IEEE P802.11

Wireless Access Method and Physical Layer Specifications

Local Area Network Market Analysis and Forecast

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Executive Summary

Wireless Local Area Networks represent an enormous opportunity to provide a (possibly) revolutionary class of communications service. However, if wireless LANs are to be successful it will likely be because these systems "stand on the shoulders" of the overwhelming market success of wired local area networks. The purpose of this paper is to summarize industry knowledge about wired local area networks, their use, applications and market acceptance as a basis for the requirements, applications and market for wireless LANs.

The data presented support certain conclusions about the wired LAN market and provide the basis of inference for the wireless LAN market.

- There is little historical use of integrated real-time voice and data communications and little documented buying demand for such services.

- LANs have become the de facto standard for desktop data connectivity. By the mid-1990's it is expected that the majority of the installed base of desktop data equipment will be attached to a LAN. The expected high market penetration of wired LANs in

the next five years should give a sense of urgency to the wireless LAN standards development process. The earlier a simple standard can be adopted, the more relevant it will likely be.

- Unshielded twisted pair has become the dominant media choice and shows capacity for the installed base of wiring to grow in capacity over time (as evidenced by movement to FDDI performance over existing UTP). It is likely that UTP will have substantial price/performance advantages over other media for some time to come and likely over most wireless technologies particularly radio technologies that require bandwidth allocation. It may always be cheaper, in many cases, to put more copper (or fiber) in the walls (space division multiplexing at its best) than petition the FCC for more spectrum. Wireless LANs should be best considered as complementary to wired LANs rather than their replacement.

- A range of LAN Operating Systems have captured the market with Novell being the dominant market choice. Most LAN applications can operate with most LAN OS, with most MAC protocols, and over most media choices with little difference in performance due to MAC design. Most network applications use a common, simple set of lower layer services that place simple requirements on the MAC layer: low latency, low packet error rate datagram transmission.

I. Introduction

Wireless Local Area Networks represent an enormous opportunity to provide a (possibly) revolutionary class of communications service. However, if wireless LANs are to be successful it will likely be because these systems "stand on the shoulders" of the overwhelming market success of wired local area networks. The purpose of this paper is to summarize industry knowledge about wired local area networks, their use, applications and market acceptance as a basis for the requirements, applications and market for wireless LANs.

Wired LANs provide a common set of horizontal local communications services used across many markets. These LAN systems consist of the following components:

- LAN applications;
- client and server computer systems;
- LAN Operating System;
- LAN MAC hardware, software communications system; and
- LAN media interconnect.

The substantial and rapidly growing installed base of wired LAN systems provides the foundation of distributed applications, network software and systems architecture that wireless LANs will extend and complement. Market momentum mandates backward compatibility and interoperability to these wired LANs.

Thus we should desire to create standard wireless LANs that support not only new, perhaps unimagined applications, but first and foremost support current wired LAN applications. Market physics mandate that in order to do that, our wireless LAN standard support current LAN architectures and network software.

Our approach here is to examine the installed base of wired LANs to discern those key lessons of compatibility that the market success of wired LANs can provide. We begin with a summary of the overall markets for synchronous (e.g. voice) and asynchronous (e.g. data) services and how these services are provided to the market. Industry standard Local Area Networks (to date all wired) have become the predominant means of desktop data device communication. We then review the market's decisions on LAN hardware, media access control, media and network operating system software. We conclude with a summary of conclusions drawn from these analyses and forecasts.

Bias. The author admits that a career in the development, sale and support of local area network systems leads to a significant bias for a simple wireless LAN standard that is substantially similar to wired LAN standards in order to support existing LAN OSs, applications and markets while providing an effective base for portable computer systems that require wireless LANs. Further, it is always at the forefront of my thoughts that first personal computers, and then local area

networks, were first adopted by the rebels within enterprises - allowing them to create information solutions in a timely manner, decoupled (at first) from the inertia of the corporate MIS department. It is my firm bias that effective wireless LANs will likewise be first adopted by these same rebels - providing them the convenience and necessary tools that wired LANs cannot.

Caveats. Of course, all forecasts must be considered problematical. The forecasts used herein represent a "consensus" of published market forecasts combined with the author's judgement. Forecasts focus on 1990-94 and are limited to US domestic shipments and installed base. The data suggest that over the period of interest, the US represents approximately half of the worldwide market for these services and, in general, there is not significant difference in the market analysis between worldwide and US numbers.

Sources. The sources for market inventory and forecasts consist of an amalgam of various public and private sources including: Dataquest, IDC, Forrester, Communications Week, Network World, Infoworld, Computerworld, New York Times, Coopers & Lybrand, the author and others. I have taken the liberty of regularizing and rationalizing and certainly all fault for mistaking their input. Since this material is pulled together from a number of sources, there may exist some residual inconsistency, but I believe these do not lead to false conclusions.

II. Voice Connectivity

One of the first design issues for a wireless local area network is the scope of services to be provided to network users. And of particular importance is the relative importance of synchronous and asynchronous communications services. In surveying the installed base of local network usage, there are two significant installed bases of synchronous network services: real-time, interactive voice transmission and synchronous data terminals. These data terminals will be examined in the next section.

A summary inventory and forecast of voice networks as well as wired LAN networks is documented in Figure 1.

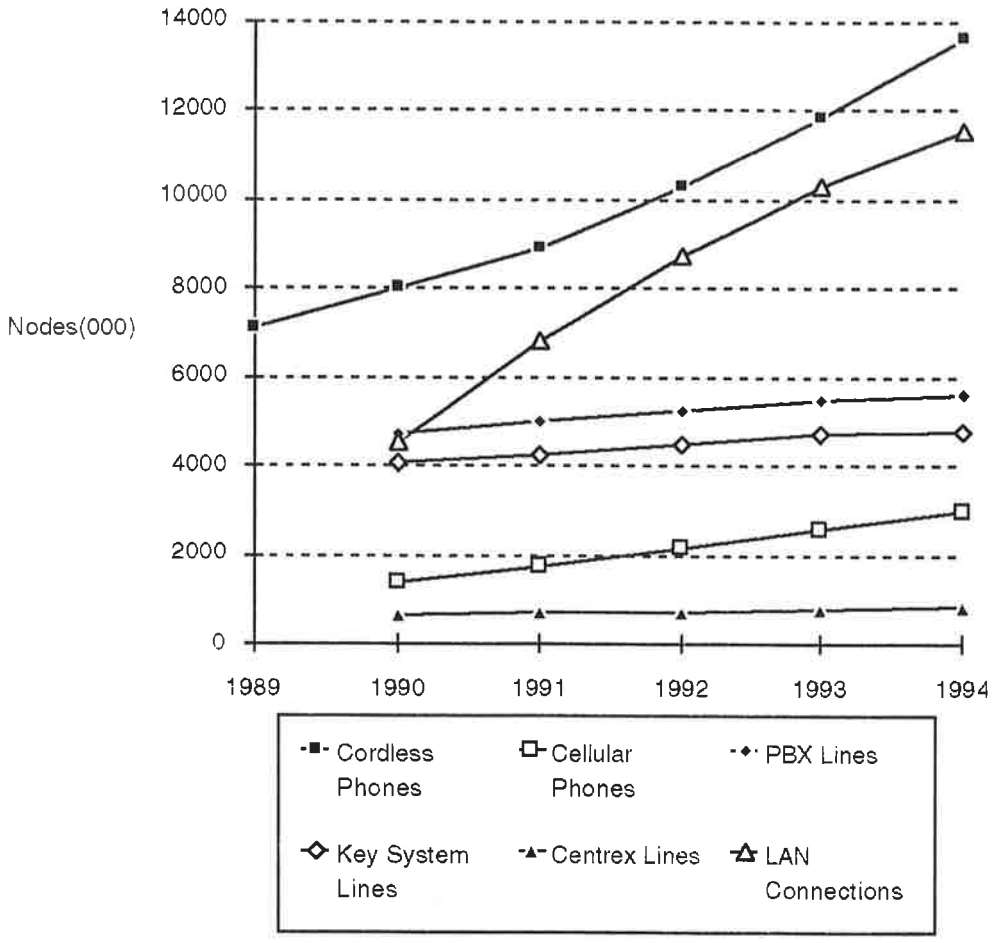

Figure 1: Voice and LAN Connectivity US Shipment Forecast

Figure 1 demonstrates the clear market saturation for business oriented synchronous, real-time voice services provided by Centrex, PBX and key systems. Forecast PBX installations for the early 1990's have about a 2.5%

CAGR in unit shipments and about a 5% CAGR in line growth. The voice services experiencing strong growth are both wireless services: consumer oriented cordless telephones and metropolitan area cellular telephones.

LAN installations, on a absolute basis, begin to dominate voice line installations during the early 1990's. Substantial leveling of the growth rate in new LAN installations is anticipated to begin in the mid-1990's as the market becomes increasingly saturated.

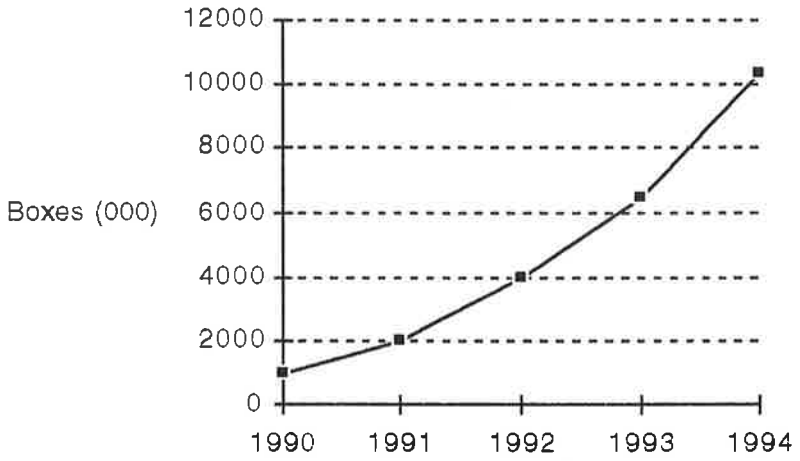

Figure 2: US Voice Mail Shipment Forecast

In contrast to the market maturity for synchronous, real-time, local voice services, the market for asynchronous, store-and-forward voice mail services is experiencing a substantial growth period. Figure 2 forecasts the US voice mail market.

III. Data Connectivity

Data connectivity, in contrast to real-time voice connectivity, remains a high growth market area. This market analysis is limited to "desktop" user equipment: personal computers (including portables), text terminals, graphics terminals, ISDN terminals and workstations. Not included are minicomputers (about 160K units/yr), mainframes (about 11K units/yr) and supercomputers. This desktop equipment is used by about 66.5 million US knowledge workers in 1989 forecast to grow to 71.5 million US knowledge workers in 1994. This equipment is based in 70.4 million locations in 1989 forecast to grow to 75.7 million locations by 1994.

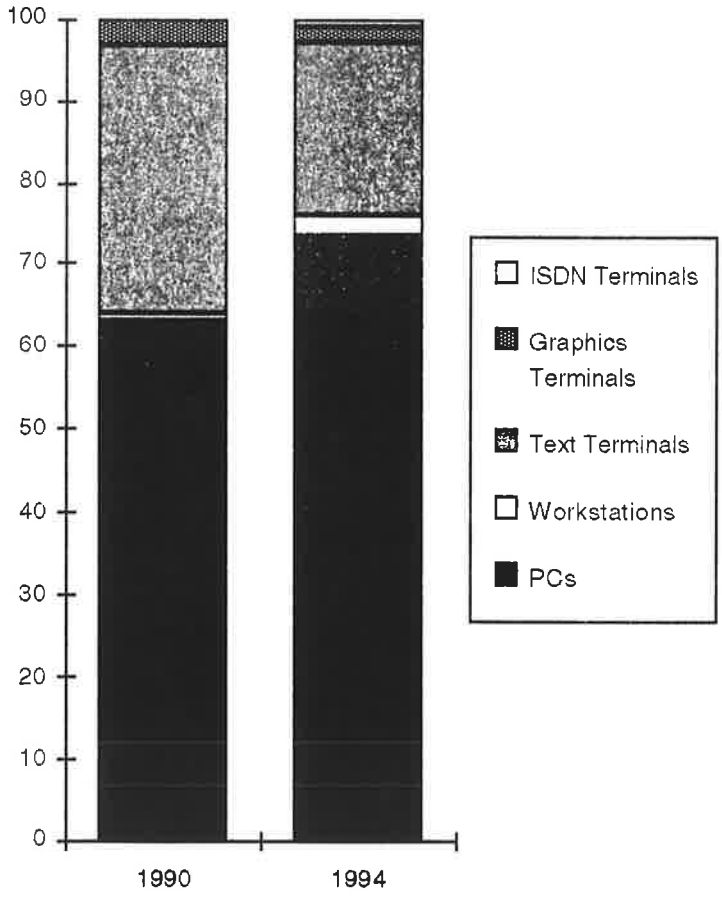

Figure 3: US "Desktop" Devices Installed Base Forecast

It is apparent that the personal computer has taken over the desktop. Additional data suggests that in the period of interest an average of at least 1/3 of all personal computer shipments will be portable computers of laptop form factor or smaller, with the majority of these battery operated. Notebook and pen based

portable computers are expected to be the fastest growing segment of the personal computer market.

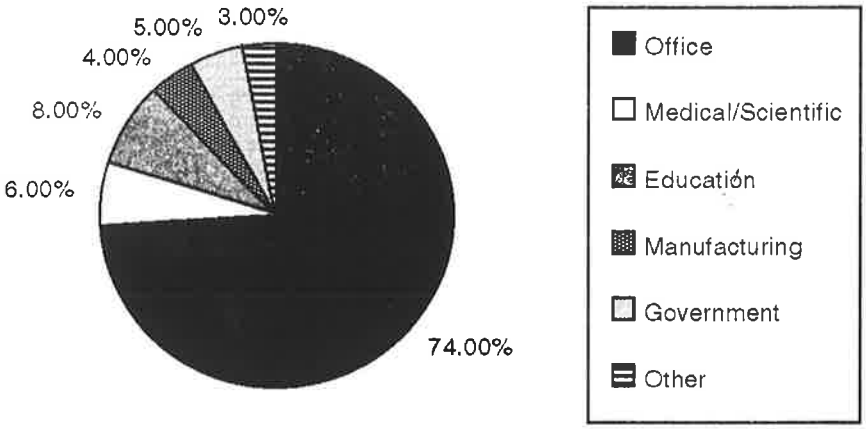

Figure 4: 1988 US LAN Share by Market Segment

Figure 4 illustrates the distribution of the US LAN installed base by market segment. It clearly indicates that the vast early acceptance of LANs for office applications. Figure 5 forecasts greater LAN penetration of education, scientific and manufacturing segments in the next several years.

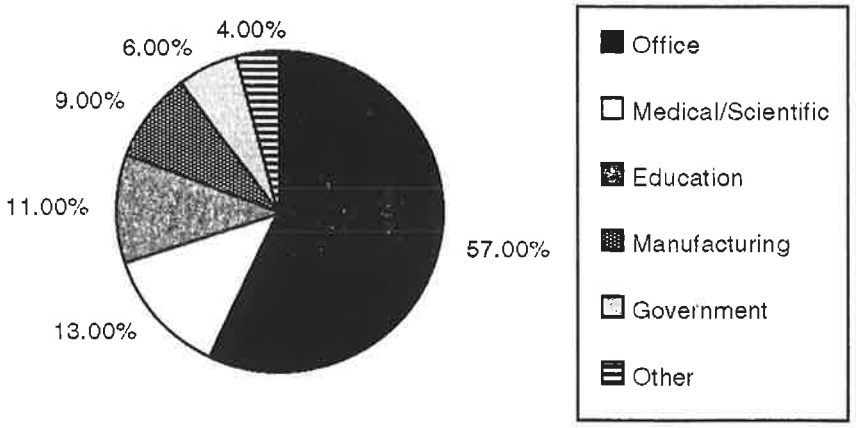

Figure 5: Forecast US 1993 LAN share by Market Segment

Figure 6 documents 1988 survey results that suggest that manufacturing automation systems are representative (if not in advance) of other market

segments in terms of the kind of computer equipment used and their use of LANs.

	% Share
PCs	91%
Midrange Systems	75%
Mainframes	42%
LANs	33%
Workstations	17%
Servers	17%

Figure 6: 1988 US Manufacturing Automation System Usage Survey

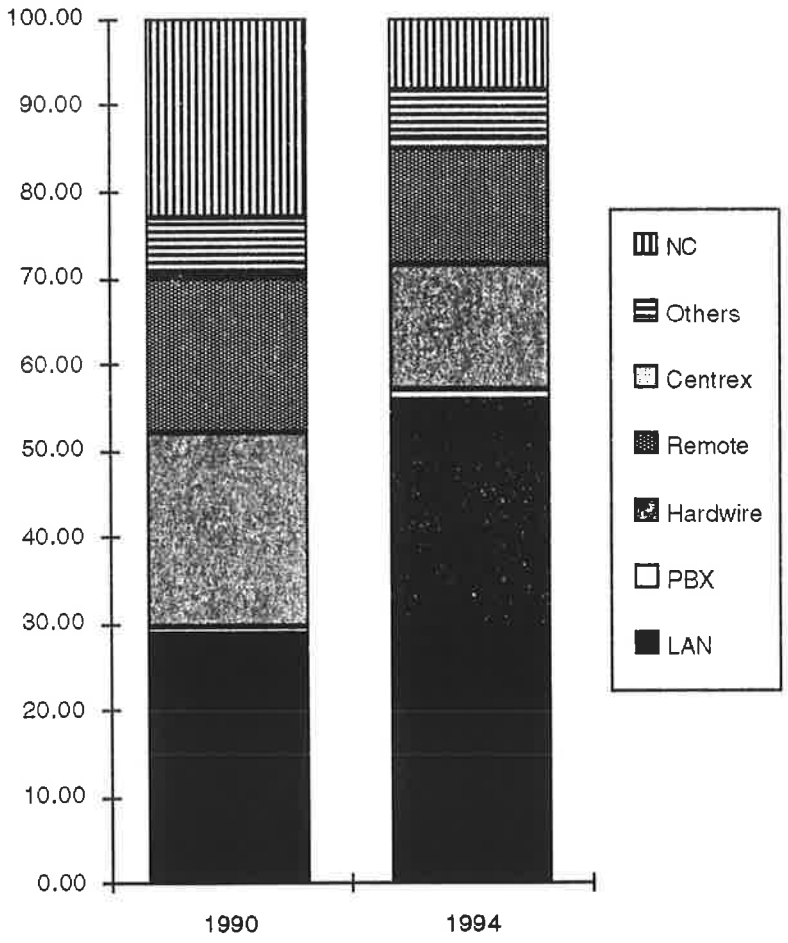

Figure 7: US "Desktop" Device Installed Base Connectivity Forecast

Figure 7 illustrates the connectivity distribution to the desktop - documenting the primary method of connectivity for devices that have one or more data connections. In 1990 it is estimated that about 25% of desktop data devices are

not connected and that only about 30% of all desktop devices are connected via a LAN. However the current strong dominance of LANs as the connectivity method of choice results in a forecast 1994 distribution with less than 10% of desktop devices remaining unconnected with over 50% connected via LANs. Almost no data devices are connected via PBX, Centrex or ISDN services and both hardwired (e.g. IBM 3270 terminals) and remote (e.g. modem) connections are forecast to lose share to LANs as their primary method of connectivity.

These trends are forecast to be common for all desktop devices, however particularly obvious for personal computers, workstations and graphics terminals (as LAN attached X-terminals predominate). By 1994 it is forecast that 65% of the personal computer installed base will be LAN attached, 98% of the workstation installed base and about 75% of the graphic terminal installed base.

IV. Media Access Control Choices

The market currently supports several choices for low-level protocol and media access control.

Ethernet	10 Mb/s CSMA/CD services over a variety of media.
Token Ring	4 and 16 Mb/s token ring services over a variety of media.
FDDI	100 Mb/s token ring services originally over fiber but soon over unshielded twisted pair (at shorter distances).
Low End	Modest performance (and cost) network services including Arcnet (2.5 Mb/s token), Starlan (1 Mb/s CSMA/CD), LocalTalk (0.23 Mb/s CSMA/CA), etc.

As will be demonstrated below, most network operating systems work equally well on most MAC systems. The choice of a MAC in the market seems more coupled to vendor recommendation, availability, price, performance of a particular adapter, and compatibility with the rest of the enterprise.

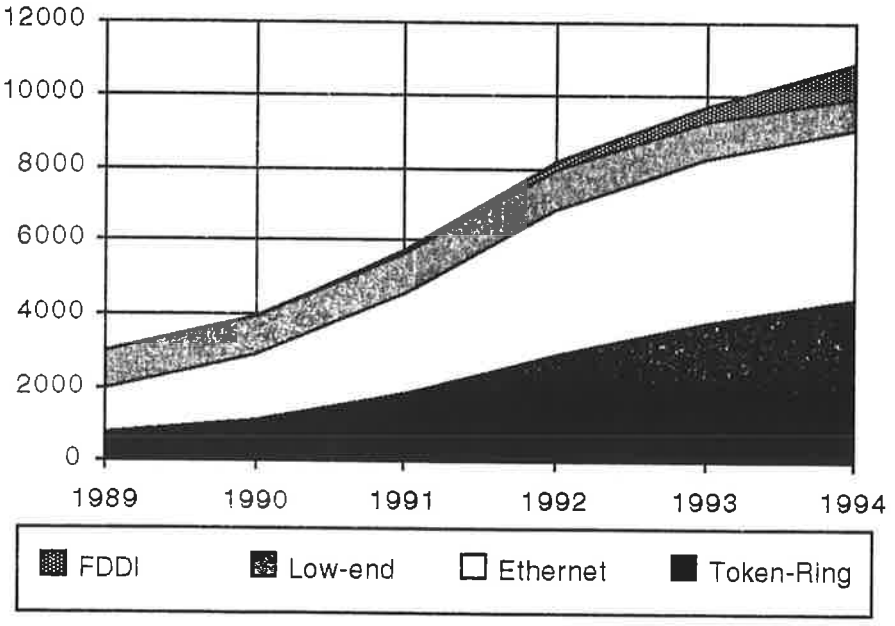

Figure 8: US LAN Adapter Shipment Forecast

Ethernet, LocalTalk and Arcnet have the bulk of the installed base with Token Ring taking increasing market share. Ethernet and Token Ring have approximately equal market share of current shipments. FDDI currently has only a small market share due to its high cost and modest product maturity. Greater than expected decreases in FDDI adapter cost and its promised support

of transmission over unshielded twisted pair could substantively increase its market share. Low-end networks can expect to not only lose market share but also absolute shipment numbers with an industry wide movement to higher performance.

Ethernet adapters currently have an average selling price of about $300 decreasing at 12%/year. Token ring adapters have an ASP of about $425 decreasing at about 18%/year. Low-end LAN adapters, as expected, have a low ASP of about $100 but continue to lose volume at about 4%/year.

V. Local Area Network Media Choices

Current local area networks are constructed from a choice of roughly three media types: unshielded twisted pair, datagrade shielded twisted pair or coaxial cable and lastly, fiber optic cable. The marketplace has made it possible for both principal types of media access control - token and CSMA - to use any of these three media. Thus the marketplace choices among them are based on vendor recommendation, performance, cost of installation and maintenance and perceived long term "safety" of the choice.

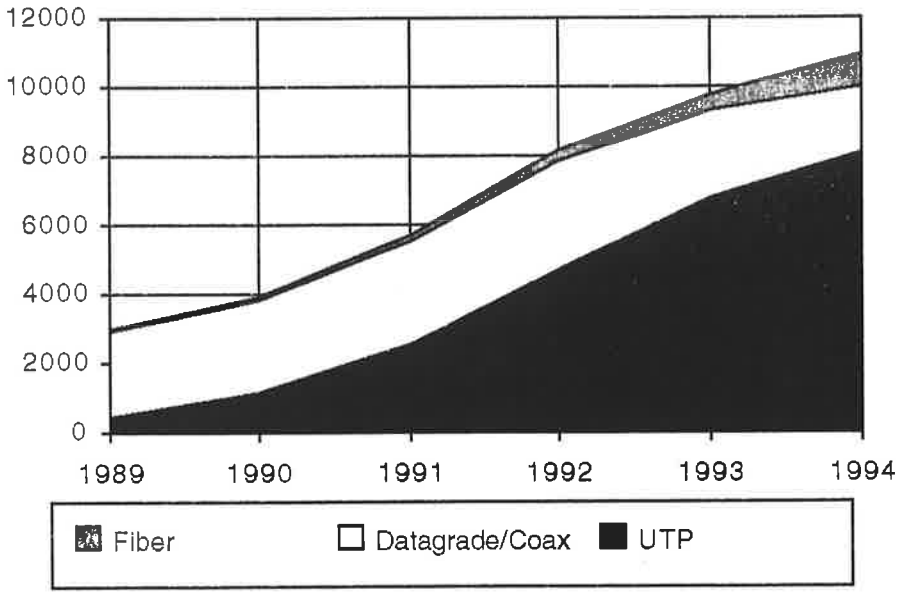

Figure 9: US LAN Media Forecast

Cost, ease of installation and maintenance, and possible reuse of existing wiring and facilities are the motivations for unshielded twisted pair becoming the dominant LAN media choice - effectively supporting either of the dominant MAC choices - Ethernet and Token Ring. Recent developments suggest that UTP will be the medium of choice not only for Ethernet and Token ring networks, but possibly for FDDI networks as well.

VI. Network Operating Systems Choices

Network operating systems (NOS) provide the essential user network services. The market currently supports a range of NOS choices each offering similar capability. All of these systems typically offer: file sharing, peripheral sharing, terminal emulation, electronic mail, file transfer and often remote procedure call services supporting client-server transaction applications.

While there is much in common between the various LAN OSs, major distinctions among include server architecture, performance, size of network supported, ease of installation, reliability and channel of customer distribution. The two types of LAN OS architecture are the central server (Novell, 3Com, IBM, Banyan and Apple 6.0) and the peer-to-peer (TOPS, Apple 7.0, OS/2 LAN Manager, DECNet, DCA 10Net). Older network architectures (Novell, 3Com, IBM, Banyan), in general, require much more care and support for installation and maintenance than "plug-and-play" LAN OSs (Apple, DCA, TOPS). Plug-and-play networks often support smaller networks and can be installed by end-users while others support larger networks and require expert installation.

In general, the vast majority of LAN OS services are based on low level, best effort delivery datagram services (e.g. IEEE 802.2 Type 1). All NOSs are based on one (or increasingly, more) protocol stacks organized as a layered hierarchy of function sharing a common ancestry with the OSI protocol architectural model. These protocol stacks implement node to node communications, routing and network services. Two nodes require a common protocol stack in order to interoperate.

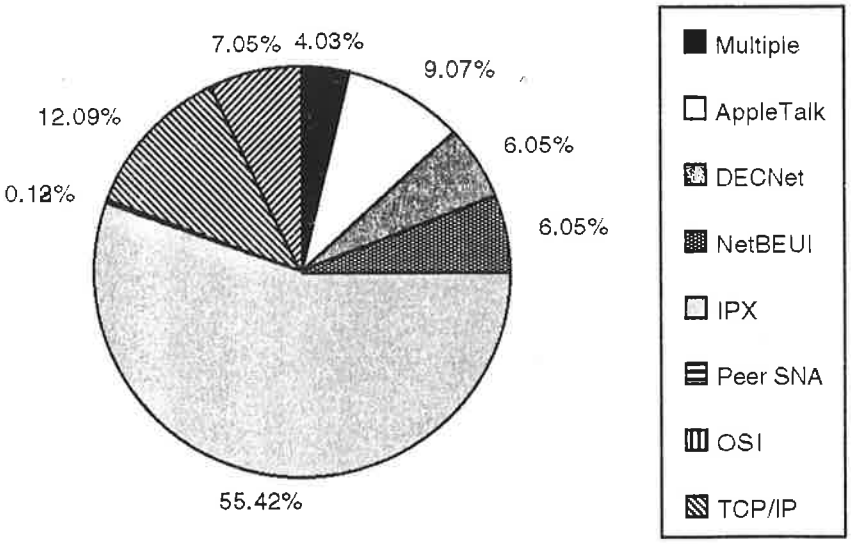

Figure 10: Forecast US 1990 LAN Protocol Share

Figure 10 illustrates the expected 1990 market share between various protocol stacks currently in LAN use.

The individual dominance of IPX, the native protocol stack for Novell Netware, is quite clear and reflects the market dominance of the Netware NOS. The aggregate dominance of protocol stacks (AppleTalk, DECNet, IPX, OSI and TCP/IP) that use only minimal best-effort delivery MAC datagram delivery services is also quite clear.

The inertia of the installed base will slow any dramatic shift between from one protocol stack to another, rather it is anticipated that many NOS will begin to support multiple protocol stacks simultaneously thus permitting, albeit awkwardly, interoperation of mixed vendor networks.

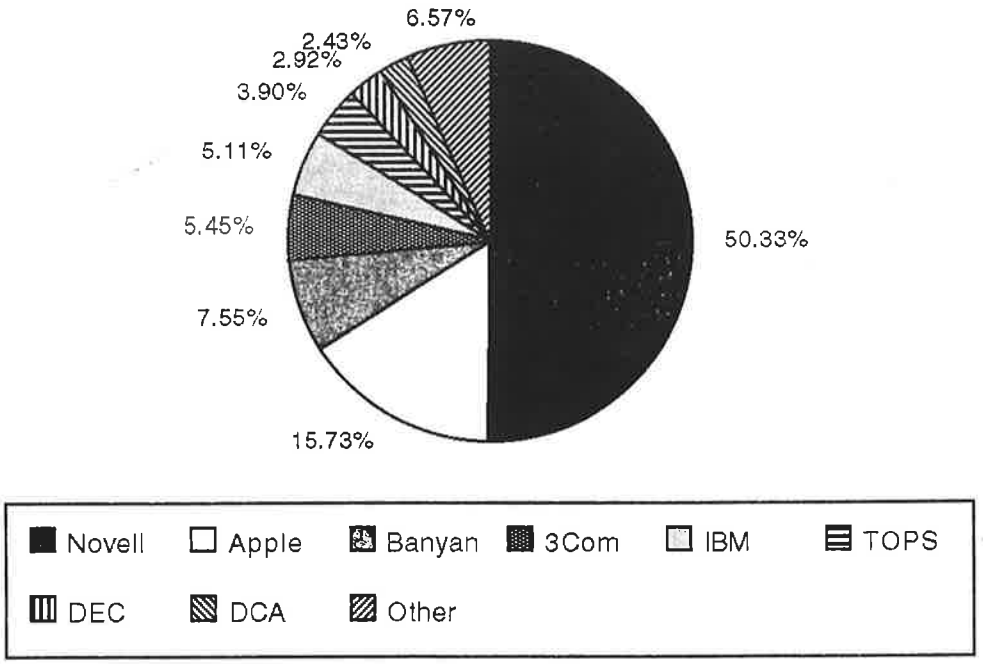

Figure 11: 1989 US Shipment Market Share for LAN OS Clients

Figure 11 illustrates 1989 shipment market share for LAN OS clients sold and installed by the major LAN OS vendors. The dominance of Novell Netware, primarily among IBM PC compatible computer users, and the disproportionate share of Apple and TOPS (since LocalTalk is shipped with every Macintosh computer) are quite clear.

Figure 12 illustrates the typical LAN segment size (in numbers of nodes) for the major NOSs. In larger organizations these segments are combined via bridges, routers and gateways into larger internetworks.

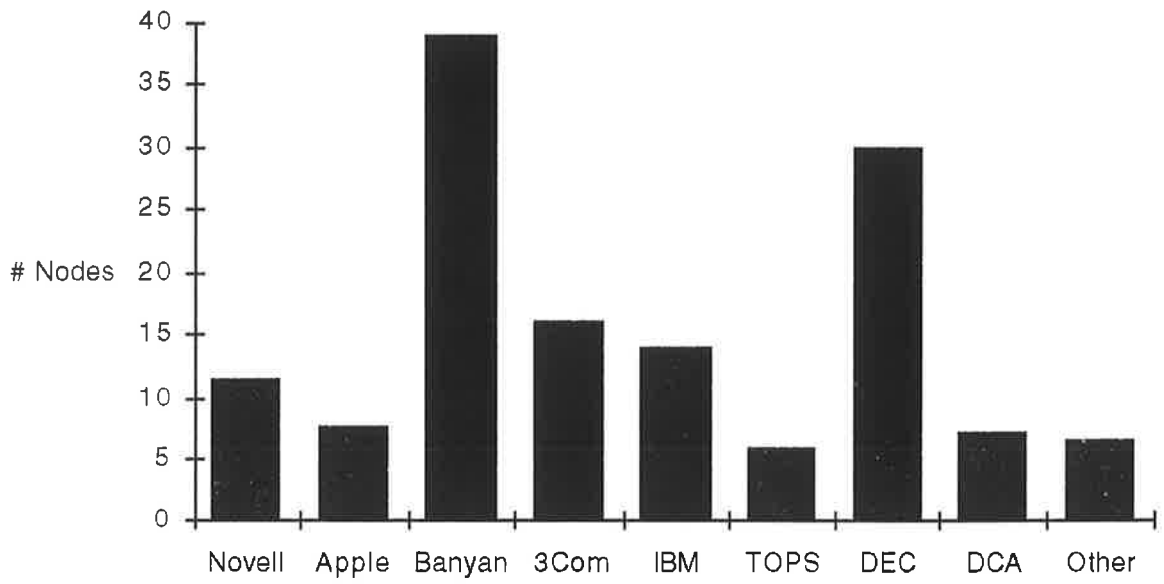

Figure 12: Distribution of Average LAN Segment Size (1989)

Historically, LANs - like personal computers - were first used by early adopter, commonly small, users. These users introduced, from a typical organization's grass roots up, PCs and LANs into their larger enterprises which subsequently maintain central MIS/telecom staffs to interconnect, maintain and install many LANs today. Even today, managers of large networks think of communications quite differently than managers of small networks.

The author sponsored a series of focus groups in 1990 to examine the concerns of both large and small network managers to the technology and products of wireless LANs. Small LAN managers exhibited natural enthusiasm for the perceived value of wireless technology with their primary concern being cost. Their reaction was in sharp contrast to the reaction of large LAN managers. This latter group expressed substantial skepticism for wireless LAN, particularly raising immediate objections about security and performance.

The author speculates that the above focus group result is entirely consistent with the spectacular market success of cordless consumer telephones and cellular telephones. Small network users are more impacted by the inconvenience of wiring and are naturally more receptive to the benefits of wireless communication. It should be expected then that small networks are the obvious early adopters of wireless LAN technology, maturing in larger enterprise networks as subnetworks of the enterprise wired network.

VII. Local Area Network Applications

A wide range of network applications are currently supported on the services provided by the NOS and in turn the network. Figure 15 lists the most common of these applications as named by LAN users.

	1990
Shared Files	84%
Device Sharing	80%
Shared Software	63%
Gateway Access	60%
E-Mail	54%
Client-Server Database	35%

Figure 15: Distribution of LAN Applications

These applications draw on a common set of LAN communications protocol services. A short summary of common traffic characteristics with industry common NOSs:

Shared Files — Bursty transaction traffic: small requests (<80 bytes) by file access clients from file servers for larger file blocks (512-2048 bytes). Request rate matched to the applications program file access rate. For many interactive applications (word processing, spreadsheets, etc.) this transaction rate is limited by the user's interaction rate and can be quite slow. However, for many shared LAN database applications, simultaneous shared file access performance is critically limited by transaction delay. In these cases, comparative performance is with high performance disk systems with transaction delay of 10-20 msec. Local and remote caching with read-ahead and write-behind is commonly used to improve LAN file access performance.

Shared Devices — Primary shared devices are printers in which spooled print files are transferred to a printer local buffer. Best characterized as file transfer limited in performance by the printing rate of the printer (today's laser printers are about .5 KB/sec).

Shared Software — Shared software can be considered as a file transfer download from a file server to a file client. Software downloads are infrequent, but demand quick response (low delay, high throughput).

E-mail — Most Email systems are structured as a client server systems with the unit of transaction a file containing a message. Each transmitted message is uploaded to the

mail server from the client and each received message is downloaded from the mail server to the client. Messages are infrequent (average of 3/day/user) of widely varying size (a few tens of bytes to a few megabytes). Since Email often occurs in background, high throughput and low delay performance is often not critical.

Client-Server — Transaction mode with the client making request and the server sending responses. Transaction rate is often bursty with performance closely coupled to transmission delay for each transaction.

The principal underlying access method in most of these applications, for most protocol stacks in use today, is fundamentally a datagram based transaction file access:

open a remote file: short (3-5) sequence of datagram transfers

request a file block: a short (< 80 bytes) datagram to the server from the client

receive file block: receive a full size datagram (512-2048 bytes) containing the file data from the file server, often with both local caching of file blocks so as to minimize remote reads and remote caching of file blocks to minimize disk latency);

send acknowledgement: a short (< 80 byte) datagram often piggybacked on next file request

repeat;

close remote file.

This reliance on datagram request/response closely couples typical NOS performance to packet transfer delay, both within nodes and across the LAN media.

While most electronic mail is largely text with some graphics, some advanced Email, particularly for Macintosh networks, is beginning to support non-realtime voice and image transmission as well as data. These are handled perfectly well by the common NOS protocols. Figure 16 forecasts aggregate public and private electronic mail usage.

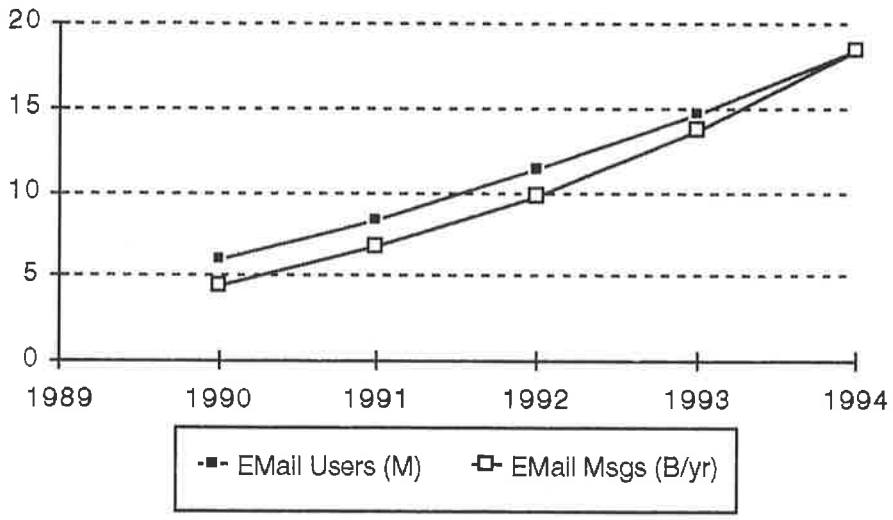

Figure 16: Forecast US EMail Installed Base

VIII. Local Area Network Performance

The key drivers of LAN performance for the applications currently is use include the following in order of importance.

Overall LAN load	Due to the bursty nature of resource demands of typical LAN applications, LANs that are operated at or near capacity will experience inevitable queuing delays. LANs should be sized to typically operate at less than 25% capacity regardless of the NOS, MAC or media choice. LANs today support this through partitioning of servers and network segments interconnected through bridges and routers.
NOS choice	Under similar loads, the single most important performance issue is the specific design and implementation of the NOS software and protocol stack. It is not unexpected to see 4:1 differences in application performance between LANs in which the only difference is the choice of NOS (e.g. identical MAC, clients, servers, media).
LAN adapter design	Using a common NOS and MAC, the interface design between LAN adapter and computer bus is a key performance issue. The interrupt service overhead and amount of adapter intelligence are both important considerations.
Channel capacity	All of the above items being equal - the LAN with the greater transfer rate and channel capacity will perform better. However, it should be noted that the variance in NOS performance or LAN adapter design can easily overshadow 2 or 3:1 differences in channel capacity.
MAC protocol	The detailed design of the MAC protocol appears to be of only minor concern given that the MAC protocol provides for low media access delay, efficient packet transfer and low net packet error rate. MACs that are optimized to provide low packet transfer delay with less than 1% packet error rates at modest loads seem the most practical.

IX. Conclusions

The data presented above can be used to support certain conclusions about the wired LAN market and provide the basis of inference for the wireless LAN market.

- There is little historical use of integrated real-time voice and data communications and little documented buying demand for such services. Integrated store-and-forward voice and data services appear to have substantial market potential. Real-time voice services have become a slow growth market. Data LANs remain a high growth market.

- LANs have become the de facto standard for desktop data connectivity. By the mid-1990's it is expected that the majority of the installed base of desktop data equipment will be attached to a LAN. The expected high market penetration of wired LANs in the next five years should give a sense of urgency to the wireless LAN standards development process. The earlier a simple standard can be adopted, the more relevant it will likely be.

- Unshielded twisted pair has become the dominant media choice and shows capacity for the installed base of wiring to grow in capacity over time (as evidenced by movement to FDDI performance over existing UTP). It is likely that UTP will have substantial price/performance advantages over other media for some time to come and likely over most wireless technologies particularly radio technologies that require bandwidth allocation. It may always be cheaper, in many cases, to put more copper (or fiber) in the walls (space division multiplexing at its best) than petition the FCC for more spectrum. Wireless LANs should be best considered as complementary to wired LANs rather than their replacement.

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  Due to the increasing prevalence of hierarchical internetworks using bridges and routers, end-to-end reliability must be provided in most instances by Layer 4 protocols rather than Layer 2 MAC level protocols.