however, that actually performs a translation of the *data* portion of the packet. This is why the gateway generally has limited functionality, is a customized device, and requires support and maintenance.[10] As such it can be an expensive undertaking. Implementation of a robust gateway is estimated to cost $20-50K and take 3-6 months to design, program and test. However, for simple data objects it can be considerably cheaper and in fact has been routinely done in the form of "drivers" in the industrial process industry for a number of years at costs as low as $2-5K.

[9] Layers 5 and 6, (Session and Presentation) are not listed here because they are generally not used in BCS protocol stacks.

[10] Gateways can become complex because they must link domains that may not share the same ideal of what objects are and how their associated methods perform; the gateway has to know a lot about both object domains to successfully bridge between them. To simplify this process, the object translations can be done at low levels in the network thereby reducing the burden on higher level objects.

Table 4: Networking Components

Protocol			Gateway	Tunneling or Multi-protocol Router	"Pure" Router	Bridge	Repeater
Layer	**Description**	**Function**					
Device Function			Route/forward and translates data frames of packets between dissimilar networks	Route/forward packets between dissimilar networks	Route/forward packets between similar networks	Store and forward data link frames	Copy bits between cable segments; regenerate weak signals
7	Application	Data object interfaces	X*				
4	Transport	End to end reliability	X				
3	Network	Addressing and routing	X	X	X		
2	Data Link	Contention resolution	X	X		X	
1	Physical	Signaling	X	X			X
Examples			• LonMark to BACnet • Proprietary to BACnet or LonTalk	• LAN-WAN router • LonTalk to IP/Ethernet • BACnet/Ethernet to IP/LAN,WAN (Annex H tunneling) • LonTalk iLON** • LonTalk to BACnet	• BACnet routers • LonTalk Routers • LAN-LAN and WAN-WAN routers		• Media extenders • LonTalk repeaters • EIA-485 repeaters

X indicates which layers are involved in providing the services of the indicated device; the functionality of the other layers is the same for both ports.

* Although generally a gateway device supports two entirely different protocols and therefore supports routing functions, it's the application layer "translations" that are key to the gateway concept. A special form of gateway may involve only the applications layer; where all other functions remain unchanged except a translation is made for the application data objects. This could occur, for example, if BACnet objects were used in a LonTalk network.

** The iLON now being developed by Echelon performs both tunneling router functions and gateway functions. The latter is inherent in supporting a web-server thus requiring a translation between a BCS protocol and HTTP for HTML support.

Likewise in the BCS industry this gateway function is also routinely supported in field panel level controllers that support sub-networks of various other controllers (see Figure 1). Some vendors such as Johnson Controls (JCI), have made gateways a fundamental part of their business model; e.g. JCI's Metasys Connectivity Partners program which claims to support protocols from over 100 other companies. Newer web-based product companies such as Silicon Energy also rely heavily on gateways to allow access to legacy networks to support their energy monitoring and analysis software products. An excellent discussion of gateways can be found in [5].

Tunneling routers obviate the need for a gateway to pass messages through different types of networks; e.g., using the Internet to collect data from remote buildings. In tunneling, the entire message (data, addressing, etc.) of a given protocol is "wrapped" (i.e., contained in the *data* portion of the packet) in a secondary protocol as opposed to making a translation. The message travels between two nodes of the tunneling (secondary) network that are each in turn connected to primary networks. At the destination the message is unwrapped and placed on the primary network port untouched. The interface devices between the two network types are called "multi-protocol routers" since they are performing a routing function between two different networks but also generally include support for different data link and signaling formats. Tunneling is being used extensively to support interconnection between networks via the Internet, and within enterprise Ethernet based Intranet LANs.

Driver – Driver is a term frequently used as a catchall phrase for code used to interface a protocol to a device. It is similar to an application-programming interface (API) in that it provides a means for interfacing the protocol to a platform's computing resources/OS and thereby performing a gateway like function of translation into the platform's native schema.

Open Communications Approaches

Proprietary Networks

Proprietary protocols have been the workhorses of earlier generations of BCS networks. They have become robust due to continual upgrading over long periods of time and because the vendors had a vested interest in ensuring a reliable infrastructure for their control devices. Since one vendor provided virtually everything, users had a single point of responsibly to address problems. Many users prefer to work with a single providers system simply to reduce complexity.

The present - Proprietary networks use the same protocol layers and techniques described earlier. Generally, they have evolved from early generations that used simple collapsed three layer structures. For the lower layers, many vendors have used specifications very similar to one another and/or used older *defacto* standards such as Modbus, Opto22, or simple EIA-485 master-slave protocols running at 1.2 to 9.6 kbps. Most of these protocols have been upgraded to higher speeds due to the availability of better transceivers and embedded processors. Also, IT developments have fostered the upgrading of the lower layers of these proprietary networks to more modern

LAN protocols such as Ethernet and therefore provide much better support for greater data transfer demands. However, the proprietary nature of these protocols is derived not so much from the lower layer specifications but from the Applications layer implementations that were and still are custom solutions.

Openness with this approach is based on vendor-supported access; i.e., agreements between vendors to support each other's needs. This has worked well and can be considered an alternative to a standards based approach. As mentioned previously, this approach follows the model that the industrial process industry has used for many years.

There are four basic ways that proprietary networks support openness:

1. Open access protocol – Equipment OEMs provide specifications for an access protocol to their equipment controllers that allows network providers to integrate the equipment into a BCS network usually using a gateway device or integration module of some sort that is interfaced to the proprietary network. JCI supports at least 75 third party vendors using this approach.
2. Open network protocol - BCS providers supply open access via published bus protocol specifications (usually upon request and at lower levels of the network hierarchy) to allow implementation by others directly into the BCS network. This then becomes a third party vendor supported gateway to third party devices. JCI's Open N2 offering is a good example of this approach.
3. Gateways – Gateway support for the BACnet standard or LonMark (see section below). Most of the major BCS vendors now support both technologies.
4. Front ends – System integration provided by support of third party protocols at the front-end workstation. JCIs Unity workstation product is an example of this approach.

The future - Complications have arisen with the proprietary openness approach because users are now demanding that these traditional networks support integration with other vendor's equipment, legacy systems, and other vendor sub-networks in a seamless way. Since the rate of adoption of new standards is slow and there is a large installed based of proprietary networks, and because the major BCS providers still want to retain control over the supply of BCSs there will always be a mix of proprietary and standards based approaches to networking similar to what exists today. However, the lower layers are rapidly becoming standardized either via IT developments or by HVAC industry efforts such as BACnet. The Application layers however, will most likely remain proprietary in the core of the major vendors networks until there is more widespread adoption of either BACnet or LonMark. However, support for these two approaches along side proprietary offerings has become, and will continue to be more, widespread. It is also likely that BCS vendors will continue to provide an alternative integration mechanism by supporting a wide number of third party protocols.

BACnet and LonMark[11]

BACnet, the standard protocol suite that ASHRAE has developed, and LonMark, a protocol suite protocol developed by Echelon Corp. based on their LonTalk protocol currently represent the two main contenders for BCS standardization. Although there is competition between these two technologies, one thing is clear - there will be no "winner." [6] These two technologies (and others) will share in being options for EMCIS specifications. This competition is most intense at the terminal and sensor bus levels of the network where the control devices are located. BACnet and LonMark devices located on the same bus are incompatible with one another. Thus the more established one protocol becomes the greater the potential for revenues based on it. Of course both of these protocols are competing with established proprietary offerings by BCS vendors. This is somewhat analogous to the situation in other industries where newly developed protocols and standards are continually competing with older ones that make up a large installed base. In fact it is our contention that all of the BCS protocols will be impacted to a large extent by ongoing advancements in information technology. The market for IT is orders of magnitude larger than those for BCS and industrial process so component prices are low, standardization efforts are greater, and capabilities are ever increasing. However, although IT dominates the landscape each industry still needs its own standard objects and services to integrate with IT standards in order to support industry specific requirements. It is this set of industry specific objects and services that defines the real value to efforts such as BACnet.

Major efforts have been mounted in the industrial process arena to adapt IT to real-time control applications. PC based SCADA, and OPC, are examples of these efforts, but the most notable is the continuing development of Ethernet. Vast changes in the Ethernet standards are being made to make it more suitable for real-time control and thus a candidate for the lower layers for virtually all levels of the network. [8-12] Opto 22 offers a digital I/O product today that uses TCP/UDP-IP over Ethernet for transmitting sensor data. It even includes a web server so that this device can be accessed over the Internet with a web browser. Cisco and GE have recently formed an alliance to pursue factory automation based primarily on the realization that Ethernet is now ready for widespread use in real-time networks.[12] [14]

BACnet

BACnet is a good example of a "true" or *de jure* standards based technology. The development of BACnet has been long and difficult, but significant progress has been made. Most BCS vendors now support BACnet to a greater or lesser degree[13], but only a few such as Alerton, Automated Logic, and Delta Controls

[11] Henceforth in this paper when we refer to LonMark we assume that it represents the LON protocol suite that is comprised of LonMark application level objects *and* the LonTalk protocol. See the LON Technology section in Appendix B for a more complete description.

[12] For the upper layers, the trend in IT is for the applications to talk to databases and web servers using IT object standards (i.e., XML) and protocols thus obviating the need for a separate set of object standards. [13]

[13] Forty-four companies that offer one or more product types are listed on the BACnet web site.

have complete, native implementations at all levels of the network. However, there is still considerable confusion about BACnet's usefulness and impact. Some of the issues are discussed in the following comments.

The present - BACnet was developed by a recognized standards body, ASHRAE, under a consensus process and is truly open and non-proprietary. Ignoring all arguments about technical issues and innovation impacts, this process is the best method for ensuring open standardization. This process has been, is being, and will be increasingly used throughout the world in virtually all industries in order to level the playing field and ensure broad and uniform implementation of and access to technology.

In the original standard BACnet developed Layer 7 applications objects and Layer 3 addressing conventions. For Layers 1 and 2, existing standards were specified; e.g., Ethernet and ARCNET. Although not a standard at the time, LonTalk was also included as another data link option. BACnet also developed a version of the commonly employed master-slave and token passing schemes called MS/TP used over the popular EIA-485 signaling protocol. These latter protocols have long been the workhorses for terminal level devices in older systems. The BACnet specification also includes a point-to-point (PTP) protocol based on the ubiquitous EIA-232 physical layer. PTP is the basis for accessing networks over modems or direct connections of BACnet gateways to workstations.

Figure 2: Internetworking with BACnet

1. Basic BACnet – Original specification for LANs that uses BACnet specifications for Layers 7 and 3, and choices for data link and physical layers.
2. Tunneling BACnet (Annex H) - A part of the original specification that supports BACnet messages over WANs via tunneling with TCP/IP. Routers carry the burden of managing IP.
3. BACnet/IP (Annex J, Addendum 135*a*) – Added in January 1999, this capability allows BACnet to support both LANs and WANs using "true" TCP/IP; i.e., network nodes are IP addressable.

With the approval of Addendum 135*a* in January 1999, BACnet fully conforms to IP standards. Technically BACnet/IP is a version of BACnet that consists of BACnet Layer 7 objects, UDP for transport, IP for addressing, and choices (typically Ethernet) for Layer 2 data links. It also includes support for broadcast messages. This is a significant development in that BACnet/IP devices can operate on standard TCP/IP networks using widely available IT networking components. It also greatly reduces the need for gateways to access BACnet networks. BACnet internetworking options are summarized in Figure 2.

The future - There are those [15] that argue that TCP/IP is not appropriate for real-time control applications. The argument is that since TCP/IP protocols were primarily devised for client-server networks that do not require the robust and deterministic two-way peer-to-peer communications capabilities of control networks, they are fundamentally unsuitable for control applications. Client-server applications generally are dedicated to transactions that are large, bursty and not time critical. Control applications are just the opposite. Furthermore, TCP (Layer 4) is a "connection oriented" protocol that establishes a virtual circuit between nodes during transactions and uses many sub-transactions for acknowledgments, packet sequencing, etc. that compromise the ability to perform real-time control. UDP on the other hand is connectionless with few accoutrements and thus has become the basis for adaptations for real-time applications.

Many of these arguments are being overcome by advancements in IT and control technologies. This situation is analogous to the early arguments about using Ethernet for control networks in that Ethernet timing is not deterministic (due to the use of contention techniques). This issue has largely been overcome by brute force of high speeds (Fast Ethernet at 100 Mbps and, in the near future, Gigabit Ethernet at 1 Gps), switching technology (allows for full duplex transmissions and private channel communications), segmented network design, and advancements in Ethernet technology (e.g., prioritize messages). [11, 16, 17] This has resulted in Ethernet supplanting ARCNET (ANSI Standard 878.1, a deterministic token passing protocol) as the data link of choice in today's BCS networks. Some BCS manufacturers have migrated to supporting Ethernet after basing their backbone network on ARCNET for many years. In addition, it is likely that advances in industrial process technology will, as usual, filter down to the BCS industry. The industry is pushing the development of Ethernet very hard, as noted previously.

As more emphasis is placed on open object based systems and on integrating control and enterprise information systems, it would appear that mapping BACnet objects in a way that is compatible with these trends is the preferred path. BACnet object services might even be augmented by more advanced and robust client-server implementations such as CORBA, DCOM, and Java RMI.[14] (Only CORBA, however, is an industry consensus specification.) This trend is currently being fueled by an alliance between Tridium, Inc. and Sun Microsystems with the development of the Building Automation Java Architecture (BAJA) standard. This effort is attempting to standardize interoperability at the enterprise level using JAVA, XML and other standard Internet protocols. [18] In any event, developments like these leave the industry specific object definitions and services themselves as the primary element of significance that BACnet brings to the table.

The availability of BACnet/IP is a major step in facilitating the wider use of BACnet but the following additional efforts also will have a major impact:

- Conformance classes are being replaced by new BIBB specifications.[15] A BIBB is a collection of BACnet services that support functions such as data

[14] Since higher level applications will most likely rely on IT object standards, it is important that BACnet objects do not interfere with implementation of services at this higher level; i.e., the focus should be on the behavior of objects not on the ultimate implementation of them. [13]

[15] Conformance classes may have been a good idea but the particular way they were implemented was confusing.

sharing, alarm/event management, trending, scheduling and device and network management. These BIBBS are in turn used in standard BACnet application profiles. All of the functionality of a BACnet device (both standard and proprietary) is required to be reported in the device PICS.

- There is much discussion in BACnet circles about developing high level objects similar to LonMark profiles that would simplify configuring and programming. However, progress has been very slow and no clear consensus has emerged as to how to proceed.[16]
- Establishment of conformance testing tools, procedures and testing agents. Currently this capability is embodied in the open source VTS tools and procedures developed by NIST, which are the basis for a companion standard (Standard 135.1) to BACnet currently (4/2001) under public review. These tools have formed the basis for current conformance testing activities by the BMA. [19]
- NIST has developed a DDC guide specification for BACnet systems. [20]
- Revisions and improvements in the standard are continually being made (e.g., Addendum 135*b* contains 17 changes and additions to the standard). The BACnet committee has been proactive in tracking and adapting to new technologies, as they become available.

[16] In this regard LonMark might be considered to be ahead of BACnet; i.e, BACnet has only recently (1999) started attempting to develop higher level objects similar to the LonMark profiles. And, in fact, there has been some discussion of using the LonMark profiles as a model for BACnet profiles.

Adoption - At first BACnet was being adopted slowly, but now it seems to be gaining momentum. The BMA has compiled the statistics shown in Table 5 reflecting the state of deployment of BACnet devices as of late 2000. [21]

Table 5: BACnet Deployment

Item	Number
Installations	19,054
Gateways	2,410
Devices Network Type • ARCNET • Ethernet • MS/TP • PTP	 95,567 11,920 248,500 1,549
Workstations	15,807
Large controllers	53,391
Unit controllers	299,600

Note that these numbers are based on reports from only six BACnet vendors but represent about 90% of the production of BACnet devices. Note also the small number of gateways and the large number of MS/TP devices relative to the others. It should also be pointed out, however, that one manufacturer who reports 15,000 installations dominates the number of installations. The change in these statistics over time will be of key importance in assessing the ultimate penetration of BACnet.

LonMark

As opposed to BACnet, LonMark exemplifies a *defacto* standards based technology. The strategy with this approach is to create such a presence in the marketplace that users will be compelled to use it simply because everybody else is and ultimately to have it adopted by a standards setting body. Most BCS vendors offer LON support and a few support it exclusively (e.g., ESUSA, Circon). Even more so than with BACnet, there is considerable confusion and controversy about the overall efficacy of this technology. Appendix B contains a detailed analysis of LON technology and its attributes and limitations. The material in this section is largely excerpted from the more complete analysis that appears in Appendix B.

The present - The LonTalk communications protocol stack (a part of the LonMark protocol suite) is modeled after the full seven layer OSI stack contrary to many other BCS systems that use much simpler 3-4 layer structures. LonTalk consists of new protocols for each layer rather than implementing existing standards. In fact the lower layers are a derivative of the CSMA technique that Ethernet uses. This approach was taken so LonTalk could address a wide variety of applications in various industries and operate over various media. To some extent these changes improve on low-load efficiency and high load saturation characteristics of IEEE 802.3 protocols. It also resulted in a maximum data rate of 1.25 Mbps although most systems seem to use 78 Kbps.[17] Although this scheme suffers from the same issues of non-determinacy as Ethernet, it seems to work well for the lower levels in the BCS architecture as long as appropriate network design is followed.

These features (plus the "packaged" LonWorks technology) denote the major innovation that Echelon has brought to the BCS industry: peer-to-peer networking technology at the terminal and sensor bus level, using twisted pair (EIA-485 type) signaling.[18] The FTT polarity free twisted pair transceivers that Echelon has developed represent a major improvement over other EIA-485 implementations.

Another key feature of this technology is that it is *hardware based* in that the technology is imbedded in proprietary Neuron chips as opposed to software based solutions that can be used on any suitable hardware platform. LON technology originally derived its "openness" from the fact that multiple vendors implemented Echelon's proprietary technology.

LonTalk (not LonMark) is now a *standard* due to its adoption by ANSI and EIA. It is still not a *de jure* standard as is BACnet since it was not created by a standard setting body using a consensus process. The support of LonTalk by ASHRAE and EIA are fundamentally different. ASHRAE's BACnet adopts LonTalk as a *data link* specification only; none of LonTalk's upper layers are specified (nor any of LonMark's application level objects). Specification of LonTalk does not ensure BACnet conformance; it represents only one part of BACnet conformance – only the data-link and physical layers much like the MS/TP and Ethernet specifications. For true compliance BACnet objects and networking need to be implemented. LonMark's Functional Profiles are a competing object model to BACnet's

[17] As of 1999 the maximum rate was increased to 2.5 Mbps.

[18] The other media supported by LonTalk have not seen significant use in the BCS networks.

Layer 7 objects; they are not compatible with one another.

EIA, on the other hand, has adopted LonTalk layers 2-7 in EIA-709.1 and Layer 1 options in EIA-709.2 and .3 but also does not include LonMark Functional Profiles in the standard: *EIA-709 standardizes LonTalk - not LonMark profiles.* LonTalk does not support Layer 7 applications services other than the rudimentary SNVTs that can be used to facilitate sharing of variables over a network. The LonMark Profiles use these Layer 7 SNVTs to implement the interoperability guideline conventions. Thus the LON standardization effort falls short of being a complete standard since it is still missing an essential element – a full application layer object specification.

The LonMark organization was created in 1994 to further the cause of creating interoperable LonTalk based products for various applications. This was necessary to address the deficiencies in the LonTalk application layer for supporting interoperability. LonMark is a trade association sponsored and controlled by Echelon (i.e., Echelon owns the LonMark trademark) and therefore LonMark lacks the autonomy and neutrality of an independent industry organization or standards body. Furthermore, the LonMark guidelines are not subjected to public review, as is the BACnet standard. A degree of interoperability is obtained by the voluntary adherence of LonMark members to the LonMark guidelines (i.e., implementers' agreements). Vendors that do not have products certified are unlikely to be compatible with LonMark certified devices, despite having compatible connectivity.

Conformance is based on a review of conformance documentation submitted by the product manufacturer (.ixf interface files) for adherence to mandatory and optional variable definitions; it is not necessary to submit the product itself. "Testing" in the LonMark conformance process refers to the review process, not actual vendor to vendor compatibility testing. A new process was under development (slated for release in 2Q2000) to allow self-certification using special testing devices that wee to be used in-situ on each type of device offered by a vendor. As of October 2000 there was been no mention of this on the LonMark website.

A number of special tools and technologies have been developed to address the deficiencies inherent in LonTalk to service emerging requirements (i.e., LonMark for interoperability, LNS for client-server support, iLON and LNS for internet access). Although these are important for broader integration it results in a cumbersome development, installation and maintenance process for what is ultimately a sub-network of a larger BCS network. For smaller systems that are solely LonTalk based, LonWorks technology may make more sense. For larger systems, offerings from providers such as Tridium that have well integrated support for LonMark products (as well as BACnet) in their web-enabled architecture obviate the need for LonWorks accoutrements

The future – On the one hand LON technology has become well established in the buildings industry as evidenced by its wide support by BCS vendors. On the other hand the future potential is mixed as summarized in the following comments.

- The packaged concept of LonWorks as opposed to the protocol itself appears to be the most compelling reason for using LonMark devices. The LON technology is a fairly complete set of tools to build products around that includes most of the necessary micro-controller, programming, and networking components as well as network management and interfacing tools. The design and development tools were built around the "one size fits all" concept to offer developers a "universal" platform for control devices. This was to obviate the need to develop low level micro-controller capabilities from scratch for each new application; a basic micro-controller platform was made available that supported "typical" functions with communications built-in from inception. On the face of it this "black box" concept allows designers a relatively easy path to build products without having to develop low level aspects from scratch. On the other hand, this approach results in some significant compromises as discussed in the *Other Limitations* section of Appendix B that limit its future potential.

- The adoption of LonTalk by EIA (EIA-709), has resulted in all layers of the LonTalk protocol now been "opened" so that the protocol can be implemented on alternative platforms. Although a license is still required from Echelon, developers are no longer required to buy Neurons or Echelon based workstation software to use the protocol. Although opened in 1996 via EIA-709 (and via ANSI acceptance in October 1999), very few alternative implementations can be found today. This suggests that there is not great incentive to "port" the protocol to other platforms most likely because it is so wedded to the Neuron processor structure and/or there is not enough market incentive to do so.[19]

- Neurons are computationally slow and relatively expensive. A better option might have been to develop a chip that implements the connectivity layers in firmware without the applications layers. In any event even this approach would be challenged by the imminent rise of Ethernet as a universal connectivity standard for all levels of the network.[20] In 1999 Toshiba introduced upgraded versions of the Neuron that included a 20 MHz clock speed (allowing 2.5 Mbps communications bit rates) and more on-board memory. This improves the raw processing capabilities but does nothing to improve the relatively old fundamental processor technology upon which the Neuron is based, or expand its computing capabilities; e.g., although promised years ago, there are still no 16-bit versions of the Neuron.

---

[19] Although the LonTalk reference implementation available from Echelon allows access to the protocol, the license agreement governing its use restricts commercial development. Commercial uses of LonTalk on other platforms are subject to additional license agreements governed by Echelon.

[20] The real competition to LonMark is not BACnet, but TCP-IP/Ethernet based products that are likely to be the focus for the future.

- Since Ethernet is now undergoing fundamental changes to improve its real-time performance, there is less and less reason to use other data link protocols such as LonTalk. On the other hand, third parties have provided Ethernet support for LonTalk allowing for its use on high-speed networks. In addition, Echelon's iLON product, LNS network operating system software, network management tools, and development systems make up a complete development and operating suite of tools that cover at least the basic requirements for web-enabled systems.
- Echelon claims that they are finally on the verge of major cost reductions due to new integrated chips being made by Cypress Semiconductor that combine the Neuron with the FTT transceiver and because of large orders derived from the adoption of LON technology by ENEL, the Italian utility as well as other non-building industries.[21] It remains to be seen if this in fact comes to pass.
- Although they are *defacto* standards, LonMark functional profiles appear to be the only high level objects available since BACnet has yet to develop them.
- The conformance process is weak and appears to be unfinished as discussed above. Also, there is no assurance in the current process that products of different types can be made compatible. This was supposed to be addressed by a new set of "system" certification procedures being developed by LonMark but there is no indication that these procedures have been adopted. In addition, there is no explicit control over future changes in the profiles since the modifications are voted on only by a select set of preferred members, i.e., "sponsors" that pay the greatest membership fees, of which Echelon is one. A further limitation is that development, configuration and network management tools are based on proprietary technology that are only available from Echelon and a few select vendors.

Despite the drawbacks noted herein, it appears that there is a significant ramp-up in vendor acceptance of LonMark technology that may ultimately have a major impact on the overall BCS market.

Adoption – Echelon has long claimed that LonTalk was a *de facto* protocol standard even before adoption by EIA. This, however, is questionable if the test is ubiquitous installation in the buildings industry (e.g., Windows OS is truly ubiquitous and therefore a *de facto* standard in the business environment; although some would argue that it is still proprietary because Microsoft drives the specification process). For example, Echelon estimates the following breakdown of Neuron uses as of June 2000.

- 13 Million nodes sold
- 45% used for BCS, 25% for industrial process,[22] 20%

[21] Pricing levels of $2 per Neuron long promised by Echelon have never been achieved.

[22] A study conducted by Venture Development Corp. disclosed the following facts about the industrial market and LonTalk penetration of it. (1) In 1998 the total *annual* device market consisted of 24 M control devices; Echelon's estimated 3 M nodes produced over 15 years is a very small fraction of the total. (2) Ethernet is

transportation, and 10% in miscellaneous products.

- The split is roughly 50% US and 50% non-US.

Thus it appears that approximately 2.3 M Neurons were used in the US buildings industry over the past decade. Based on the analysis contained in Appendix B it appears that most of the ~2 M nodes are dedicated to a mixture of lighting, access, residential applications, and BCS vendor offerings.[23] This number of nodes is a small fraction of the BCS installed base.[24] Since the major equipment OEMs currently offer very few or no LonMark based products most of the volume is provided by BCS vendors.

Echelon also claims that worldwide 3500 companies are involved in developing products and that 1400 products now exist. These numbers depend heavily on how the counting is done. Echelon literature suggests that 3500 represents the number of development systems sold, not the number of products being developed for sale. Moreover, many companies produce slightly different versions of the same product. If we use LonMark listed products as an example we find that Leviton offers 7 types of occupancy sensors, and Siemens offers 29 versions of their DESIGO RX controller for fan coils and radiant heating and cooling systems.[25] If *distinct* product types were counted, the number is likely to be far less as indicated by our estimates in Table B6;[26] which shows that the total distinct products is about one-half of the total products listed on the LonMark website. Likewise, LonMark claims to have over 200 member companies. However, only about 50[27] companies are listed on the LonMark product list.

Summary and Conclusions

Our major conclusions regarding the evolution of open systems networks are summarized in the following:

General

- Information technology will drive the development of EMCIS and BCS communications networks; these technologies will augment and possibly displace elements of current protocol and/or object standards.
- Ethernet is likely to become the standard for the lower layers in all levels of the network.
- Networks will be "flatter" and less hierarchical.
- Despite the increased influence of new IT based technologies, there will still be a need for the industry specific application level objects and

estimated to increase to 22% of the industrial market in 2003 from 8.4% in 1998. Over 75% of the market is projected to be divided between just four basic protocols. Although not explicitly mentioned, LonTalk is assumed to be included in the "others" category that accounts for 24% market share. [8]

[23] Lack of detailed and reliable data prevents a finer breakdown.

[24] If market growth had matched expectations projected at the 1995 LonUsers conference where annual volumes of 100 M (downgraded to 85 M at 1996 conference) Neurons were anticipated by year 2000, then claims of being a *de facto* standard may have been legitimized. In fact only a total of 10 M chips were sold in 12-15 years. [23]

[25] Ironically DESIGIO systems use BACnet for the BCS backbone.

[26] This product list grew by about 10% in a one year period, mostly in lighting and I/O products categories.

[27] As of mid-2000.

services that LonMark and standards like BACnet provide.

Proprietary Networks

- Proprietary solutions have adapted to the demands for integration and interoperability by supporting third party protocols and emerging standards.
- Proprietary communications network offerings represent an alternative to the pure standards based approach.
- Proprietary networks will continue to be an important part of the mix of solutions for the foreseeable future.

BACnet

BACnet is still very much a work in progress. However, BACnet has a number of attractive features:

- BACnet is truly an open and complete *de jure* standard allowing implementation on virtually any computing platform of choice without licensing requirements.
- BACnet/IP will facilitate the use of BACnet in TCP-IP/Ethernet networks, the emerging standard for higher levels in the BCS architecture, and it will foster integration with IS networks and the Internet.
- The imminent approval of Standard 135.1p and the advent of conformance testing by the BMA, will significantly improve the conformance certification process.[28]
- BACnet will continue migrating to lower levels in the network.
- BACnet is having difficulty moving beyond the primitive object level to create higher-level applications objects similar to LonMark's.
- Due to its inherent flexibility, software vs. hardware orientation, and scalability, BACnet is well suited to sophisticated solutions and adaptation to technological change.

LonMark

In terms of current availability it seems that LonMark has an edge over BACnet in that it has a more complete offering including support and development tools and hardware components supplemented with the LonMark conformance certification procedure.

- Hardware dependence on Neurons will limit their long-term usefulness.
- The attractiveness of the LonTalk protocol will be challenged by the imminent rise of Ethernet as a universal connectivity standard for all levels of the network and will compete with LonTalk and other similar protocols.[29]
- LonMark is a technology best suited for low-end applications for small systems (light commercial and residential) or for lower levels in large EMCIS networks.

[28] Critics have pointed to the BACnet conformance issue as evidence that BACnet is not really interoperable. However, most BACnet providers have either thoroughly tested their products with other vendors on their own initiative or through the NIST conformance testing standard development project. In addition, about 60% of BACnet vendors use the Cimetrics BACnet protocol stack which Cimetrics claims has been rigorously tested for interoperability.[31]

[29] The real competition to LonMark is not BACnet, but TCP-IP/Ethernet based products that are likely to be the focus for the future.

- The LonMark profiles represent a significant contribution toward simplifying implementation of interoperability.
- For EMCIS specifiers (and developers) *caveat emptor* should be exercised when reviewing LonWorks marketing and promotional materials (see Appendix B).
- LonMark products are distributed broadly across low-end applications, are supported by many large BCS vendors, and the installed base is growing.

Federal facilities perspective

It is inevitable that energy practitioners will be drawn into the controversy surrounding protocols. This is especially true with regard to BACnet and LonMark because Federal practitioners place greater emphasis on adherence to standards than their commercial counterparts.

However, one should bear in mind that the primary impact of standards will be on the configuration, procurement, and integration of systems and components. Although there is tremendous interest, lack of consensus, and even controversy surrounding protocol options, energy and O&M savings are derived primarily from *applications* and not communications technology or its infrastructure (except is so far as it might improve control dynamics.) – the applications ultimately are where the true intelligence of these systems resides.[30] None of the options (proprietary, BACnet nor LonMark) are total solutions or panaceas. If the goal is true interoperability and vendor independence then BACnet and LonMark can be seen as one step in the process toward this goal but they share the solutions landscape with proprietary offerings for the foreseeable future.

Although these protocols will have no significant direct impact on operations, control, and energy use there may be an impact on reliability and on first cost (higher initially, lower later). The protocols represent esoteric details that manufacturers and implementers might care about, but end users are primarily interested in the functionality of the system and good reliability at low overall cost (including maintenance and upgrade cost).

Thus multi-vendor interoperability and interchangeability are important issues for the end user over and above the subtleties of how it is achieved.

Standards help because they tend to cultivate uniformity, longevity, broad support, and reliability. However, standards need to be supplemented by an appropriate conformance certification and testing process and attention to equivalent functionality.

[30] Considerable controversy surrounds projects such as 450 Golden Gate as to the impact that implementing a multi-vendor BACnet network has had on increasing energy savings. Any savings that have resulted have been due to the changes in control logic and equipment rather than overtly to the protocols themselves. [30]

Appendix A – Glossary

Acronyms and Definitions	
ARCNET	Attached Resource Computer Network (Layers 1 and 2 protocols with some Layer 3 features built in; 156 Kbps-10 Mbps token passing scheme developed by Datapoint Corp. and standardized in 1992 by ANSI as ANSI/ATA 878.1. The protocol is embedded into firmware provided by two suppliers.)
ASHRAE	American Society of Heating, Refrigerating and Air-Conditioning Engineers
ANSI	American National Standards Institute
ATA	ARCNET Trade Association
ASP	Application Service Providers (vertically integrated and centralize database and computing services that support specific applications)
BACnet	Building Automation Control Network (Building industry consensus protocol standard developed under auspices of ASHRAE.)
Baja	Building Automation Java Architecture (Standards efforts by Sun and Tridium to create buildings industry specific Internet based enterprise level interoperability standards.)
BAS	Building Automation System

Acronyms and Definitions	
BIBB	BACnet Interoperability Building Blocks (Specifications for objects to facilitate consistent data exchange between nodes.)
BCS	Building Control System
BMA	BACnet Manufacturers Association (Vendor trade organization that intends to provide conformance testing and certificaiton.)
BMS	Building Management System
CAFM	Computer Aided Facility Management (primarily for management of facility physical assets)
CAN	Controller Area Network (Primary protocol used for transportation vehicles.)
CMMS	Computerized Maintenance Management System (Maintenance work order generation and dispatch management; e.g. Maximo.)
CSMA/CD	Carrier Sense Multiple Access/collision detection
CORBA	Common Object Request Broker Architecture (object standards for client server communications)
DSSS	Direct Sequencing Spread Spectrum (wireless physical layer protocol where data packet is encoded by spreading it simultaneously across multiple frequencies.)
EIA/DOE	Energy Information Agency (The energy statistics providing arm of DOE)

Acronyms and Definitions	
EIA	Electronic Industries Alliance (High technology trade organization representing the electronics industry best known for promulgating signaling standards)
EIS	Enterprise Information System (See IT/IS.)
EMCIS	Energy, Management, Control and Information System
EMCS	Energy Management and Control System
EMS	Energy Management System
ESP	Energy Service Provider
FAS	Facility Automation System
FDM	Frequency Division Multiplexing (Data link MAC sub-layer multiplexing technique where messages from multiple nodes are each sent over an individual frequency channel.)
FHSS	Frequency Hopping Spread Spectrum (Wireless physical layer protocol that sends data packets over multiple frequencies, one packet per frequency.)
FTT	Free Topology Transceiver (EIA-485 type of signaling transceiver developed by Echelon that allows easier field connection due to its lack of polarity sensitivity.)
HTML	Hypertext Markup Language
HTTP	Hypertext Transport Protocol

Acronyms and Definitions	
IEEE	Institute of Electrical and Electronics Engineers (Largest professional organization in the world, issues electrical engineering and computing standards.)
iLON	Internet LON (A new device to be offered in 2-3Q2000 that includes LonTalk to TCP-IP/Ethernet tunneling router and Internet gateway web-server.)
IEQ	Indoor Environmental Quality
IP	Internet Protocol
IS	Information Systems
ISM	Instrument, Scientific Medical band (Electromagnetic spectrum bands that do not require government licensing: between 902-928 Mhz, 2.4-2.484 GHz, and 5.725-5.850 GHz.)
ISO	International Organization for Standardization (ANSI is the USA representative to ISO.)
IT/IS	Information Technology/Information Systems (Those systems used to support general business activities usually not control related.)
ITU	International Telecommunication Union (Formerly the CCITT – the ITU-T sector’s function is to manage bandwidth allocation and develop phone and data communications standards.)

Acronyms and Definitions	
LAN	Local Area Network
LLC	Logical Link Control (Sub-layer protocol of OSI data link layer.)
LNS	LonWorks Network Services (PC based network operating system software required to port LonTalk data into the client-server environment.)
LON	Local Operating Network (Echelon's trade name for their LAN technology.)
MAC	Media Access Control (Sub-layer protocol of OSI data link layer.)
MEMS	Micro Electromechanical Systems
MIS	Management Information System
MS/TP	Master-slave/token-passing (Non-contention (and thus deterministic) Layer 2 and 3 protocol developed by BACnet to run over EIA-485 physical layer.)
NIST	National Institute of Standards and Technology
Node	A computer or micro-controller device attached to a network. In the IS industry these are also referred to as hosts.
OEM	Original Equipment Manufacturer
OLE	Object Linking and Embedding
OMG	Object Management Group

Acronyms and Definitions	
OPC	OLE for Process Control (An object based protocol derived from Microsoft OLE and COM client server standards now being developed by the industrial process industry.)
OS	Operating System
OSI	Open Systems Interconnection
PLC	Programmable Logic Controller or Power Line Carrier
PDA	Personal Digital Assistant
PICS	Protocol Implementation Conformance Statement (Description of BACnet supported capabilities.)
PPP	Point-to-Point Protocol (Newer datalink protocol for PTP networks that supports multiple higher layer protocols.)
PTP	Point-to-Point
RFC	Request for Comment (Technical specifications used as a vehicle to create standards under auspices of the Internet Society's IRTF (Internet Research Task Force).)
RMI	Remote Methods Invocation
RTP	Real Time Pricing
SIG	Special Interest Group (Trade or professional groups formed to pursue agreements on communications issues of common interest; quasi-standards body.)

Acronyms and Definitions	
SLIP	Serial Line IP (Older datalink protocol used in point to point networks; supports only IP networking layer.)
SNVT	Standard Network Variable Type (Echelon's trade name for LON device data variables.)
TCP	Transport Control Protocol
SONET	Synchronous Optical Network
TDM	Time Division Multiplexing (Data link MAC layer multiplexing technique where messages from multiple nodes are divided into time slot channels on a single frequency.)
VTS	Visual Test Shell (Conformance testing procedures and toolkit developed by NIST.)
WAN	Wide Area Network
WDM	Wave Length Division Multiplexing (DWDM or Dense WDM is a similar technology.)
XML	Extensible Markup Language (The emerging object standard for information manipulation and presentation on client devices within the web environment that is rapidly replacing HTML.)

Appendix B – LON Technology

Definitions – One must distinguish carefully between some of the major elements of Echelon's technology and related terminology in order to avoid confusion. *LonWorks* refers to the overall technology developed by Echelon Corp.; it includes an array of hardware and software components and tools to develop and operate LonWorks based systems. *LonTalk* on the other hand, refers to the communications protocol part of the LonWorks technology; it is the only part that is standardized. *LonMark* refers to the trade organization that Echelon formed to develop implementers agreements to promote interoperability efforts. The LonMark organization has developed a series of Functional Profiles that represent the application level object definitions that promote interoperability between LonMark devices.

LON of course stands for Local Operating Network, an Echelon coinage of their LAN technology. A *Neuron* is the fundamental building block of the LonWorks technology; it is a custom micro-controller now being manufactured by Toshiba and Cypress Semiconductor (Motorola, the original maker of Neurons, has ceased production of these chips).

The LonTalk communications protocol stack is modeled after the full seven layer OSI stack contrary to many other BCS systems that use much simpler 3-4 layer structures. This was done so LonTalk could address a wide variety of applications in various industries and operate over various media. Unfortunately, this also introduces extra complexity and overhead not generally required in BCS control systems.[31] LonTalk consists of new protocols for each layer rather than implementing existing standards. In fact the lower layers are a derivative of the CSMA technique that Ethernet uses. This was done to optimize its performance for lower speed networking typically found in low-end applications and to allow for consistent operation over multiple media. To some extent these changes improve on low-load efficiency and high load saturation characteristics of IEEE 802.3 protocols. It also results in maximum data rates of 1.25 Mbps although most systems seem to use 78 Kbps.[32] Although this scheme suffers from the same issues of non-determinacy as Ethernet, it still seems to work well for the lower levels in the BCS architecture as long as appropriate network design is followed.

These features (plus the "packaged" LonWorks technology) denote the major innovation that Echelon has brought to the BCS industry: peer-to-peer networking technology at the controller and sensor bus level, using twisted pair (EIA-485 type) signaling.[33] The FTT polarity free twisted pair transceivers that Echelon has developed represent a major improvement over other EIA-485 implementations. What is less clear, however, is if there is any significant advantage to using LonTalk or CSMA for that matter at these levels of the network.

[31] The interested reader may want to review the reasons why the full OSI protocol stack is not particularity good for actually implementing communications; it has been more useful as a *model* for discussing layered communications protocols (see Tannenbaum [2], Section 1.4.4 for an excellent discussion of this point).

[32] In 1999 Toshiba introduced upgraded versions of the Neuron that included a 20 MHz clock speed (allowing 2.5 Mbps communications bit rates) and more on-board memory.

[33] The other media supported by LonTalk have not seen significant use in the BCS networks.

As shown in Table 3 there are many tradeoffs that must be considered to determine whether there is a significant advantage for the particular applications being addressed. Moreover, since Ethernet is now undergoing fundamental changes to improve its real-time performance, there is less and less reason to use other technologies like LonTalk. The choice to use LonTalk frequently boils down to the "other factors" that Tannebaum denotes.

The packaged concept of LonWorks appears to be the most compelling reason for using LonMark devices. The LON technology is a fairly complete set of tools to build products around that includes most of the necessary micro-controller, programming, and networking components as well as network management and interfacing tools. The design and development tools were built around the "one size fits all" concept to offer developers a "universal" platform for control devices. This was to obviate the need to develop low level mico-controller capabilities from scratch for each new application; a basic micro-controller platform was made available that supported "typical" functions with communications built-in from inception.

On the face of it this "black box" concept allows designers a relatively easy path to build products without having to develop low level aspects from scratch. On the other hand, this approach results in some significant compromises as indicated in the *Other Limitations* section below.

Standards - LonTalk (not LonMark) is now a *standard* due to its adoption by ANSI and EIA. It is still not a *de jure* standard as is BACnet since it was not created by a standard setting body using a consensus process. Echelon is attempting to follow the path of other proprietary protocol developments such as Ethernet and more specifically ARCNET in becoming a standard, which is first to try to become a *de facto* standard by shear volume in the market.[34]

The real significance of the adoption of LonTalk by EIA (EIA-709), however, is the fact that all layers of the LonTalk protocol have now been "opened" and can be implemented on alternative platforms. Although a license is still required from Echelon, one is no longer required to buy Neurons or Echelon based workstation software to use the protocol. However, prior to EIA adoption, none of LonTalk protocol layers were standards; they were all proprietary. Another key feature of this technology is that it is hardware based in that the technology is imbedded in proprietary Neuron chips as opposed to software based solutions that can be used on any suitable hardware platform. LON technology derived its "openness" from the fact that multiple vendors have implemented Echelon's proprietary technology. Although opened in 1996 via EIA-709 (and via ANSI acceptance in October 1999), very few alternative implementations can be found today. This suggests that there is not great incentive to "port" the protocol to other platforms most likely because it is so wedded to the Neuron processor structure and/or there is not enough market motivation to do so.[35]

---

[34] Ethernet was created by Xerox/DEC/Intel and later adopted by IEEE as IEEE 802.3. ARCNET was a tightly controlled proprietary protocol (similar to LonTalk) for almost 20 years, finally standardized in 1992 but still has only two suppliers.

[35] Although the LonTalk reference implementation available from Echelon allows access to the protocol, the license agreement governing its use restricts commercial development. Commercial uses of LonTalk on

The support of LonTalk by ASHRAE and EIA are fundamentally different. ASHRAE's BACnet adopts LonTalk as a *data link* specification only; none of LonTalk's upper layers are specified (nor any of LonMark's application level objects). EIA, on the other hand, has adopted LonTalk layers 2-7 in EIA-709.1 and Layer 1 options in EIA-709.2 and .3.

Specification of LonTalk does not ensure BACnet conformance; it represents only one part of BACnet conformance – only the data-link and physical layers much like the MS/TP and Ethernet specifications. For true compliance BACnet objects and networking need to be implemented. LonMark's Functional Profiles are a competing object model to BACnet's Layer 7 objects; they are not compatible with one another. *EIA-709 standardizes LonTalk - not LonMark profiles.* LonTalk does not support Layer 7 applications services other than the rudimentary SNVTs that can be used to facilitate sharing of variables over a network. The LonMark Profiles use these Layer 7 SNVTs to implement the interoperability guideline conventions. Thus the LON standardization effort falls short of being a complete standard since it is still missing an essential element – a full application layer object specification.

LonMark products penetration – Echelon has long claimed that LonTalk was a *de facto* protocol standard. This, however, is questionable if the test is ubiquitous installation in the buildings industry (e.g., Windows OS is truly ubiquitous and therefore a *de facto* standard in business the environment; although some would argue that it is still proprietary because Microsoft drives the specification process). For example, Echelon estimates the following breakdown of Neuron uses:[36]

- 10 Million nodes sold as of June 1999.
- 40% used for BCS, 30% for industrial process,[37] 20% transportation, and 10% in miscellaneous products.
- The split is roughly 50% US and 50% non-US.

Thus it appears that approximately 2M Neurons were used in the US buildings industry over the past decade. This installed base is made up primarily of OEM factory mounted control products and field supplied products by BCS vendors. On the OEM side, we have estimated that a total of almost 9M units of various types of commercial HVAC equipment[38] have been produced by equipment OEMs over the 10 year period of 1990 to 2000. Of these we estimate that about 3M have digital controls. Roughly 150K of these units are likely to have LON based controls. Based on this analysis it appears that most of the 2M

other platforms are subject to additional license agreements governed by Echelon.

[36] As of June 2000 these numbers have changed somewhat: 13 M nodes worldwide, 40/60% US/other, 25% industrial. [22]

[37] A study conducted by Venture Development Corp. disclosed the following facts about the industrial market and LonTalk penetration of it. (1) In 1998 the total *annual* device market consisted of 24M control devices; Echelon's estimated 3M nodes produced over 15 years is a very small fraction of the total. (2) Ethernet is estimated to increase to 22% of the industrial market in 2003 from 8.4% in 1998. Over 75% of the market is projected to be divided between just four basic protocols. Although not explicitly mentioned, LonTalk is assumed to be included in the "others" category that accounts for 24% market share. [8]

[38] These consist primarily of VAV boxes, medium to large rooftops, water source heat pumps, fan coils, and packaged terminal air conditioners (used primarily in hotel and motels).

nodes are dedicated to a mixture of lighting, access, residential applications, and BCS vendor offerings.[39] This number of nodes is a small fraction of the BCS installed base.[40]

This analysis suggests two things; 1) a substantial fraction of the HVAC equipment production is still sold *without* factory mounted controls, and 2) BCS vendors are the primary purveyors of LonMark products. Since the trend is for more factory mounting of controls, it remains to be seen how this might change over time since the major equipment OEMs currently offer very few or no LonMark based products.

Echelon also claims that worldwide 3500 companies are involved in developing products and that 1400 products now exist. These numbers depend heavily on how the counting is done. Echelon literature suggests that 3500 represents the number of development systems sold, not the number of products being developed for sale. Moreover, many companies produce slightly different versions of the same product. If we use LonMark listed products as an example we find that Leviton offers 7 types of occupancy sensors, and Siemens offers 29 versions of their DESIGO RX controller for fan coils and radiant heating and cooling systems.[41] If *distinct* product types were counted, the number is likely to be far less as indicated by our estimates in Table 6.[42] This list totals to about one-half of the total products listed on the LonMark website.

Table B6: LonMark Products

Product class	Distinct Products*
Access	1
Energy management	3
Fire	1
HVAC	
• Chilled Ceiling	2
• Fan coil	6
• Heat pump	2
• Damper actuator	5
• Equipment controller (e.g., AHU)	5
• Roof tops	4
• Thermostat	1
• Vav Box Controller	9
• I/O products	21
Industrial	4
Lighting	17
Motor controls	4
Networking	3
Sensors	16
Other	6

* Distinct products per company times the number of companies; e.g., two companies that make the same device are counted once each, but the same company that makes variants of a product for essentially the same application gets counted once only for each application, not each variant. [25]

LonMark – The LonMark organization was created in 1994 to further the cause of creating interoperable LonTalk based

[39] Lack of detailed and reliable data prevents a finer breakdown.

[40] If market growth had matched expectations projected at the 1995 LonUsers conference where annual volumes of 100 M (downgraded to 85 M at 1996 conference) Neurons were anticipated by year 2000, then claims of being a *de facto* standard may have been legitimized. In fact only a total of 10 M chips were sold in 12-15 years. [23]

[41] Ironically DESIGIO systems use BACnet for the BCS backbone.

[42] This product list grew by about 10% in a one year period, mostly in lighting and I/O products categories.

products for various applications. This was necessary to address the deficiencies in the LonTalk application layer for supporting interoperability. LonMark is a trade association sponsored and controlled by Echelon (i.e., Echelon owns the LonMark trademark) and therefore LonMark lacks the autonomy and neutrality of an independent industry organization or standards body. Furthermore, the LonMark guidelines are not subjected to public review, as is the BACnet standard. A degree of interoperability is obtained by the voluntary adherence of LonMark members to the LonMark guidelines (i.e., implementers' agreements). Vendors that do not have products certified are unlikely to be compatible with LonMark certified devices, despite having compatible connectivity.

Conformance is based on a review of conformance documentation submitted by the product manufacturer (.ixf interface files) for adherence to mandatory and optional variable definitions; it is not necessary to submit the product itself. "Testing" in the LonMark conformance process refers to the review process, not actual vendor to vendor compatibility testing. A new process under development (due for release in 2Q2000) will allow self certification using special testing devices that will be used in-situ on each type of device offered by a vendor.[43] However, there is no assurance in the current process that products of different types can be made compatible. This is being addressed by a new set of "system" certification procedures being developed by LonMark. In addition, there is no explicit control over future changes in the profiles since the modifications are voted on only by a select set of preferred members, i.e., "sponsors" that pay the greatest membership fees, of which Echelon is one. A further limitation is that development, configuration and network management tools are based on proprietary technology that are only available from Echelon and a few select vendors.

Moreover, interoperability between devices in legacy LonTalk networks is not assured since pre-LonMark systems (prior to 1994) relied heavily on the technique of "foreign frames" where-in a proprietary protocol was embedded into a LonTalk frame (see the tunneling discussion above). This means that communications with these systems is essentially proprietary and incompatible with newer LonMark based devices. Furthermore, these are virtually inaccessible to newer remote access technologies without a gateway. [24]

Another issue is device complexity. Apparently, LonMark objects are somewhat weak in terms of being able to inherit properties of other objects. Therefore, as complexity grows new objects have to be created rather than being a separate instance of a more robust single object. This could explain why there are so many versions of basically similar devices in the LonMark list. On the other hand, LonMark has succeeded in developing higher level objects that make implementation easier, something that BACnet is still struggling with. [13]

LonMark Acceptance - LonMark claims to have over 200 member companies. However, only about 50[44] companies are listed on the LonMark product list. This plus the arguments presented earlier

[43] As of October 2000 there was been no mention of this on the LonMark website.

[44] As of mid-2000.

about distinct LonMark products suggests the following possibilities:

1. There are many LonMark products still in the pipeline awaiting agreements.
2. There is a lag in the commitment to interoperability in general.
3. LonMark is not being broadly accepted in the buildings industry.

Other Limitations - LonMark nodes are generally used for terminal and ancillary devices since there are limitations on the number of variables that can be shared on the network (64 network variables), in the amount of memory that can be supported with Neuron chips, and the bandwidth of the bus and therefore the amount of traffic that can be supported. Large applications need to be supported by a number of nodes with continuous interaction, a solution that has not been wholeheartedly embraced by the industry, or by using the Neuron as a communications coprocessor with another processor for applications - a better solution but one that increases cost.[45] Given these limitations, LonTalk has not been used as the sole EMCIS network protocol or as a backbone to any large extent in large building systems.[46] The vast majority of large system BCS vendors include LonTalk networks as sub-nets of larger systems for terminal or sensor bus level devices. Thus gateways are required at some point, usually at the field panels, in the network.

Some developers contend that it takes significant effort to get around the built-in limitations and roadblocks inherent in the LonWorks approach. For example, the SNVTs are actually quite limited resources that are mostly committed (i.e., bound) during configuration. If during later monitoring one wants to acquire unbound SNVTs data, one must resort to other more arcane methods to access them. These types of limitations are inherent in “packaged” or generic solutions. Packaging results in many tradeoffs and compromises and the broader the scope of applications to be addressed by a package the more compromises there are for any given application. Added to this is the fact that the basic Neuron processor technology is old - the basic design is now over 15 years old.[47] Many of the limitations arise from the need to protect against overwhelming the processor’s capabilities. Unfortunately, the very high level of software integration that made the Neuron so attractive in the first place now makes it immune from improvement. Neuron software is not upgradable, so the installed base of Neurons represents a non-upgradable legacy product. Most current technologies such as system-on-a-chip solutions incorporate flash memory that allows quick, remote upgrades of OS, protocol and application codes.

The lack of effective network management and support tools has been a major impediment to easy deployment of LonMark systems. There are some alternative platforms available for network tools, including Echelon's LonWorks Network Services (LNS) and IEC's Peak Components. Performance (such as speed of discovery of networks)

[45] Some practitioners believe that LonWorks does not scale well in large applications using muli-layer architecture due to the namespace limitations of the network variables. [13]

[46] One example of this might be the Dirksen Courthouse in Chicago that was originally specified with a LonTalk backbone but was subsequently changed to Ethernet apparently due to performance problems.

[47] See footnote 32.

is an issue, as well as other features such as platforms that they can operate on, industry standard interfaces that they support, etc. For example, LNS is designed to operate on a PC platform, while Peak was designed to operate on smaller embedded platforms as well as PC platforms. LNS has it's own plug-in interface, which it markets as a "*de facto*" standard. The Consumer Electronics Association (CEA) has recently created an open device plug-in standard for network tools (EIA/CEA-860) that is independent of network management platforms like LNS and Peak. At the time of this writing, it is unknown how widely adopted EIA/CEA-860 will become in the future. [26]

These limitations result in LonWorks technology, being relegated to lower end, simpler applications developed by lower skilled developers – precisely the way it is being played out in the market. LonWorks is not capable enough for high-end, custom, robust, high complexity systems. Going forward it will be at an increasing disadvantage compared to newer processing and communications technology currently being developed. [13], [27] Implementation costs are another issue. Anecdotal comments suggest that building a product on LonWorks technology is not as simple as Echelon portrays - several projects required significantly more time and money than originally anticipated. These appear to result primarily from having to find ways around some of the limitations built into the technology as alluded to earlier.

Marketing and Promotion - A discussion of LonMark would not be complete without a comment about marketing and promotion.

In what may be a response to a competitive environment, Echelon's marketing strategies and methods appear to control information availability, and thus can make it difficult for a prospective client or specifier to make well-informed purchasing decisions.[48] Many of Echelon's marketing materials regarding their own products are heavily promotional in nature. From these materials it is often difficult to obtain a clear appraisal of the potential of LonWorks, LonTalk and LonMark in terms of acceptance, use, and capabilities, as we have indicated in the discussions above. This tends to cause confusion among developers, specifiers, and users. It also engenders lowered confidence about the overall merits of the technology in general. We therefore caution Federal energy practitioners about accepting at face value statements in literature of this type. Additionally, Echelon statements regarding the merits of alternative approaches such as BACnet (see statements about BACnet in [25, 29]) should be viewed with caution and evaluated with care. We recommend using independent information sources and trusted, unbiased experts to evaluate functionality and performance claims before making purchasing decisions.

Because it is important to ensure availability of a sufficiently wide range of compatible products for future extensibility, practitioners should also be cautious when in comes to evaluating the penetration of both LonMark and BACnet technologies in the market. There is very little solid data to back up claims being made. Data about types of products or, better yet, sales volumes of

[48] For example, IEC Intelligent Technologies has been repeatedly denied access to LonWorld to show their products that compete with Echelon's LNS. [28]

products by type are the only reasonable way to make definitive statements about penetration and growth rates. In terms of number of nodes being sold it appears the market is somewhat balanced between BACnet and LonMark with Honeywell and Siebe (Invensys) leading with LON devices and Alerton, Automated Logic, Delta Controls and Trane leading with BACnet products. It would be better if the types of products and their volumes were known.[49]

[49] Accumulating these numbers is a valuable contribution that an organization such as the BMA could make.

Appendix C – References

[1] Webster, T. L., "Trends in Energy Management Technology - Enabling Technologies," DOE/FEMP, December 2000.

[2] Tannebaum, A. S., *Computer Networks*, 3rd ed., Prentice Hall, New Jersey, 1996.

[3] "Control Network Protocol Specification," EIA-709.1, Electronic Industries Alliance, April 1999.

[4] Tannebaum, p. 301.

[5] Bushby, S. T., "Communications Gateways: Friend or Foe," *ASHRAE Journal*, April 1998, p. 50.

[6] Hull, G. G., "Myths of LonWorks and BACnet," *ASHRAE Journal*, April 1999, p. 22.

[7] *Internet Protocols* [Website]. Cisco, November 8, 1999. Available from: www.cisco.com/univercd/cc/td/doc/cisintwk/ito_doc/ip.htm.

[8] "Control Network Shuffle Continues," *Control*, June/July 1999, p. 12.

[9] Caro, D., and R. Mullen, "Ethernet as a Control Network," *Control*, February 1998, p. 38.

[10] Merritt, R., "Technology Trends," *Control*, April 2000, p. 40.

[11] Waterbury, B., "Ethernet Ready to Strike," *Control*, August 1999.

[12] "Profibus Supporters Ponder Life with Ethernet," *Control Design*, October/November 1999, p. 14.

[13] McParland, C., Personal Communication, January 2001, Computer Scientist, Lawrence Berkeley National Laboratory.

[14] "GE, Cisco systems Form Networks Unit for Factories," *Wall Street Journal*, June 6 2000.

[15] Knollman, R., Personal Communication, November 1999, Applications Engineer, CTI Products.

[16] Thomas, G., "Looking Deeper into Ethernet," *The Industrial Ethernet Book*, Spring 2000, p. 16.

[17] Feeley, J., R. Merritt, T. Ogden, P. Studebaker, and B. Waterbury, "100 Years of Porcess Automation," *Control*, December 1999, p. 17.

[18] Tridium, "White Paper: Baja: A Java-based Architecture Standard for the Building Automation Industry," Tridium Inc., 2000.

[19] "Method of Testing Conformance to BACnet," ASHRAE 135.1P, ASHRAE, 2000.

[20] Bushby, S. T., Newman, H. M., Applebaum, M. A., November ., "GSA Guide to Specifying Interoperable Building Automation and Control Systems Using ANSI/ASHRAE Standard 135-1995, BACnet," NISTIR 6392, National Institute of Standards and Technology (NIST), 1999.

[21] BMA, "BMA 2000 Annual Report," BACnet Manufacturers Association (BMA), December 2000.

[22] Tennifoss, M., Personal Communication, February 27, 2001, Vice President, Marketing, Echelon Inc.

[23] "LonWorks Product Update," presented at LonUsers International, San Jose, CA, May 1995.

[24] Chervet, A., Personal Communication, January 2000, FAE, Echelon Corp.

[25] *Current Listing of All LonMark Products* [Website]. LonMark Interoperability Association, November 8 2000. Available from: www.lonmark.org/products/prod_list.cfm.

[26] Wittkowske, C., Personal Communication, May 31, 1999, Systems Integration Engineer, Trane Co.

[27] Robin, D., Personal Communication, February 2000, Senior Research Engineer, Automated Logic.

[28] DesBiens, D. *"NOOO PEAKING!" at LonWorld® - AGAIN!*

IEC Denied Admission [Website]. IEC Intelligent Technologies, 2000. Available from: http://www.ieclon.com/News/20000928.html.

[29] *LonTour99* [Powerpoint]. Echelon Corp., November 1999.

[30] Diamond, R., T. Salsbury, G. Bell, J. Huang, and O. Sezgen, R. Mazzucchi, J. Romberger, "EMCS Reftofit Analysis Interim Report," LBNL-43256, Lawrence Berkeley National Laboratory, March 1999.

[31] Lee, J., Personal Communication, April 2001, President, Cimetrics.

Appendix D – Bibliography

Allen, E., Bishop, J., "The Niagara Framework," Tridium, Inc., 1998.

"BACnet Test Standard Recommended for Review," *ASHRAE Journal*, March 2000, p. 22.

"LonMark Product Conformance Review," LonMark Interoperability Association, December 1999.

"LonWorks Product Update," presented at LonUsers International, San Jose, CA, May 1995.

"The Next Wave," *Business Week*, August 31 1998, p. 80.

"Potential for Reducing Peak Demand with Energy Management and Control Systems," WCDSR-137-1, Wisconsin Center for Demand Side Research, 1995.

"Standard 135-1995 - BACnet® - A Data Communication Protocol for Building Automation and Control Networks," ANSI/ASHRAE 135-1995, ASHRAE, 1995.

Bushby, S. T., Personal Communication, November 1999, Senior Program Manager, NIST.

Elyashiv, T., "Beneath the Surface: BACnet Data Link and Physical Layer Options," *ASHRAE Journal*, November 1994, p. 33.

Falk, H. S., "Overview of Plant Floor Protocols and their Impact on Enterprise Integration," presented at Autofact '94, Detroit, MI, 1994.

Feeley, J., "What Network Works for You," *Control Design*, February/March 2000, p. 30.

Hartman, T., "Practical Considerations for Protocol Standards," *Heating/Piping/Air Conditioning*, August 1994, p. 45.

Hougland, B., "Ethernet Advantages at I/O Level," *The Industrial Ethernet Book*, Spring 2000, p. 9.

Hess, M., Personal Communication, December 2000, Systems Marketing Engineer, Trane Co.

Kinsella, T., R. Hirschmann, "Ethernet in Industrial Automation - Today and Tomorrow," *The Industrial Ethernet Book*, Spring 2000, p. 29.

Klien, J., "Battle of the Protocols," *Energy User News*, February 1999, p. 1.

LeBlanc, C., "The Future of Industrial Networking and Connectivity," *The Industrial Ethernet Book*, Spring 2000, p. 6.

Merritt, R., "DCS Dead Yet?," *Control*, July 1999, p. 34.

Middaugh, K. M., "Industrial LANs: Sorting out your communications options," *I&CS*, November 1993, p. 45.

Mostia, W. L., "What's New in the Wireless World," *Control*, June 1999, p. 77.

Naylor, T., Personal Communication, December 1999, Application Engineer, Coactive Networks.

Newman, H. M., "BACnet Goes to Europe," *Heating/Piping/Air Conditioning*, October 1998, p. 49.

Newman, H. M., *Direct Digital Control of Building Systems, Theory and Practice*, 1st ed., John Wiley & Sons, New York, 1994.

Newman, H. M., "Integrating Building Automation and Control Products Using the BACnet Protocol," *ASHRAE Journal*, November 1996, p. 26.

Putnam, A., Personal Communication, November 30, 1999, Development Director, Cimetrics Technology.

Roberts, J., Personal Communication, January 19, 2000, Principal Engineer, LonMark Interoperability Association.

Rosenbush, S., "Charge of the Light Brigade," *Business Week*, January 31, 2000, p. 62.

Sakamar, G., "FireWire Gets Ready for Control," *Control Design*, April/May 2000, p. 74.

Studebaker, P., "Object Technology Targets Process Control," *Control*, June 1998, p. 57.

Tatum, R., "Interoperability Marks new Generation of Commercial Building Products," *Building Operating Management*, July 1996, p. 23.

Turpin, J. R., "Getting to the BAS Point (and Counterpoint)," *Engineered Systems*, August 2000, p. 48.

Waterbury, B., "Network Computers are Dead: Long Live Thin Clients," *Control Design*, April/May 1999, p. 34.

Waterbury, B., "Platforms for Decentralized Intelligence," *Control*, March 2000, p. 97.

Waterbury, B., "Web Closes the Loop on Real-time Information," *Control Design*, April/May 2000, p. 37.

Weiss, G., "Smiling as Highfliers Blow Up," *Business Week*, June 26 2000, p. 223.