

An Overview of the PATHWORKS Product Family

By Alan Abrahams and David A. Low

1 Abstract

As the number of personal computers continues to grow, so does the demand for networking products and services to allow these PCs to share networked resources. Digital's Personal Computing Systems Architecture enables the integration of PCs into Digital's enterprise-wide network systems. The software products developed using this architecture are referred to as the PATHWORKS product family. PATHWORKS products support a variety of PC platforms and operating systems, and accommodate different physical networks and transport and service protocols. This flexibility allows PC users to access resources outside their PC environment, such as remote files, printers, databases, and electronic mail.

2 Introduction

When the IBM Corporation introduced its first personal computer in 1981, few could have foreseen that by 1992 millions of PCs would have been sold worldwide, radically changing the computer market in the process. The term PC usually implies an Intel 80x86 family or a Motorola 68000 series processor, sized to fit under a desk or smaller and commonly priced under \$5000. The low price has helped to fuel an explosive growth in the number of hardware products and software applications available for PC platforms. PCs are now ubiquitous and represent the largest class of networked computers.

Even before the introduction of the PC, small computers were being networked together to share data and hardware resources. In 1990 as many as 40 percent of the installed PCs were networked.[1] By 1994, an estimated 75 percent of the increasing number of PCs will be linked together with products from many networking vendors. These vendors provide services that commonly include transparent access to remote files, printers, databases, and electronic mail.

Digital Equipment Corporation is a worldwide leader in networking services. Since 1986, we have been developing the Personal Computing Systems Architecture (PCSA) to meet the growing needs of PC client-server applications in local and wide area network systems. Many technical obstacles were met and overcome in the design and development of PC integration products. The PATHWORKS product family, derived from PCSA, reflects the diversity of Digital's customers' needs and environments. PATHWORKS software products support a variety of PC platforms and operating systems, and accommodate different physical networks and transport and service protocols.

An Overview of the PATHWORKS Product Family

To help the reader comprehend the scope of the PATHWORKS offerings, we begin this paper with a basic discussion of PC hardware and software, followed by information about the various protocols used in PC networking. We then describe how Digital's PATHWORKS product set allows integration of PCs into network systems.

3 PC Hardware

This section describes the PATHWORKS Intel and Macintosh client platforms and introduces related PATHWORKS services.

Intel Platforms

The most popular operating systems in the world, IBM's PC-DOS, Microsoft's MS-DOS, and Microsoft Windows, are designed to take advantage of the features of the family of Intel chips that includes the 8086, 80286, i386, and i486 microprocessors.

The 80x86 memory architectures have evolved from 16-bit addressing with implicitly referenced 64-kilobyte segments in the 8086 processor, to 32-bit addressing with a paged virtual memory in the i386 or higher processors. Recent Intel processors have features previously associated with minicomputers. The i486 chip, for example, has an integrated floating-point processor, instruction and data caches, and hardware support for multitasking. This range of processor capacity highlights a major concern of the designers of Digital's PATHWORKS products, i.e., how to efficiently accommodate the range of differing functionality found in the installed Intel-based PCs.

Although this PC market has had little de jure regulation, IBM's market presence has shaped the de facto interface standards. The industry standard architecture (ISA) system bus and the video graphics array (VGA) display technologies are examples of such standards.

The most common system bus, the ISA bus, provides 16-bit data access to a 24-bit (i.e., 16-megabyte) address space. Physical and electrical interface conventions have been established and thousands of interface boards are available. IBM introduced the ISA bus and later developed the Micro Channel Architecture (MCA) bus, which provides 32-bit data access to a 32-bit (i.e., 4-gigabyte) address space, automatic bus sizing, and accelerated data transfer mechanisms. The MCA bus is not compatible with the ISA bus. Consequently, a number of manufacturers other than IBM joined forces and devised the extended ISA (EISA) bus, with features analagous to those of the MCA bus. Even though Digital's PCs use either the ISA or EISA bus, we support our customers' MCA bus machines through software and peripheral device offerings.

Graphical user interfaces (GUIs) such as the one provided by the Microsoft Windows software are becoming the rule rather than the exception. IBM's color graphics adapter (CGA) display was an early standard at 320 columns by 200 rows and a range of 4 colors. VGA is a more recent standard, with

2 Digital Technical Journal Vol. 4 No. 1, Winter 1992

An Overview of the PATHWORKS Product Family

variants that can generate a screen up to 1024 by 768 in 256 colors. There is no widely accepted display standard beyond VGA, and it may be sufficient for manufacturers of innovative display technologies to provide device drivers for transparent use by Microsoft Windows applications. For example, the PATHWORKS eXcursion for Windows display server, which implements the X Window System protocol and operates in the Microsoft Windows environment, uses the display drivers supplied with the Windows software. The eXcursion server thus leverages any new display technologies with which Windows drivers are supplied. However, the standalone DOS-based X Window System servers supplied with the PATHWORKS software must be modified to use a new display technology.

Network interface cards (NICs) provide access to local area network (LAN) systems. NICs that adhere to ISA, MCA, and EISA standards are available from dozens of manufacturers for many networking topologies. Digital manufactures NICs for thick, thin, and twisted-pair Ethernet connections. PATHWORKS products support the Network Datalink Interface Specification (NDIS) and thus accommodate Ethernet and token ring cards from other vendors. NDIS also permits the use of parallel transport stacks in the PATHWORKS for DOS and PATHWORKS for OS/2 products. Digital also supplies NetWare drivers for its DEC EtherWORKS cards for use on Novell networks.

Macintosh Platforms

The Apple Macintosh PC embodies an integrated hardware and software system architecture that has not been cloned by competitors and thus has fewer variants than the Intel-based PCs. Macintosh PCs use the Motorola 68000 series microprocessor. The later versions of these microprocessors provide 32-bit operations on a 32-bit address bus, with virtual paged memory. Application programmers are largely shielded from the underlying hardware by an extensive operating system application programming interface (API).

All current Macintosh PCs are equipped with bit-mapped graphics, sound-generating hardware, a desktop bus for keyboard and mouse connection, and an AppleTalk network communications port. Some Macintosh PCs have system buses that permit peripheral card extensions. All Macintosh PCs allow communication by means of the AppleTalk family of protocols over the LocalTalk LAN.[2] Ethernet/LocalTalk bridges and routers are available from several vendors. Digital's PATHWORKS product family includes VMS AppleTalk transport stacks and an AppleTalk/DECnet gateway.

4 PC Operating Systems

The PATHWORKS product set supports several client operating systems, namely MS-DOS, Microsoft Windows, Apple Macintosh, and OS/2, a joint effort of IBM and Microsoft.

An Overview of the PATHWORKS Product Family

MS-DOS Operating System

Microsoft's MS-DOS (and IBM's PC-DOS) operating system evolved as a collection of services for a single-tasking, Intel-based PC. In addition to file and print services, DOS provides a simple framework for I/O, memory management, and other system services. A command line interpreter is used to load an application, which may invoke DOS services or take over various hardware functions on its own. Although DOS is evolving in the direction of providing a protected virtual machine environment, applications may bypass or subvert systems services provided by current DOS versions. This complicates the design of DOS client systems services such as PATHWORKS networking software.

Microsoft Windows Environment

Microsoft Windows software operates over the DOS operating system to provide a protected multitasking (nonpreemptive scheduling) virtual machine operating environment and a graphical user interface. Unlike DOS, the Windows environment imposes severe constraints on application structure and interface design, and on the design of system support software such as PATHWORKS network drivers. Although much of the success of the Windows software is due to its ability to multitask traditional DOS applications, there is a rapidly growing number of Windows-specific applications that take advantage of the graphical environment, such as the PATHWORKS eXcursion for Windows server.

Macintosh Client Software

The first Macintosh client was an integrated multitasking hardware and software system with a well-defined application structure and interface definition. Subsequent hardware and software development has refined and extended operating system services. The Macintosh Communications Toolbox, for instance, defines an API that is used by the PATHWORKS Macintosh client to enable Macintosh PCs to participate in a DECnet network.

OS/2 Operating System

OS/2 was conceived by Microsoft and IBM as a protected-mode operating system. OS/2 software features preemptive multitasking, process threads, interprocess communication, and an extensive GUI. OS/2 provides only limited support for DOS applications, partly because of the constraints of the Intel 80286 microprocessor, and has yet to achieve its anticipated popularity. However, OS/2 remains a powerful operating system and applications development environment, and IBM is addressing perceived inadequacies. Digital's PATHWORKS family includes OS/2 LAN Manager server and client offerings.

5 PC Networks

Even before IBM coined the term PC, microprocessor-based machines were using networks to share expensive hard disks. Sales of networks on which PCs act as both servers and clients have undergone tremendous growth and have outpaced minicomputer networks in the last several years. The most common service offered by PC networks is transparent access to remote files and printers, which permits PC applications to share resources provided by a network server.

The popularity of PC networks has also spawned a variety of distributed applications such as database, electronic mail, and group productivity products. Most PC client-server applications are simply PC applications that simultaneously share files stored on a remote file server. These applications use a file server to achieve their distributed nature.

PC networks are implemented over more than a dozen underlying physical layers; Digital's PATHWORKS products support Ethernet, token ring networks, and asynchronous lines. All minicomputer and mainframe vendors have products that permit PCs to obtain services from their enterprise-wide networks. Digital's PATHWORKS for VMS and PATHWORKS for ULTRIX products provide transparent file and print services to DOS, Windows, OS/2, and Macintosh PC clients. PC files stored on the VMS or ULTRIX operating system may be accessed by other PCs or by users of the host operating system. In addition, PATHWORKS products provide database access, X Window System support, terminal emulation, electronic mail, and many other services familiar to those in a Digital environment.

As noted above, PC networks use many physical networking protocols. In the following sections, we describe PC transport protocols and the application-level service protocols used to encode the remote service primitives.

Transport Protocols

Commercial PC networks use a wide variety of transport and service protocols. Although minicomputer transports are available to meet some needs, most vendors have introduced their own to address concerns such as performance and size, which are critical in competitive concerns such as performance and code size.

The network basic I/O system (NetBIOS) software, developed by IBM, defines an interface to a connection-oriented transport, a connectionless datagram service, and a name service API.[3] In addition to being the Microsoft LAN Manager transport interface, NetBIOS has become a widely accepted standard for PC applications communicating directly with transports.

Figure 1 shows that NetBIOS can be implemented by PC network vendors over a

variety of underlying transports. Digital's PATHWORKS products have NetBIOS interfaces to the DECnet protocol and the transmission control protocol /internet protocol (TCP/IP).[4,5] Other popular commercial transports incorporating NetBIOS interfaces are the internet packet exchange (IPX), the Xerox Network System (XNS), and the NetBIOS extended user interface

An Overview of the PATHWORKS Product Family

(NetBEUI). Many of these transports also have a native transport API that allows the application to make use of features not available through the NetBIOS interface.

The TCP/IP protocol family is beginning to achieve some visibility in the PC network market. At first largely associated with UNIX and ULTRIX networks and Sun Microsystems' Network File Service (NFS) protocol, TCP/IP has been lately offered as an underlying transport for NetBIOS in several vendors' products, including Digital's PATHWORKS family. In addition to transparent file and print services, PC users of TCP/IP require access to a variety of tools and utilities, such as mail and terminal emulation, which may resemble UNIX or ULTRIX tools and utilities. Digital's PATHWORKS family has adopted the approach of maintaining parallel TCP/IP and DECnet implementations, both of which have a PC-centric rather than a host-centric orientation.

The PATHWORKS TCP/IP implementation operates over either an Ethernet or a token ring network, and provides a file transfer protocol (FTP) utility, a TELNET terminal emulator, and a Berkeley Software Distribution (BSD)-like socket interface for application developers.

Many of Digital's customers have extensive DECnet networks. Digital's PATHWORKS product family provides PC clients with full Phase IV end-node functionality, including file access listener (FAL), network file transfer (NFT), command terminal (CTERM), and network utilities. PATHWORKS products also support a NetBIOS implementation that uses the DECnet protocol as a transport. The PATHWORKS DECnet implementation operates over either an Ethernet or a token ring network and provides a BSD-like socket interface for application developers.

NetWare software from Novell Corporation is a popular family of PC network services. The internet packet exchange protocol is Novell's derivative of the Xerox internet datagram protocol. IPX is the network transport that underlies SPX, a sequenced reliable protocol. IPX is also used by the NetWare core protocol, NCP. Novell also supplies an implementation of the NetBIOS interface over the IPX protocol. Digital supports the IPX /SPX protocol on DOS clients through the PATHWORKS for NetWare coexistence product, and has announced plans to integrate NetWare protocols into PATHWORKS products in a way that parallels current use of LAN Manager protocols.

The AppleTalk family of protocols employed by Macintosh PCs accommodates three hardware layers: token ring, Ethernet, and LocalTalk. AppleTalk includes a datagram delivery protocol, routing and name binding protocols, and several session-level and service protocols.

For efficiency, many PC network vendors have invented their own protocols.

For example, both the IBM/Microsoft NetBEUI and the 3Com Corporation NBP transport protocols have been optimized to work on LAN topologies.[6] Digital's PATHWORKS software provides the local area transport (LAT) and local area system transport (LAST) protocols on several of its client

An Overview of the PATHWORKS Product Family

platforms; these protocols are used to access terminal services and InfoServer disk services.

Service Protocols

Service protocols encode high-level service requests at the application layer; these protocols are often vendor-specific. Typically, an application issues a standard I/O request, such as "open file," to a systems interface to obtain transparent access to a remote file or print service. The request may be either intercepted (e.g., in Novell's NetWare software on DOS) or channeled through the operating system (e.g., in the Microsoft LAN Manager or Apple Macintosh software) to a redirector or shell software module that encodes it into a service protocol packet. The redirector then sends the service request to the local transport. When the response packet arrives from the service provider, the redirector interprets the service protocol and provides the application with the appropriately formatted response. The redirector may also provide an API for access to nontransparent services such as peer-to-peer communication and management of a remote server. Figure 2 illustrates the role of service protocols in fulfilling a client request.

The Microsoft LAN Manager redirector software uses the server message block (SMB) protocol to access remote file and print services.[7] This protocol may run over multiple transports, each transport accessed by means of a NetBIOS interface. The redirector also provides a client API over the SMB protocol for many nontransparent services such as peer-to-peer communications via named pipes, a messaging service, and remote server management.

Novell's NetWare software uses the NCP protocol to access remote file and print services. This popular service protocol runs only on the IPX transport stack. The NetWare shell provides client APIs over NCP for many nontransparent services such as transaction tracking, semaphores, and remote server management.

Apple's AppleShare software uses the AppleTalk suite of protocols. This suite includes the AppleTalk filing protocol (AFP) and printer access protocol (PAP), which permit transparent file and printer redirection.

Sun's NFS system has widespread multivendor support in UNIX and ULTRIX environments. There are a variety of PC products that work over the IP protocol family to provide file services from a standard UNIX or ULTRIX NFS server.

PATHWORKS Product Family

Commensurate with Digital's role as a network integrator, the PATHWORKS

product family is large and diverse. In the following sections we characterize the PATHWORKS family by its client platforms, server platforms and services, and physical networks and network protocols. Table 1 shows the history of the PATHWORKS product family.

An Overview of the PATHWORKS Product Family

Table 1: Product History

Area Supported	1986--89	1990	1991
File and Print	LAN Manager	LAN Manager	LAN Manager
	AppleShare	AppleShare	
Server	VMS	VMS	VMS
		ULTRIX	ULTRIX
		OS/2	OS/2
Transport	DECnet	DECnet	DECnet
		AppleTalk	AppleTalk
		TCP/IP	TCP/IP
			NetBEUI
Network	Ethernet	Ethernet	Ethernet
		LocalTalk	LocalTalk
			Token Ring
Clients	DOS	DOS	DOS
		OS/2	Macintosh
		Macintosh	OS/2
			Windows 3.0
			NetWare
			Coexistence

Since its introduction in 1986, the PATHWORKS product family has continued to expand the list of client platforms, servers, and transports it supports. The most popular client platforms are Intel-based and operate under DOS and/or Microsoft Windows. These clients can be serviced by VMS,

ULTRIX, and OS/2 servers. The Macintosh clients can be serviced by VMS servers.

The PATHWORKS product family offers transparent file and print services through two technologies: the Microsoft LAN Manager is used for DOS, OS/2, and Windows client platforms; AppleShare is used for Macintosh platforms. In addition, on DOS and Windows platforms a dual-service stack approach is used to allow these platforms to access native NetWare services through the PATHWORKS for NetWare Coexistence product. Table 2 shows how clients and servers can be connected by means of different transports. The first column is a list of the supported servers; each cell shows the transports that can be used to connect the client and the server.

An Overview of the PATHWORKS Product Family

Table_2: _Client-Server_Transports_____

Server Supported	Client_Platforms_____			
VMS	DOS	Windors	OS/2	Macintosh
	DECnet	DECnet	DECnet	AppleTalk
	TCP /IP	TCP /IP	TCP /IP	
	LAST	LAST		
ULTRIX	DECnet	DECnet	DECnet	
	TCP /IP	TCP /IP	TCP /IP	
OS/2	DECnet	DECnet	DECnet	
	TCP /IP	TCP /IP	TCP /IP	
	NetBEUI	NetBEUI	NetBEUI	

The Macintosh client also supports the DECnet transport. However, file and print services are only available through the AppleTalk stack. Clients also have access to a number of transport gateways, including AppleTalk-DECnet, X.25, and the System Network Architecture (SNA), the latter two through Digital network products.

The default PATHWORKS network protocol is the DECnet protocol. TCP/IP is available as an optional add-on to the base platform. The DECnet protocol allows the user to access the following services in addition to the transparent file and print services:

- o A full set of management tools (e.g., the DECnet network control program for managing the transport).
- o The NFT utility for transferring files to systems that do not have server software.
- o A remote disk (as opposed to remote file) mechanism over the LAST protocol. This mechanism allows access to Digital's InfoServer products

that support networked CD-ROMs, i.e., read-only optical disks.

- o DOS and Windows terminal emulators operating over the LAT or CTERM protocols, as well as asynchronous lines. The LAT protocol may also be used to attach a local PC printer to a VMS print queue.
- o A DOS-based X Window System server that allows the PC to act as a display device for Motif or DECwindows applications.
- o A low-end electronic mail utility that provides a PC front end to the VMS and ULTRIX mail systems.

An Overview of the PATHWORKS Product Family

- o Development tools in the form of programming libraries for access to peer-to-peer communication with remote applications.

The TCP/IP protocol allows the user access to the following services in addition to those listed above:

- o The FTP utility for file transfer
- o The ability to use the base terminal emulator to allow operation over TELNET
- o The ability to run the DOS-based X Window System server over TCP/IP as well as over the DECnet protocol

Every Macintosh PC includes software to access basic file and print services over the AFP. The PATHWORKS Macintosh product family provides those services on server platforms, but also provides a set of transport protocols and utilities on the Macintosh client. In particular, PATHWORKS products supply a DECnet stack with file transfer and management utilities, a LAT implementation and terminal emulator, and an X Window System server implementation that operates over the DECnet or an optional TCP/IP stack. The PATHWORKS Macintosh client includes a programming tool for access to remote databases on Digital platforms.

The PATHWORKS OS/2 client provides a LAN Manager redirector and SMB access to basic file and print services over the DECnet protocol or an optional TCP/IP stack, and a collection of tools and utilities similar to those for the PATHWORKS DOS client. Some features, such as an X Window System server, are lacking.

In addition to the applications included in the base PATHWORKS product, the following client applications are available as layered products:

- o eXcursion for Windows, a Microsoft Windows/X Window System server application that allows X Window client applications to share the PC display device with native Windows applications
- o X.400 mail, which provides PC front-end access to Digital's X.400 mail server products
- o Conferencing, which provides a PC front end to VAX Notes
- o Videotex, which provides a PC front end to Digital's Videotex servers
- o DECquery software, which provides a PC front end to structural query language (SQL) services

Digital also provides development tools for building distributed applications on the PATHWORKS base system. These development tools include database access to a host-based SQL server by means of the SQL services and distributed transaction processing through the DECTp for ACMS product.

10 Digital Technical Journal Vol. 4 No. 1, Winter 1992

An Overview of the PATHWORKS Product Family

6 Summary

The PATHWORKS product family provides direct access to the local and wide area enterprise environment from desktop devices. Clients can access multiple file and print servers, gateways, database servers, transaction processing systems, and electronic mail systems on a variety of server platforms in a consistent manner from multiple desktop platforms.

The services provided by the PATHWORKS product set are the foundation for the integration of desktop applications with host system services such as those available with the VMS, ULTRIX, and OS/2 systems. PATHWORKS network software makes it possible to develop front-end processors for today's host-based applications and to design new distributed applications. Hence, PATHWORKS products allow the existing computing infrastructure to progressively evolve towards a distributed model.

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8 Biographies

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Microsoft's LAN Manager into Digital's PCSA and helped design Digital's NetBIOS emulation and remote boot of MS-DOS systems. Alan received B.S degrees in computational and statistical science and in mathematics from the University of Liverpool.

Digital Technical Journal Vol. 4 No. 1, Winter 1992 11

An Overview of the PATHWORKS Product Family

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