LONWORKS® for Audio Computer Control Network Applications

January 1995

Executive Summary

LONWORKS is a control network technology developed by Echelon for monitoring and controlling electrical devices of all kinds. LONWORKS meets the criteria specified by the audio industry for a computer control network, and is ideal for amplifier and equalizer control, automatic crossover control, sequential load control, equipment fault monitoring, set-top box automation, and home theater control. Neuron Chips embedded with the LONWORKS protocol have been produced by both Motorola and Toshiba since 1992, and hundreds of thousands of chips have been sold worldwide. Neuron Chips can communicate with one another, allowing data and decisions to be shared between equipment manufactured by different companies. Transceivers, routers, gateways, development tools, and programming and diagnostic tools are available off-the-shelf. Instead of *developing* control network technology, customers can *use* LONWORKS technology to build better, more intelligent, less expensive audio products.

Introduction

A control network is a system of sensors, actuators, displays, and logging devices (referred to as "nodes") that are linked together to monitor and control electrical devices. Supervisory functions are typically handled automatically and require no manual intervention except to respond to faults that the system cannot itself correct. In audio applications, a control network may monitor equipment fault conditions, adjust gain and crossover settings, monitor MIDI inputs, transport SMPTE time codes, sequentially turn equipment on or off, control special effects equipment, and display network status on a computer or custom status display.

The list of criteria that are typically considered essential in an audio control network include:

- Peer-to-peer architecture
- Inexpensive development cost
- Open architecture
- Application Programming Interface (API)
- Connection-based topology
- Object orientation
- Fault tolerance
- Network-wide synchronization
- Predictable network latency
- Multiple media in the network
- Inexpensive node cost
- Compatibility with existing systems
- Control architecture
- Connectionless data transfer
- Pre-setable environments
- Predictable response times
- Efficiency
- Multicast data channels
- Consistency with the OSI model
- Open availability and support

Because it satisfies this long list of criteria, leading companies are embracing Echelon's LONWORKS technology as the standard for audio control.

LONWORKS - A General Purpose Control Network

A wide variety of industries – access control, air conditioning, avionics, fire/life safety, heating, home automation, process control, refrigeration, security, telecommunications, and transportation – have specified a feature set similar to the list defined by the audio industry. This confluence of goals isn't surprising since all control networks perform the same basic set of functions; industries differ primarily in their implementation of the sensors, actuators, displays, and logging nodes.

The similarity between the control network requirements of different industries long ago caught the attention of A.C. ("Mike") Markkula, a co-founder of Apple Computer. In the mid-1980s Markkula began to define a control networking technology that would be flexible enough to be applied across all industries, and sufficiently programmable to be tailored to the needs of each one separately. The fruit of this research was a control network technology called LONWORKS, and in 1988 Markkula established Echelon Corporation to develop and promote LONWORKS technology. M. Kenneth Oshman, co-founder and former president of ROLM Corporation, joined Echelon in 1988 as president and chief executive officer.

To fund Echelon's plans, $30 million was raised in 1988-89 from leading venture capital firms, private investors, 3COM Corporation and Apple Computer; since then, Motorola Inc. invested an additional $30 million and owns a 21% stake in the company. The Quantum Fund, headed by the legendary investor George Soros, and Detroit Edison, the largest utility in Michigan, each invested $10 million in 1994 and each owns about five per cent of the company.

In 1990, Echelon announced agreements with Toshiba and Motorola to manufacture and sell under an exclusive license a family of Neuron® Chips, the microcontrollers at the heart of LONWORKS. These agreements give the company's customers access to the latest semiconductor manufacturing technology and a low-cost, reliable supply of components. Today Motorola and Toshiba are developing their third generation of Neuron Chips, and have steadily driven down the price of the chips.

Echelon realized early that it needed a significant presence in international markets. In June, 1990 Echelon opened a European subsidiary, Echelon Europe, based in London. Echelon Japan K.K., based in Tokyo, was established in 1991. In 1993, subsidiaries were opened in Paris and Munich. Today Echelon has more than 1000 customers worldwide, and roughly half of the company's revenues are derived from export sales.

The best means to understand how LONWORKS meets the requirements of the audio industry is to compare the audio industry's control network criteria with the capabilities of LONWORKS. The overlap between the two is the best testament to the suitability of LONWORKS for audio computer control applications.

Peer-to-Peer Architecture

The Neuron Chip is a sophisticated VLSI device that incorporates communications, control, scheduling, and I/O support. The Neuron Chip enables nodes to communicate with one another using the 7-layer LonTalk® protocol which is embedded in every Neuron Chip. This protocol supports distributed, peer-to-peer communication that enables individual nodes, such as actuators and sensors, to communicate directly with one another: a central control system is not required.

Each Neuron Chip includes the following features:

Three 8-bit pipelined CPUs: The CPUs have a selectable input clock rate from 625kHz to 10MHz. The *application* CPU executes the application program along with layers 6 and 7 of the LonTalk protocol. The *network* CPU implements 3 through 5 of the LonTalk protocol. The *media access control* CPU implements layers 1 and 2 of the LonTalk protocol;

Static RAM: The RAM is used for application and firmware data. The RAM is 2 Kbytes on the Neuron 3150 Chip, 1 Kbyte on the Neuron 3120 Chip;

512 byte or more EEPROM: The EEPROM is used for application code, network configuration, and non-volatile data. Non-volatile network configuration simplifies installation and maintenance of LONWORKS networks;

10 Kbyte ROM with the Neuron Chip Firmware (Neuron 3120 Chip only): Minimizes node cost by embedding the firmware on the chip;

External memory interface (Neuron 3150 Chip only): Supports applications with up to 42 Kbytes of code;

11 programmable I/O pins: The I/O pins support 33 programmable modes of operation for interfacing to a variety of sensors, actuators, and other I/O devices. Four of the pins include programmable pull-up resistors. Four of the pins support a 20mA current sink;

2 16-bit timer/counters: The timer/counters can be used with the I/O pins to support interfacing to a variety of I/O devices with frequency, pulse width, or pulse count interfaces;

5 pin programmable network communications port: The programmable network communications port enables the Neuron Chip to be used with a variety of communications transceivers including twisted pair, link power, power line, radio frequency, fiber optic, coax, and infrared. The communications port includes a built-in transceiver for a direct connect twisted pair network. Transceivers can operate at bit rates from 610 bps to 1.25 Mbps;

Sleep mode: The application can put the Neuron Chip into a sleep mode to reduce current consumption for battery powered applications. The Neuron Chip retains the application state so that when the Neuron Chip is awakened by an external event, the operating state of the application is preserved;

Neuron Chip firmware: The Neuron Chip firmware includes a complete implementation of the 7-layer LonTalk protocol which saves development time, ensures a reliable implementation of the protocol, and provides interoperability between nodes from different groups or vendors. Network management and diagnostics are included in the firmware so that every node can be installed using a single installation strategy, and networks can be easily maintained using a common set of diagnostic and maintenance commands;

Service pin support: A single pin is used for a service button input and service LED output. The service button input can be used to identify nodes when they are physically attached to a network. The service LED output provides a visual indication of node health;

Neuron ID number: Every Neuron Chip has a unique 48-bit ID number, called the *Neuron ID*, installed by the chip manufacturer. The Neuron ID is used by an installation tool during installation to communicate with the Neuron Chip and assign it a unique network address;

Authentication Key: A 48-bit authentication key allows a node receiving a message to challenge the sender of the message and verify that the sender has the same key. This security feature can be used for a variety of functions including the prevention of unauthorized network programming.

Inexpensive Node Cost

The existence of multiple manufacturers of Neuron Chips, transceivers, routers, gateways, serial interfaces, and network management tools has resulted in tremendous price competition. In contrast with sole source suppliers, competing suppliers battle one another by offering better prices, and the cost of a LONWORKS node has fallen significantly over the past four years. When introduced in 1991, Neuron Chips were priced around $10; Motorola and Toshiba are currently quoting prices of just over $2 for volume orders for the end of 1995. Motorola and Toshiba are currently designing third generation Neuron Chips, and with each generation both the die size and price have fallen. The same phenomenon is expected to hold true over the coming years.

Inexpensive Development Cost

A complete set of developer's tools is available for developing nodes. Called the LonBuilder® Developer's Workbench, this tool allows customers to develop application code in Neuron C (a variant of ANSI C), debug the code, emulate node hardware, analyze network traffic, and download code into the nodes. This complete tool can dramatically reduce the time required to develop a complete network, and eliminates the need for a customer to cobble together a set of separate, expensive tools for network development. Since faster time to market can mean the difference between a hot new product and a me-too look-alike, the LonBuilder usually pays for itself in very short order. Customers can either purchase or lease a LonBuilder; leasing is available through Echelon Credit Corporation.

LONWORKS Independent Developers

For customers seeking design assistance, Echelon has established a network of about 70 LONWORKS Independent Developers (LIDs). LIDs are engineering firms that work under contract with customers to design LONWORKS control networks for their specific applications. In many cases, the LIDs will also supply the LONWORKS nodes on an OEM basis. LIDs can simplify the task of incorporating LONWORKS into new or existing products for customers who lack the resources or time to complete this work in-house.

Compatibility with Existing Systems

There are five ways in which LONWORKS can be integrated with existing systems: input/output (I/O) integration, gateways, Dynamic Data Exchange (DDE) servers, serial interfaces, and microprocessor interface programs. Each of these methods will be described in turn.

Input/output (I/O) Integration

I/O integration involves connecting existing sensors, actuators, displays, and related electrical devices to the I/O of a Neuron Chip, at which point the signals can be processed as LONWORKS signals. Typical audio inputs and outputs would include analog voltage and current levels, triac outputs, quadrature inputs, MIDI input/outputs, SMPTE time codes, serial and parallel signals, and Microwire devices.

The Neuron Chip connects to external hardware via eleven pins – IO0 through IO10. These pins may be configured in numerous ways to provide flexible input and output functions with a minimum of external circuitry. The Neuron C programming language generates code to configure the I/O pins and invoke the appropriate I/O drivers built into the Neuron Chip firmware. The programmer interfaces with the pins using high-level *I/O objects* that manage the I/O state and control interaction with I/O devices. Use of I/O objects simplifies code development and minimizes the code space required to interface with I/O devices. Some of the 33 I/O objects provided by Neuron C and supported by the Neuron Chip firmware and I/O hardware are described below:

1 *Bit, nibble, and byte nibble input/output*. Interface with any device using bit, nibble, or byte-wide digital I/O;

2 *Bit-shift input/output*. Interface with any device using a clocked serial bit stream such as a shift register;

3 *Dual-slope input*. Implement low cost A/D converters for analog input;

4 *Edge log input*. Measure the high and low intervals of an input signal. Can be used to decode any type of bit stream that contains data in the time domain, such as a bar code input;

5 *Frequency output*. Use for frequency synthesis to drive an audio transducer or to drive a frequency to voltage converter to generate an analog output;

6 *Infrared input*. Decode an input signal from an infrared controller;

7 *Level detect input*. Detect an input pulse from devices such as proximity sensors;

8 *Magcard input*. Read input data from an ISO 7811-compatible magnetic card reader;

9 *Multiplexed bus input/output*. Interface with any device requiring an address and data bus such as a programmable UART;

10 *Neurowire input/output*. Interface with any device using a Motorola SPI or National Microwire™ compatible serial interface. A variety of devices support this standard including A/D and D/A converters, and time of day clocks;

11 *Oneshot and pulsewidth output*. Produce output pulses of a specified period or duty cycle. Use to implement D/A converters or to control any device with a pulsewidth modulated input;

12 *On-time or period input*. Measures the pulsewidth or period of an input signal. Use to implement A/D converters, frequency counters, or tachometers;

13 *Parallel input/output*. Exchange data with another processor over an 11-bit parallel port. Used by the MIP/P20 and MIP/P50 versions of the Microprocessor Interface Program (MIP) to transform the Neuron Chip into a communications co-processor;

14 *Pulse count input/output*. Perform average frequency measurements and implement tachometers. Use the pulse count input to control devices requiring a precision count of pulses such as stepper motors;

15 *Quadrature input*. Monitor input data from shaft encoders for low cost angular position input;

16 *Serial input/output*. Interface with devices using asynchronous serial I/O such as intelligent LCD displays or terminals;

17 *Total count input*. Count external events such as contact closures;

18 *Triac output*. Control AC circuits using a triac device such as lamp dimmers;

19 *Triggered count output*. Control stepper motors or position actuators that provide position feedback in the form of a pulse train;

20 *Wiegand input*. Read input data from a Wiegand-compatible card reader.

Gateways

Gateways provide a means of converting between the LonTalk protocol and another protocol. Protocol conversion is typically accomplished in software/firmware. A gateway might be used to interconnect a LONWORKS network with existing systems using Crown IQ, MediaLink, Crestron NexSys, or PA-422 protocols - without modifying the existing, installed system. Table 1 presents a list of some of the LONWORKS gateways currently available.

Table 1 Off-the-shelf LONWORKS Gateways

Gateway	**Manufacturer**	**Application**
LONWORKS to Telephone Gateway	Echelon +1-415-855-7400	Provides interface to Hayes compatible dial-in/out telephone modem
LONWORKS to Fieldbus Gateway	Gesytec +49-24-089-44-101	Provides gateway to CAN, Bitbus, Profibus (DIN 19 245), DIN 19 244, DIN 66 348, DIN 66 019, SUCONET class 2, Modnet-1F, Modnet-1N, Modnet-1/SFB, DUST (Siemens 3964R), SINEC-L1, and SINEC-L2 a.A.
LONWORKS to Industry Standard I/O Modules Gateway	Grayhill +1-708-482-2165	Provides gateway to Grayhill, Opto22 (digital only), and comparable modules
LONWORKS to OptoMux Gateway	Grayhill +1-708-482-2165	Provides gateway to OptoMux network
LONWORKS to ModBus Gateway	TechniSys +1-713-787-9991	Provides gateway to ModBus network
LONWORKS to T1/Ethernet Gateway	Matrix +1-919-231-8000	Provides gateway to Ethernet and T1 networks
LONWORKS to X.25 Gateway	CommTech +1-908-651-0707	Provides gateway to X.25 networks. 16 port X.25 concentrator also available

Dynamic Data Exchange (DDE) Server

DDE defines a standard way for Microsoft Windows applications to share information with one another. Applications that support DDE, such as Microsoft Word, Microsoft Excel, Microsoft Visual Basic, National Instruments LabView, and Wonderware InTouch, have the ability to monitor and modify network communications in a LONWORKS network. Figure 1 below shows two applications (clients) communicating via DDE with Echelon's DDE Server, and the relationship between the clients, the DDE Server, and the network. The DDE Server provides a simple means of interfacing a LONWORKS network to a wide variety of existing Windows applications, thereby allowing customers to take advantage of programs already developed for other applications.

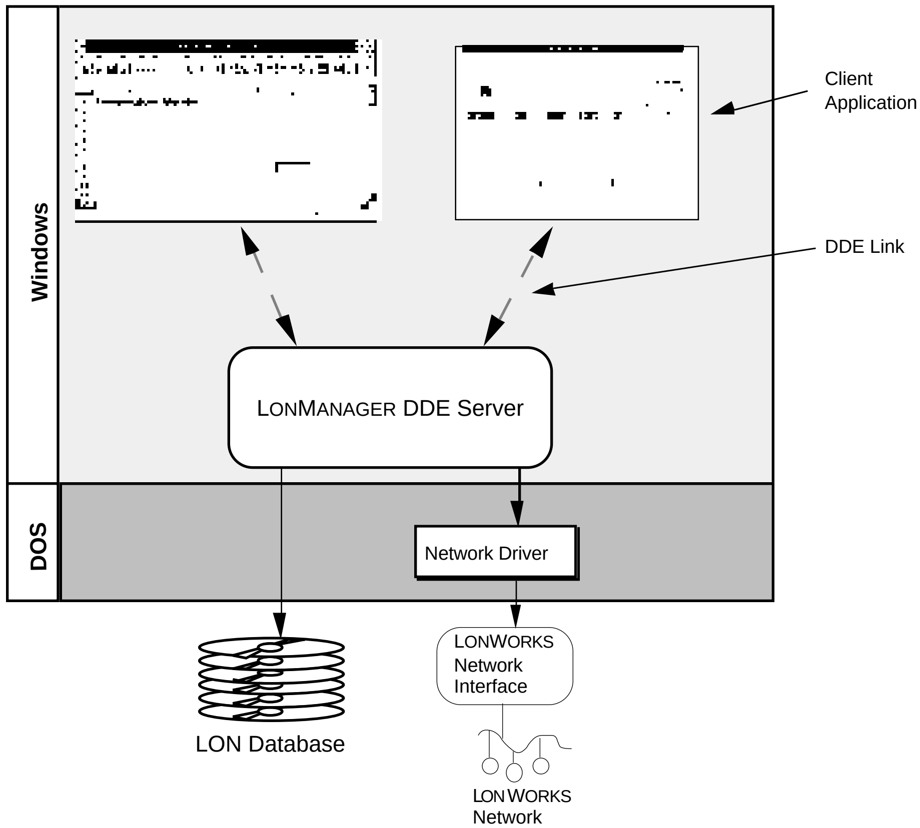

Figure 1 LONWORKS DDE Server Overview

Serial interfaces

Many audio devices incorporate RS-232 serial interfaces for communicating with a terminal, computer, or modem. Echelon and third party vendors manufacture serial LonTalk interfaces that enable any host processors with RS-232C serial ports to connect to a LONWORKS network. The serial interface moves the upper layers of the LonTalk protocol to the attached host, which acts as an application node on the network. When used with a PC host and an Echelon API, the serial interface can also be used to build sophisticated network management, monitoring, and control applications. When used with a modem, the serial interface allows a remote host computer to access the network over standard dial-in/out telephone lines.

The availability of serial interfaces allows existing IBM PC compatibles, Apple Macintosh computers, Sun workstations, and VME-based computers to access a LONWORKS network.

Microprocessor Interface Programs (MIP)

Many existing audio devices use microprocessors for various functions, and these processors can become the interface into a LONWORKS network. Using one of Echelon's microprocessor interface programs, the Neuron Chip is transformed into a communications co-processor for the attached host processor. The upper layers of the LonTalk protocol are transferred to the attached host microprocessor, allowing these devices to interface with a LONWORKS control network.

Open Architecture

An open architecture is one that is accessible for review by all, and for which parts/components are available on the open market. LONWORKS satisfies both of these criteria. The LonTalk protocol is published in the document *LonTalk® Protocol Specification, Version 3.0*, and is available from Echelon for $50 by ordering bulletin 078-0125-01. Neuron Chips are available worldwide from Motorola, Toshiba, and their distributors. LONWORKS-compatible transceivers, routers, serial interfaces, and network management tools are available both from Echelon and third party vendors. Table 2 below includes a partial summary of these products.

Table 2 Off-the-shelf LONWORKS Transceivers, Routers, Network Interfaces, and Drivers

Transceivers

Transceiver	Manufacturer	Application
78kbps Transformer-isolated twisted pair	Echelon +1-415-855-7400	New or retrofit bus wiring topologies using 22AWG Level IV cable
1.25Mbps Transformer-isolated twisted pair	Echelon +1-415-855-7400	New or retrofit bus wiring topologies using 22AWG Level IV cable
78kbps link power twisted pair	Echelon +1-415-855-7400	New or retrofit bus, loop, and/or star wiring topologies; sends power and data on a common twisted wire pair
78kbps free topology twisted pair	Echelon +1-415-855-7400	New or retrofit bus, loop, and/or star wiring topologies; compatible with link power

49MHz radio frequency	Wornall +1-816-333-6299	New or retrofit applications requiring short haul, bi-directional or unidirectional radio communications
450/900MHz radio frequency	Motorola R-Net +1-415-525-4601	New or retrofit applications requiring bi-directional or unidirectional radio communications up to 5 miles
900MHz spread spectrum radio frequency	Utilicom +1-805-964-5848	New or retrofit applications requiring bi-directional or unidirectional radio communications up to 5 miles
400-450MHz radio frequency	Multitone +44-256-20292	New or retrofit applications requiring short haul, bi-directional or unidirectional radio communications
1.25Mbps coaxial cable - video and data	DGA Electronics +1-416-422-1036	New or retrofit applications requiring signaling via coaxial cable
1.25Mbps coaxial cable - data	Leitch Video +1-416-445-9648	New or retrofit applications requiring signaling via coaxial cable
Fiber optic	Microsym +1-416-293-8263	New or retrofit applications requiring signaling over fiber optic cables
Fiber optic	Fabrisys +32-2363-1732	New or retrofit applications requiring signaling over fiber optic cables
InfraRed	Fasirand +1-206-746-1140	New or retrofit applications requiring signaling via infrared
100kHz to 450kHz spread spectrum power line	Echelon +1-415-855-7400	New or retrofit applications requiring signaling over AC or DC power circuits
9kHz to 95kHz spread spectrum power line	Echelon +1-415-855-7400	New or retrofit applications requiring signaling over AC or DC power circuits
125kHz to 140kHz narrow band power line	Echelon +1-415-855-7400	New or retrofit applications requiring signaling over AC or DC power circuits

Routers

Router	**Manufacturer**	**Application**
Prepackaged router	Echelon +1-415-855-7400	Routers in enclosures for routing between twisted wire pair transceiver types
Router modules	Echelon +1-415-855-7400	Router modules for OEM integration for routing between twisted wire pair, power line, and radio transceivers
Router Core Module	Echelon +1-415-855-7400	Router module in a SIM package for OEM integration for routing between twisted wire pair, link power, power line, radio, coaxial cable, and/or fiber optic transceivers
Power line-to-twisted pair	Pensar Corp. +1-414-739-4355	DIN-rail mounted power line-to-twisted pair router with integral power supply

Power line-to-twisted pair	Intelligent Energy +1-303-989-6197	PCB power line-to-twisted pair router with integral power supply
Fiber optic-to-link power/twisted pair/power line	Microsym Computers +1-416-293-8263	Fiber optic to link power or twisted pair or power line router

Network Interfaces

Network Interface	Manufacturer	Application
115kbps Serial Network Interface	Echelon +1-415-855-7400	Provides a high speed EIA RS-232 network interface for direct serial connection or remote connection via modem
ISA Bus Network Interface	Ziatech +1-805-541-0488	Provides an ISA bus network interface for PC hosts
PC/104 Network Interface	DMS +1-714-731-5113	Provides a PC/104 bus network interface for embedded PC hosts
STD32 Bus Network Interface	Ziatech +1-805-541-0488	Provides an STD32 bus network interface for PC hosts
VME Network Interface	Enginuity +1-602-275-3363	Provides a VME bus network interface for VME-based hosts

Drivers

Driver	Manufacturer	Application
SLTA/2 DOS Driver	Echelon +1-415-855-7400	Provides a Microsoft DOS driver for the SLTA and SLTA/2 Serial LonTalk Adapter
SLTA/2 Unix Driver	Echelon +1-415-855-7400	Provides a Unix driver for the SLTA and SLTA/2 Serial LonTalk Adapter
MIP DOS Driver	Echelon +1-415-855-7400	Provides a Microsoft DOS driver for the Echelon MIP/P20 and MIP/P50 Microprocessor Interface Program
MIP Driver for Motorola 68332	Motorola Don Aldridge +1-602-302-8077	Provides a Motorola 68332 driver for the Echelon MIP/P20 and MIP/P50 Microprocessor Interface Program
MIP Driver for Motorola 68HC11	Motorola Don Simon +1-512-505-8316	Provides a Motorola 68HC11 driver for the Echelon MIP/P20 and MIP/P50 Microprocessor Interface Program

Control Architecture

LONWORKS uses a peer-to-peer architecture with priority messaging. The priority feature uses separate buffers within each node to allow outgoing priority packets to supersede non-priority packets, even non-priority packets that have already been queued for transmission.

Device/User Interface/Network Management Application Programming Interface (API)

Echelon's Application Programming Interfaces (APIs) provide programmers with a comprehensive library of network and data base services, freeing developers to focus on application development. The APIs contain node configuration and monitoring functions as well as multi-channel, multi-media, and router management capabilities. The APIs can be used to simplify and accelerate the development of network management, installation, and maintenance tools, network monitoring and control nodes, operator interfaces, and embedded host application nodes (such as front panels displays).

Operations that would require the development of code are replaced with single function calls. For each LONWORKS installation and configuration task (such as node installation, node replacement, network variable and message tag binding, and application code downloading) the APIs provide highly integrated and easy-to-use functions. These functions perform error checking; build, send, and process all required network messages; calculate LonTalk timers, and manage the relationships between data items, creating and removing linked data base records as needed to keep the network and data base synchronized.

The APIs include an integrated data base that reflects the addressing and configuration information of every node in the network. The data base and its associated management functions reduce the development effort required to create network management, monitoring, and control applications.

The Windows version of the API is provided as Windows Dynamic Link Libraries (DLLs). Through the use of DLLs, developers can combine the multi-tasking, ease-of-use, and productivity enhancements of Microsoft Windows with the extensive network management, monitoring, and control capabilities of the API.

An overview of Echelon's APIs is shown in Figure 2. Table 3 summarizes the features of the APIs.

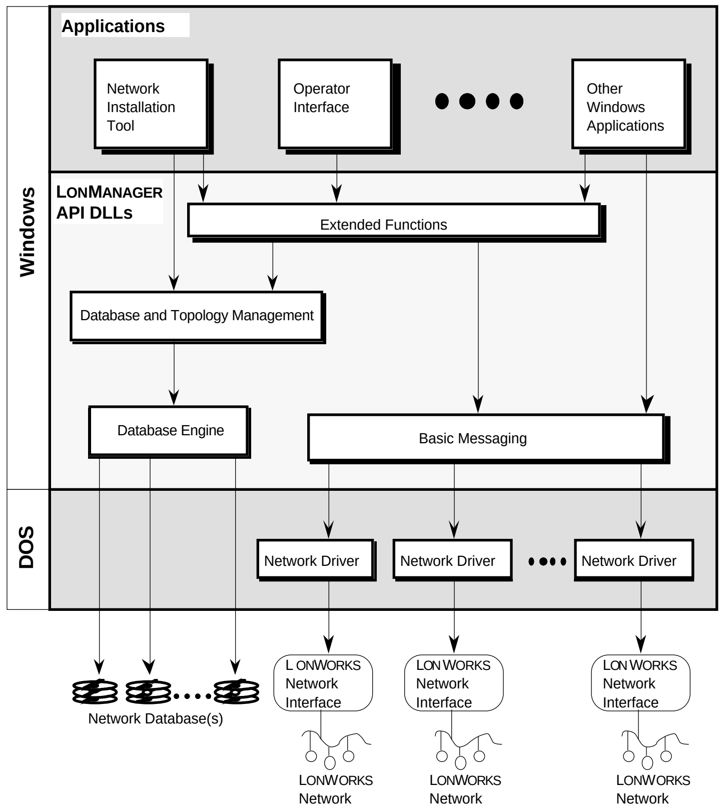

Figure 2 LONWORKS API Overview

Table 3 Overview of API features

Feature	**Function**
Topology management and analysis	Analyze the topology and configure routers, detect redundant routers, detect conflicting routers, and calculate message timers based on the network topology.
Application loading	Verify the compatibility of a target node and a Neuron Chip executable image and load a Neuron Chip executable image into a node.
Messaging functions	Send and receive messages, compute messaging transaction timers, and translate database object names into network addresses.

Database management	Add, modify and remove records, traverse lists, save and restore context, and start, abort and commit transactions.
Network interface management	Set and determine buffer sizes and counts, manage queue sizes and aging parameters, and bring the interface on-line and off-line.

Managed Objects	Function
Domains	Manage all domain parameters including domain ID size, domain IDs, and authentication keys.
Subnets	Manage all subnet parameters and links, including subnet membership within a domain.
Nodes	Manage all node resources including domain table entries, network variable configuration table entries, and address table entries. Manage membership relationships with subnets, and membership relationships with groups. A maximum of 50 nodes are supported.
Channels	For a single channel, manage all channel parameters.
Groups	Manage all group parameters and links, including group membership within nodes.
Programs	Manage all program parameters and links, including program usage by nodes.
Network variables	Manage all network variable parameters such as type and direction and all links, including network variable membership within a program, network variable membership within a node, and network variable relationships within connections.
Message tags	Manage all message tag parameters such as type and direction and all links, including message tag membership within a program, message tag membership within a node, and message tag relationships within connections.
Connections	Manage all network variable and message tag connection parameters such as connection members and timing parameters and all connection resources such as network variable selectors.

Connectionless Data Transfer

All LonTalk products are connectionless for single packet messages. File transfers require connections.

Connection-based Topology

Network variables and network variable binding provide a connection-based topology once the system is configured.

Pre-setable Network-wide Environments

Network management tools such as the NSS-10 Network Manager and APIs provide network-wide configuration environments that can be automatically downloaded.

Object Orientation

The LONMARK™ Interoperability Association document *LONMARK Application Layer Interoperability Guidelines* specifies the object methodology for node functions. One of the main benefits of the object methodology is that it allows devices from different manufacturers that share the same object set to interoperate in the same network. For example, a Crestron or AMX controller could communicate with Crown, Crest, or JBL amplifiers, an IED paging system, an IRP equalizer, and a Studer recorder. Interoperability is not a dream of the future, either. Today thousands of nodes from scores of manufacturers interoperate in installations worldwide, covering industries as diverse as theatrical lighting, audio, security, HVAC, fire/life safety, process control, and machine control.

Predictable Response Times

An audio control network needs predictable response times, especially during periods of network overload. The ability of a control network to exhibit predictable response time under overload conditions is a function of what happens above the MAC sublayer and at the application.

The LonTalk media access protocol uses a variant of the carrier sense multiple access protocol (CSMA) called predictive p-persistent CSMA protocol. In the predictive p-persistent CSMA protocol, a node uses probability calculations to determine when and when not to transmit on slotted channels, and dynamically adjusts the number of packet time slots based on predicted network traffic. By dynamically allocating network bandwidth, the LonTalk protocol permits the network to continue operating in the presence of very high levels of network traffic without slowing during periods of light traffic. The benefits of this technology are its high efficiency, low overhead, low cost hardware, elimination of the need for network wide synchronization, and lack of loss-prone tokens.

Two key features of the LonTalk protocol overcome limits of other CSMA protocols: first, the protocol can be used with transceivers that limit the number of stations on a single network segment; second, each node is limited to a single outgoing transaction at a time and transmitters stop and wait for an acknowledgment prior to accessing the communications medium again. These two implementation details make it impossible for a node to be denied access to the communications medium indefinitely.

Network Overload

When a network is lightly loaded (and this should be its condition in normal operation), response times will generally be good without regard for the protocol used. The reason that light loading should be the condition for normal operation is because the traffic is usually not uniformly distributed over time. Instead it arrives in bursts, and these bursts should not exceed the capacity of a network for very long.

When a network is heavily loaded, as is often the case during periods of emergency or error, response times will be poor. This is because the offered traffic exceeds the bandwidth of the network and messages queue within nodes while awaiting access to the medium. If the overload persists, the nodes may run out of buffer memory to queue additional messages. This will either stop or reset the application in the node, causing further delays. The LonTalk protocol includes three features that prevent such conditions:

1 Graceful degradation: some number of messages are allowed to get through regardless of the offered traffic load. During an overload condition, the network responds in a controlled manner without failing catastrophically;

2 Priority: not all messages will get through in time during overload so the LonTalk protocol allows emergency messages to have priority over other messages. Priority messaging allows high priority messages to lock out low priority messages. This has the effect of dedicating the network bandwidth to emergency traffic and holding off messages that the customer has decided can be deferred;

3 End-to-end acknowledgment: the LonTalk protocol includes this message service since it is vital for an application either to know that a message got to its destination or that it did not get there within the real time requirements of the system.

The reason the LonTalk protocol includes so many features designed to accommodate overload conditions is simple: the protocol was designed specifically for control network applications where overloads can and do occur. Since control applications must continue operating reliably and/or degrade gracefully during overload conditions, the LonTalk protocol was tailored to such a mode of operation.

Response Times

One might question whether the LonTalk protocol can provide well defined network timing given that the number of timing slots vary dynamically. Using the end-to-end acknowledgment service allows the application to know whether an operation has succeeded or not within a bounded amount of time. The protocol tracks elapsed time from the point that an application requests that a packet be sent, rather than when the packet is actually sent on the communications medium. For example, suppose that a packet must be sent and acted upon within 50 milliseconds, and if it is not acted upon in that time, the sender of the packet must take immediate action. Such a packet could be sent using acknowledged service with a retry count of 2 and a retry interval of 16 milliseconds. In this way, the application will either know that the transaction completed successfully by receiving the acknowledgment, or the application will know that the transaction failed in 48 milliseconds.

If the sample transaction described above fails, the application might then send an emergency message using the priority feature of the protocol. The priority feature uses separate buffers within each node to allow outgoing priority packets to precede non-priority packets which have already been queued for transmission. Additionally, the priority feature uses dedicated bandwidth (also referred to as "priority slots") at the end of each packet to eliminate contention for the communications medium after the transmission of a packet. Collision resolving transceivers can also be used when the channel bandwidth is limited and/or there is a need to run the network at its maximum capacity for a sustained time.

Fault Tolerance

LONWORKS offers several types of fault tolerance, both at the physical layer and at higher protocol layers. Network communications can be configured in a self-healing ring that will automatically redirect signals in the event of a line cut. Ring topology is supported by free topology twisted pair, link power twisted pair, power line, 78kbps transformer-isolated differential Manchester, and fiber optic transceivers. The differential Manchester transceiver requires an intelligent data switch for signal rerouting; switches are available off-the-shelf from third party vendors like AT&T and CommTech. The fiber optic ring transceiver requires only a single fiber strand over which signals are sent bi-directionally between transceivers. In the event of a cut, the transceivers automatically reroute communications around the faulty fiber strand.

Additionally, the LONWORKS peer-to-peer architecture inherently affords fault tolerance since network nodes can be preprogrammed to redirect signals around a failed network node.

Efficiency

LonTalk packets are optimized for control network applications and packets incorporate a minimum number of bits. LONWORKS technology is cost efficient, too, because the complete 7-layer protocol stack is incorporated in a single silicon processor, the Neuron Chip, which also includes the control microprocessor. Node programming is efficient because of the use of Neuron C, a version of the commonly used ANSI C programming language.

Network-wide Synchronization

LONWORKS nodes can be synchronized over the network to within approximately 1 millisecond.

Multicast Data Channels

Multicast data channels are provided in LONWORKS. End-to-end multicast service is provided over multiple channels, including channels with routers.

Predictable Network Latency

Network latency is bounded in LONWORKS. A patented collision avoidance technology ensures bounded worst case latency under high traffic conditions. This feature avoids the need for customers to implement expensive collision detection hardware.

Consistency with the OSI Model

The Neuron Chip firmware and communications hardware implement a complete 7-layer communications protocol. The 7-layers follow the reference model for open systems interconnection (OSI) developed by the International Standard Organization (ISO).

1 *Physical*. The physical layer defines the physical interconnect to the communications medium. The Neuron Chip may be directly connected to a twisted pair for small self-contained networks where common mode voltage levels are minimal and a high-level of noise immunity is not required. For other communications media, the Neuron Chip can be connected to a variety of communications transceivers that manage the electrical interconnection to the communications medium. Communications transceivers are available for twisted pair, link power, power line, radio frequency, fiber optic, coaxial cable, and infrared communications media.

2 *Link*. The link layer manages media access and data encoding. When a node has a message to send, the link layer determines the timing of when the message is transmitted. Prior to transmitting a message, the link layer waits for the communications channel to become idle. Since multiple nodes may be waiting simultaneously for the channel to become idle, the link layer waits for a random interval prior to transmitting. If another node starts transmitting during the interval, the process is repeated. When the network is idle, the random interval is 1 of 16 delay times, known as randomizing slots. A unique feature of the LonTalk protocol is that the number of randomizing slots increases as network load increases. This feature ensures reliable sustained network performance, even for networks that are heavily loaded.

3 *Network*. The network layer manages delivery of message packets to the correct destination nodes. Messages can be addressed to a single node, to any group of nodes, or to all nodes. Group addressing reduces network traffic by supporting the delivery of a single message packet to multiple nodes. Addresses are formed using a hierarchical structure which supports the use of routers that filter messages based on their destination address. By supporting routers at the network layer, the LonTalk protocol supports the installation of very large systems with thousands of nodes. Routers use the network layer to confine traffic to segments within a large network, thereby increasing the total capacity of the network.

4 *Transport*. The transport layer ensures reliable delivery of message packets. Messages can be exchanged using the *acknowledged* service, where the sending node waits for an acknowledgment from the receiver and resends the message if the acknowledgment is not received. The application is informed if an acknowledgment is not received after a configurable number of retries. Duplicate messages are detected and rejected by the transport layer if a message is resent due to a lost acknowledgment. Messages not requiring the reliability of acknowledged service can use *unacknowledged* or *repeated* services to send the message once, or a configurable number of times, without waiting for an acknowledgment.

5 *Session*. Message packets can use a class of service known as request-response to invoke an action on a remote node. For application messages, the request is passed to the receiving application which generates the response. The LonTalk session layer defines a range of standard message codes for network management and diagnostic messages. These messages are handled by the session layer and are not passed to the application. Network management messages facilitate network installation and maintenance by providing commands to remotely define a node's network configuration data in Neuron Chip EEPROM. Network diagnostic messages support network diagnosis and repair. A standardized session layer ensures that all LONWORKS nodes can be installed using compatible installation methods.

The session layer defines an authentication protocol that enables receivers of a message to determine if the sender is authorized to send the message. This can prevent unauthorized access to nodes and their applications. The use of authentication is configured individually for each network variable. Network management transactions may also be optionally authenticated.

The session layer also defines an optional network interface protocol that can be used to support LONWORKS applications running on any host processor. The host processor manages layers 6 and 7 of the LonTalk protocol, and the Neuron Chip manages layers 1 through 5. The LonTalk network interface protocol defines the format of packets exchanged between the network interface and the host.

6 *Presentation*. Messages are exchanged between applications by the presentation layer. The presentation layer interprets message packets as network variables, explicit messages, or foreign frames. Applications typically exchange data using network variables. Network variables are a class of message packets with an identifier that identifies the data as a Neuron C variable that is shared by multiple nodes on a network. When a network variable is exchanged, the presentation layer manages the translation between a network variable declared in the application program and the network variable identifier encoded in the message packet. The presentation layer also manages the transfer of data between network variable storage and the message packet buffer.

Explicit messages are used by applications requiring a different data interpretation model than network variables. Explicit messages are message packets with a single byte message code that identifies the packet to the receiving application. The applications exchanging explicit messages must agree on the interpretation of the message codes, and must manage the transfer of data into and out of the message packet buffer. Foreign frames are exchanged as a simple array of bytes that can be interpreted by the application in any way.

7 *Application*. Each network variable has a data type declared by the application program. To facilitate interoperability, the LonTalk protocol application layer defines standard network variable types which specify how applications will interpret the network variables. For example, two nodes exchanging a temperature network variable can use a standard network variable type to ensure that both nodes interpret the temperature data using the same units.

Multiple Media in the Network

LONWORKS is media independent and will support virtually any type of communication transceiver. Today communication transceivers are available for the following media:

- Manchester encoded twisted wire pair: transformer-isolated, bus topology transceivers are available with bit rates of 78kbps and 1.25Mbps;
- Free topology twisted pair: transformer-isolated, free topology transceiver supports star, loop, bus, and combination wiring schemes over cables from 22AWG (0.65mm) to 16AWG (1.3mm);
- Link power twisted pair: free topology transceiver sends both network data and power on a twisted pair, eliminating the need for independent local power supplies. The transceiver supports star, loop, bus, and combination wiring schemes over cables from 22AWG (0.65mm) to 16AWG (1.3mm). The transceiver is compatible with the free topology twisted pair transceiver;
- Power line: signal through any AC or DC power circuit with models available for Europe and other countries abiding by the CENELEC standard, North America and other countries abiding by FCC standards, and Japan (MTT standard). These are the ultimate transceivers for retrofit installations;
- Fiber optic: dual-strand (transmit and receive pair) and single strand (bi-directional signaling on a single fiber) offer high speed, EMI-free signaling for electronically harsh environments;
- Radio frequency: 49MHz, 400-450MHz, 900MHz spread spectrum, 1.2GHz spread spectrum, and 2.4GHz spread spectrum radio transceivers are available for wire-free or rapid deployment applications;
- Infrared (IR): high speed IR transceivers are ideal for portable applications or where it's not possible to install wires;

- Coaxial cable: high speed data-only or data and video transceivers for applications requiring signaling over coaxial cables.

In many applications, it is desirable to use more than one medium to reduce installation costs. For example, remote amplifier monitoring might be best accomplished with power line signaling, but equipment clusters might be better served by a twisted pair network. Media conversion is simple with LONWORKS because of the availability of off-the-shelf media routers. Routers provide seamless transitions from any medium to any other medium without the need to customize hardware or software, and with minimal effect on network performance. Routers are available from Echelon and third party vendors in desktop, DIN rail, NEMA panel, printed circuit board (PCB), and single in-line module (SIM) packages.

LONWORKS application programs do not have to be modified to work with routers; only the network configuration of a node has to be modified when it is installed or moved to the far side of a router. The required modifications to the network configuration can be done automatically by Echelon installation tools or installation programs.

Routers can forward an unlimited number of network variables. This saves development costs since no code development is required to use routers, and saves installation and maintenance costs since router configuration is automatically managed by the installation tools. All network configuration is performed over the installed network, further minimizing installation and maintenance costs since routers do not have to be physically accessed to change their configuration.

Open Availability Worldwide

LONWORKS technology is available worldwide, and is supported by a comprehensive customer service, training, and development assistance program. Through its LonSupport™ Premier program, Echelon offers 4-hour response to technical questions. In addition, Echelon has field application engineering offices throughout the United States, as well as in London, Munich, Paris, and Tokyo; Echelon distributors offer technical support throughout Europe, Asia, the Pacific region, the Middle East, and Latin America. Motorola and Toshiba also offer field support through their own application engineering offices. Training classes are offered worldwide by Echelon in English, French, German, Swedish, Dutch, Italian, and Japanese, and include classes in

LONWORKS design, network management, host computer applications, and custom node development.

The following LONWORKS training classes are available through Echelon:

Intelligent Distributed Control

Intelligent control networks have until now been costly, or limited in their domain of usage. Communication protocols are difficult to design and implement, and tools for development and testing of networked applications have been lacking.

A practical solution for intelligent distributed control must provide robust multiple media communication capabilities, flexible but easy to use node I/O interfaces, and application software development in a high-level language with good support tools.

Echelon's LONWORKS tools and components provide the means to build *local operating networks*. LonTalk networks consist of intelligent nodes connected to multiple communication media, and use a common, message-based communication protocol.

The purpose of this course is to prepare engineers to develop LonTalk networks for a variety of applications, using the facilities available in the LonBuilder Developer's Workbench.

Design of Network Installation Tools

The true power of Neuron Chip-based nodes is their ability to work together in LonTalk networks. While individual Neuron Chip-based sense and control nodes may be quite simple, they can be interconnected with large numbers of other such nodes to create powerful and sophisticated networks.

Echelon's LONWORKS tools and components provide the means to logically connect (or ‘bind’) Neuron Chip-based nodes into LonTalk networks. Nodes in simple LonTalk networks may be linked using software that runs in the Neuron Chip-based nodes themselves. LONWORKS nodes may also be connected using network installation tools which are built around a Neuron Chip and which can be developed for specific applications.

With the use of Echelon’s API, an IBM-compatible personal computer can be programmed to serve as a flexible and comprehensive network management tool.

The purpose of this course is to prepare engineers to develop network installation and network management tools for a variety of applications, using the facilities available in the Neuron C language and in the API.

Control Network Systems Engineering

Neuron Chip-based nodes have the ability to work together in LONWORKS networks. While individual Neuron Chip-based sense and control nodes are often quite simple, they can be interconnected with large numbers of other such nodes to create powerful and sophisticated networks.

The development of a LONWORKS network requires a distinct and well-considered network architectural planning phase. Networks must be designed with orderly control relationships and careful attention to communications alternatives. Large networks are often partitioned by routers, so as to discipline the flow of message packets. Network performance can be tuned and enhanced. Many aspects of network communications services and timing can be configured.

In addition, a number of general issues of interest to network designers and developers are addressed in this course, such as system design methodology, network reliability, network safety, and user interface design.

The purpose of this course is to prepare engineers to design control networks for a variety of applications, taking advantage of the plethora of facilities available in the LONWORKS technology.

Custom Node Development

Intelligent control networks have until now been costly, or limited in their domain of usage. Communication protocols are difficult to design and implement, and tools for development and testing of networked applications have been lacking. Echelon's LONWORKS tools and components provide the means to build intelligent control networks. LONWORKS networks consist of intelligent devices connected to multiple communication media and use a common, message-based communication protocol.

The primary objective of this course is to provide the participant with the basic skills necessary to select, design, and develop robust LONWORKS based node hardware. At the end of this course participants will be able to: debug hardware using the hardware development and debug facilities of the LonBuilder Developer's Workbench; implement I/O circuitry using the I/O and memory interface options of the Neuron Chip; choose a network transceiver interface; strengthen designs using ESD and EMI design techniques illustrated with Echelon's transceiver offering; and design with Echelon transceiver building blocks.

LONMARK Interoperability Association Program

LONWORKS technology makes possible a new generation of smart products that can talk to one another. The LONMARK Interoperability Association Program is focused on establishing LONWORKS technology as the international standard for control networks. Networks are inherently multi-vendor and the LONMARK Program is aimed at fostering collaborative efforts among LONWORKS product developers. LONWORKS technology provides a rich framework for designing, managing and controlling networks of nodes from multiple vendors. Manufacturers can expand the markets for their products and expand customer choices by offering new LONWORKS-based products that can work together.

Defining the standards for LONWORKS networks is a collaborative effort between Echelon and LONWORKS product developers. Manufacturers can take a leadership role in establishing standards for their industry by becoming LONMARK Partners. LONMARK Partners have the opportunity to help create and endorse worldwide standards and influence the future development of the LONWORKS control networking platform.

Under the umbrella of Echelon's LONMARK Program, manufacturers can participate in both technical and marketing focus groups. LONMARK Partners can participate in technical efforts to define industry standards for product design, and also collaborate on joint promotional activities.

Interoperability

In order to promote interoperability among LONWORKS-based products, Echelon has established object oriented variables, referred to in the LonTalk protocol as Standard Network Variable Types (SNVTs). SNVTs facilitate interoperability by providing a well-defined interface for communication between nodes made by different manufacturers. A node may be installed in a network and logically connected to other nodes via network variables as long as the data types match. A list of all available SNVTs is provided in the document *The SNVT Master List and Programmer's Guide*, document 005-0027-01 Rev E. This document is available free of charge.

Multi-vendor interoperability is supported by an independent LONMARK™ Interoperability Association Industry Council, whose job is to ensure that interoperability standards are never compromised.

Summary

The benefits of using LONWORKS for audio applications are clear. LONWORKS meets all of the criteria set forth by the audio industry for a control network. LONWORKS is an open platform for building control networks, and the protocol is published and available to all. Neuron Chips embedded with the LONWORKS protocol are available worldwide from both Motorola and Toshiba. Since the protocol is common among all LONWORKS nodes, these nodes can interoperate - sharing data and decisions that allow the network to operate seamlessly without the need for a central controller.

LONWORKS customers are freed from the burdens of developing network management tools on their own since LONWORKS network management tools are available off-the-shelf. These include preconfigured hand-held programmers, PC and Macintosh-based tools, and API tools that can be customized to provide a unique look-and-feel to each customer's network interface. LONWORKS DDE servers are also available for displaying and controlling network status via such popular software programs as Excel, Word, and InTouch.

A complete development system is available for creating nodes. This tool allows customers to develop application code in a variant of ANSI C, debug the code, emulate node hardware, analyze network traffic, and download code into the nodes. This complete tool can dramatically reduce the time required to develop a complete network, and eliminates the need for a customer to assemble a set of separate, expensive tools for network development.

Instead of developing technology, customers can use LONWORKS technology to build better, more intelligent amplifiers, mixers, equalizers, speakers, power supplies, recording devices, set-top boxes, and multi-room controls. LONWORKS allows control networks for these products to be developed in record time, speeding their time to market and giving LONWORKS' customers a competitive edge.

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