LAN Standards

In this report:

Datapro Summary

No single technological trend other than the development and proliferation of the PC has had the impact upon our work habits and styles as have local area networks. It was not that long ago when we viewed PCs as sophisticated replacements for typewriters. Networking PCs was something ever distant—the cost of networking was prohibitive. But those costs have plummeted. An Ethernet connection, which in 1982 cost approximately $2,000, is often less than $150 today. The development of LAN standards has fueled PC networking even more than the technology itself.

Introduction (A Little History)

During the mid-to-late 1970s, a small company in Texas developed a capability to provide access to shared direct access storage device-disks (DASDs) from microprocessor workstations located within a reasonable distance from the DASD. The company was Datapoint Corp. and the technology was Arcnet—Attached Resource Computer Network. At about the same time, Xerox Corp. was developing its experimental Ethernet. These were the first LANs to be offered as commercial products.

In the 1980s, with the near demise of Datapoint, and Xerox's alliance with Digital Equipment Corp. and Intel, the IEEE had little choice when it adopted an "Ethernet-like" approach for its local network standard. Other organizations, such as General Motors and IBM, had their own ideas about what the *ideal* LAN should look like. The result was a family of LAN standards to be known as the IEEE Project 802 LAN standards.

Despite the 802 "steamroller," Arcnet did not quite disappear. Licensees continued to make Arcnet interfaces, but now focused on the PC as the workstation. Today, Arcnet continues to enjoy a useful life as a mature and highly functional proprietary implementation. In fact, there

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are implementations of Arcnet that operate at 20M bps, an order of magnitude greater than the original 2.5M bps LAN. Efforts to have the Arcnet implementation adopted as a "de jure" standard have finally borne fruit in the form of "ANSI standard" status.

Unfortunately, however, the patient has become almost comatose. In the past year, only 300,000 Arcnet adapters have been sold—compared to 8 million Ethernet and 2 million token-ring adapters. The "multivendor breeding" of Ethernet, along with its highly flexible cabling options, has led to a stronger, more widely acceptable product. Arcnet, on the other hand, with its pedigree status, seems to have passed its peak.
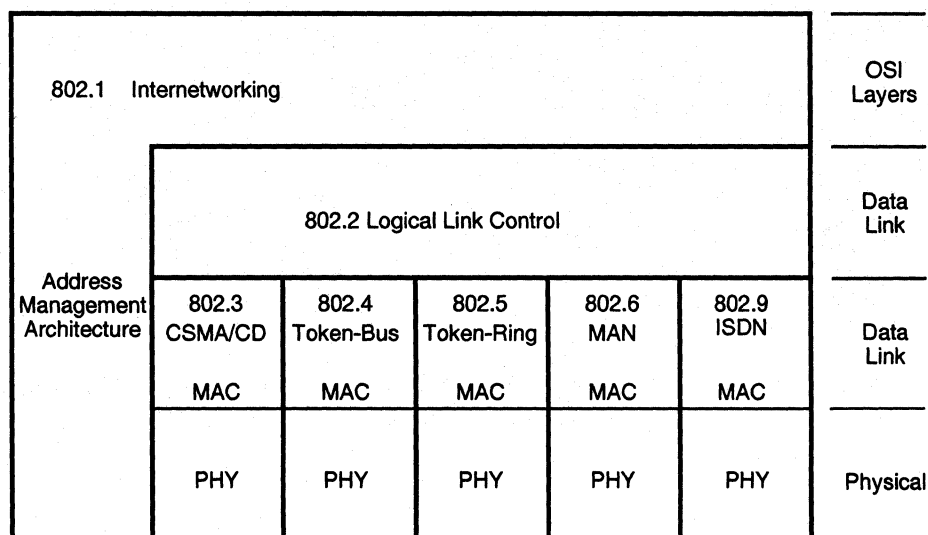
With the ever increasing popularity of LANs, new requirements have developed calling for higher-speed networks of greater geographic range. In response to these requirements, vendors have developed alternatives to the standard implementations, and standards bodies such as ANSI have produced Fiber Distributed Data Interface (FDDI) while the IEEE, despite several false starts, has finally adopted its IEEE 802.6 Metropolitan Area Network (MAN).

The bottom line is that while there are currently numerous standard implementations, there are also proprietary implementations from leading vendors, which have become "de facto" standards, and may suit one's needs very well. As long as technology continues to improve, entrepreneurs will continue to come up with "better ways." Some of these "better ways" will

802.1 Internetworking						OSI Layers
Address Management Architecture	802.2 Logical Link Control					Data Link
	802.3 CSMA/CD MAC	802.4 Token-Bus MAC	802.5 Token-Ring MAC	802.6 MAN MAC	802.9 ISDN MAC	Data Link
	PHY	PHY	PHY	PHY	PHY	Physical

fade quickly after initial flurries of excitement, while others will pave the way for new and better standards.

The standards organizations naturally have a responsibility to assume that improvements are compatible and interoperable with earlier standard versions. Standards are not *static*, and the network architect must realize that there will always be a better solution tomorrow. Of course, if one continues to wait for the better solution, no solution will ever be implemented.

It is also essential to realize that there are a variety of competing forces in the standards development world—each with its own agenda (hidden or unhidden). The result is often a less than perfect compromise. It is often said that the two things you really do not want to watch being made are sausages and computer network standards.

Overview of IEEE 802 Standards

The IEEE 802 standards essentially address only the two lower layers of the Open Systems (OSI) Reference Model (see Figure 1).

The Physical Layer corresponds to the OSI Physical Layer, while the OSI Data Link Layer is divided into two *sublayers*: medium access control (MAC) and logical link control (LLC). The MAC sublayer addresses the specific procedural issues associated with distributed arbitration of channel access.

The LLC sublayer provides a mechanism accommodating those functions of wide area network Data Link protocols that pertain to LAN management. Unlike the wide area Data Link protocols such as High-level Data Link Control (HDLC), which address specific nodes, LLC protocol data units only contain service access points or internal memory addresses of software entities. Physical node addresses and error-detection are handled by the MAC sublayer.

There are four basic access methods defined, as well as a subset of higher Data Link Layer functions. In addition, there are several working groups whose activities are focused on specific technologies which are applicable across a broad range of the access methods.

The Carrier Sense Multiple Access with Collision Detection (CSMA/CD) method was the first to be developed by the IEEE, and was modeled after the Digital/Intel/Xerox (DIX) Ethernet. While many people refer to the 802.3 specification as "Ethernet," the two are not really compatible. There are a number of differences in the physical and medium access implementations, but these have usually been resolved through "interface agreements" and special-purpose bridges. Since it is more difficult to change tradition than to accept it, we will continue to use the terms Ethernet and IEEE 802.3 interchangeably. Table 1 defines the differences between Ethernet and IEEE 802.3 implementations.

Table 1. Ethernet/IEEE 802.3 Differences

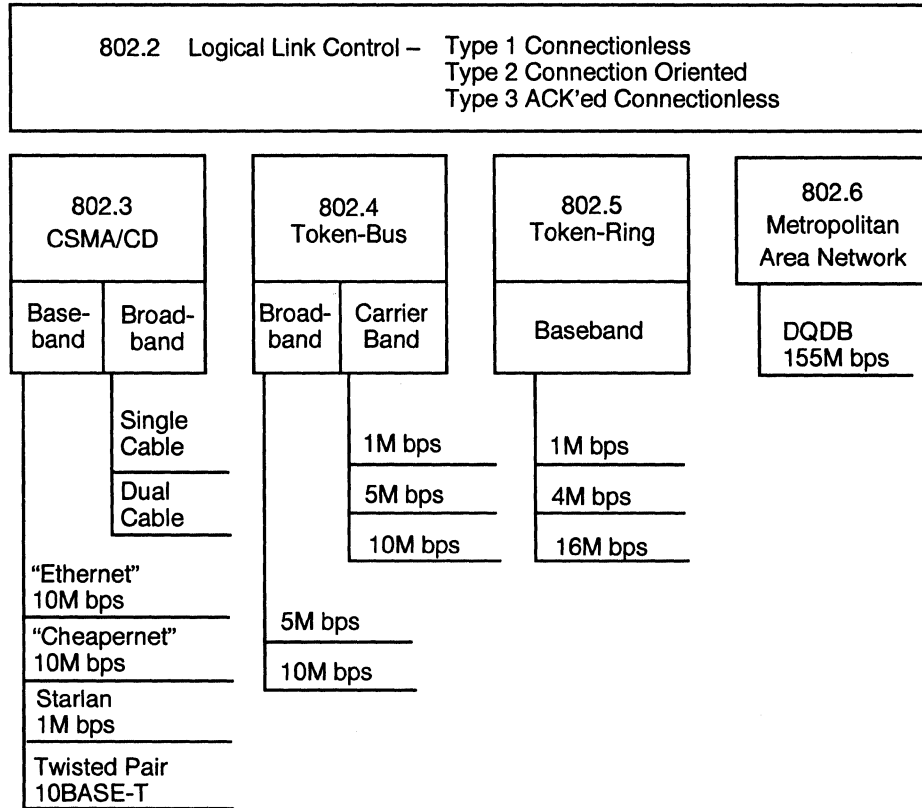| Feature	Ethernet Version 1	Ethernet Version 2	IEEE 802.3
Specification	1980 Blue Book	1982 Blue Book	1983, 1985
Transceiver Cable	3 pairs AWG 22	4 pairs AWG 20	4 pairs AWG 20
Grounding at Host	Inner/outer shield common at backshell & pin 1	Same as Version 1	Inner shield to backshell; outer to pin 4
Electrical Signal	0 V to negative	+ & − signal	+ & − signal
Signal Quality Error (SQE)	None; no heartbeat	Yes; heartbeat	Yes; heartbeat
Repeater Specification	None	None	Multiple collision protection
Jabber Control	None	Yes	Yes
Type/Length Field	Type (>1500)	Type (>1500)	Length (<1500)
Coaxial Cable	50Ω Double shield	Same	Same

Figure 2.
IEEE Standards Variations

There are variations within each of the IEEE 802 standards.

Figure 3.
10BASE5 Termination Hardware
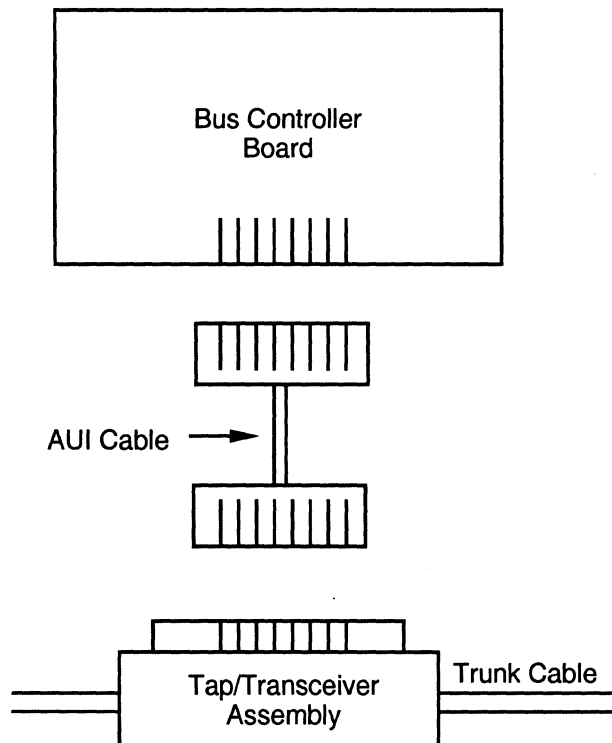
The 10BASE5 version of IEEE 802.3 uses thick Ethernet coaxial cable and various termination hardware.

The 802.4 specifications were developed primarily in response to requirements for the *deterministic* performance of token passing, coupled with the facility of bus-oriented cabling. The employment of broadband technology provided the additional benefits of increased bandwidth, geographic coverage, and numbers of terminations.

The 802.5 token-ring specification was developed under the "guidance" of IBM and reflected the emerging "blue" perspective on local area networking. While the initial versions of the network provided less capacity than Ethernet, the expected improvements associated with deterministic performance and priority mechanisms yielded other benefits.

Over time, however, we have seen a wide variety of implementations emerge—each reflecting specific vendors' "better ideas." Some of these have been standardized, while others will likely become standards in the near future (see Figure 2).

The chairman of the 802.3 working group, Don Loughry, once spoke at an Interface Conference session with this author, and remarked that the "nice thing about standards is that you have so many to choose from." While this is certainly humorous, and may also evoke some concern for the viability of so many variations, it does in fact insure that there will be a standard implementation to meet most user requirement scenarios.

One more important background note—many of the 802 specifications have been adopted as ISO/IEC 8802-n series standards: where "n" is the IEEE 802 extension. Thus, IEEE 802.3 becomes ISO/IEC 8802-3.

With this backdrop, we will explore the specific 802 LAN standards.
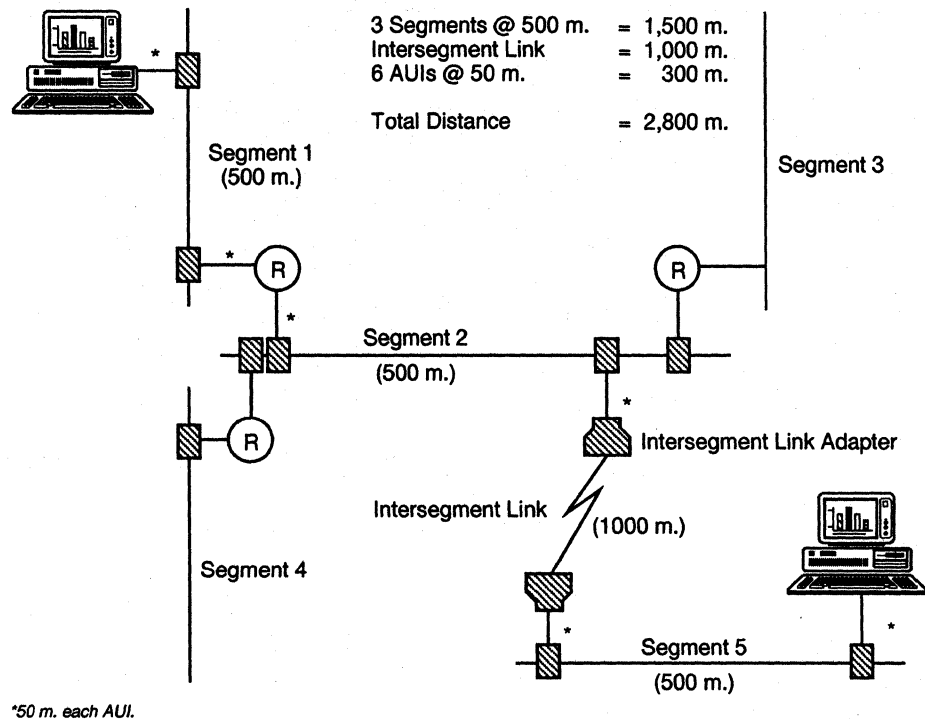
IEEE 802.3 (CSMA/CD)

IEEE 802.3 standards are characterized by a shorthand notation which facilitates their description in as few words as possible. The notation is composed of three elements:

1. Megabits per second divided by 10^6

Figure 4.
Multisegment CSMA/CD LAN

For a multisegment 802.3 LAN, the maximum distances between segments can vary; however, the maximum distance between any two communicating stations is limited to 3,000 meters.

3 Segments @ 500 m. = 1,500 m.
Intersegment Link = 1,000 m.
6 AUIs @ 50 m. = 300 m.

Total Distance = 2,800 m.

Segment 1 (500 m.)
Segment 2 (500 m.)
Segment 3
Segment 4
Segment 5 (500 m.)

Intersegment Link Adapter
Intersegment Link (1000 m.)

*50 m. each AUI.

2. Baseband or Broadband

3. Meters per segment divided by 100

10BASE5

Thus, 10BASE5 means 10M bps, baseband, 500-meter segments. This was the first version of the specification to be developed, and most closely resembled the earlier Version 1 and 2 Ethernets (1980 and 1982, respectively). The 10BASE5 LAN employed the "thick Ethernet," 50-ohm coaxial cable. While this cable was difficult and relatively expensive to install, it provided significant advantages over other implementations in terms of distance and the number of terminations permitted for each segment.

The workstation contained an adapter board called the "bus controller" in Ethernet parlance. Attached to the bus controller was a multiconductor cable known as the attachment unit interface (AUI) cable. This was, in turn, connected to a transceiver/tap assembly called the medium attachment unit (MAU) which was connected to the Ethernet trunk cable, usually employing a "vampire" tap (see Figure 3).

When Ethernet products were first developed, this assemblage of components normally cost $1,500 to $2,000. Since LAN implementations are very sensitive to workstation termination costs, less expensive alternatives were required. This problem was resolved in two ways. First, vendors developed less expensive implementations (the old "better way" trick), which we will explore in a moment, and second, the natural momentum in declining semiconductor costs reduced these implementations to a fraction of their former selves.

Due to the sensitive timing issues associated with the performance of the CSMA/CD protocols, limits were imposed upon the overall length of a multisegment LAN, as well as the maximum signaling rate. A typical large-scale CSMA/CD LAN is limited to a distance of 2,800 meters between any two communicating stations. This is often implemented by using three 500-meter segments and a 1,000-meter interrepeater link. An important distinction between a link and a segment should be noted. Segments may have workstations attached, while links are simply media used to extend the overall distance of the LAN without any additional terminations (see Figure 4).

Table 2. 802.3 10BASE5/10BASE2 Differences

Feature	10BASE5	10BASE2
Name	802.3 Ethernet	Cheapernet, thin or thinwire Ethernet
Type of Cable	50Ω thick dual shield	50Ω RG-58
Maximum Segment Length	500 meters	185 meters
Spacing of Devices on Cable	2.5 meters minimum	0.5 meters minimum
Maximum Number of Taps for a Segment	100	30
Maximum Number of Full Repeaters in a Path Between Two Stations	2	2
Type of Taps	Vampire	BNC T connector for daisy chaining

Figure 5.
10BASE5/10BASE2 Interconnectivity
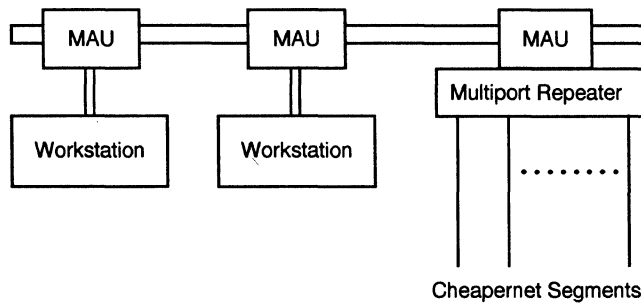
Cheapernet Segments

In environments with multiple work areas, or work areas with
multiple 10BASE2 LAN segments, a backbone 10BASE5 segment
can be used to provide intersegment connectivity.

Figure 4 illustrates a 10BASE5 LAN with the maximum distance between two workstations. Other constraints associated with 10BASE5 LANs concern the number of devices that can be terminated on the trunk cable. Up to 100 devices can be placed on a 500-meter segment, with a maximum of 1,024 devices on the entire network. This limitation can be circumvented through the use of bridges, which partition a LAN into several connected, but independent LANs—thus yielding the maximum length and number of workstations for each.

10BASE2

10BASE2 (also known as "thin Ethernet" or "cheapernet") employs a thin, flexible coaxial cable (RG-58) which connects to the adapter board in the workstation by means of a BNC "T" connector. In earlier implementations, the transceiver functions were onboard, but in the interests of using the bus controller for either implementation, a variety of MAUs and adapter boards has been developed which provide options for both 10BASE5 "vampire" taps, attachment unit interface cables, 10BASE2 BNC connectors, as well as the ever popular 10BASE-T connections which we will discuss shortly.

The standard 10BASE2 LAN can support only 30 terminations on each coaxial cable segment of 185 meters. While this may seem like a major constraint, it is often adequate for most moderate work area environments. Where a requirement exists for interconnecting multiple work areas, or work areas with multiple 10BASE2 segments, a backbone 10BASE5 segment can be employed to provide intersegment connectivity. Figure 5 illustrates this type of configuration.

1BASE5

This standard option was designed by AT&T to accommodate its earlier Starlan products. It operates at 1M bps and as such is often most useful for small work areas or low traffic environments. 1BASE5 also employs inexpensive twisted-pair interconnected through a hierarchical system of concentrator hubs. The hubs emulate a bus configuration by broadcasting all data and collision information on all ports. 1BASE5 implementations have all but given way to 10BASE-T.

10BASE-T

One of the most exciting developments on the local network scene has been the development of the 10M bps unshielded twisted-pair (UTP) Ethernet. Virtually every provider of Ethernet LAN products now offers 10BASE-T components. It is important to note that these implementations are limited to approximately 100-meter segments due to the greater attenuation and signaling difficulties of twisted pair. This should not present any unusual problems since these networks can be concatenated and interconnected with fiber optic backbones, as well as 10BASE2 and 10BASE5 implementations.

It is imperative, however, that organizations planning these networks have their existing twisted-pair certified for both attenuation and capacitance before making any assumptions on its salvageability. Like other star-wired LANs, these systems use concentrators to interconnect multiple stations and emulate the bus operation.

10BROAD36

The 10BROAD36 implementation uses much of the same hardware as the baseband implementations. The essential difference is the substitution of a broadband electronics unit and a passive broadband tap for the baseband MAU. This enables an organization to use its existing bus controller boards in the workstations for connection to either a baseband or broadband system. The primary functions of the broadband electronics unit are to create the frequency-derived channels of 14MHz for data and 4MHz for collision consensus. It also converts the signals from the baseband-coded signal of the AUI to the analog signal necessary on the broadband channel (see Figure 6).

Workstations can be placed up to 1,800 meters from the "head-end" of the broadband cable plant. By placing the head-end in the center of the configuration, workstations can be installed up to 3,600 meters from each other.

Although a viable standard, many large organizations that formerly supported RF broadband implementations have returned to baseband implementations. This trend is attributed primarily to the difficulty in designing, installing, and maintaining RF broadband systems. It is also facilitated by the introduction of bridges which permit users to expand their networks while still employing the simpler baseband transmission technologies.

Fast Ethernet

The IEEE 802 project has recently been transformed into a fierce battleground of the behemoths. In a quest for a higher-speed backbone Ethernet installation, the committee has defined a requirement for a new "Fast Ethernet" which will operate at 100M bps. Two competing armies are assembling their supporters at the gate to the arena.

Table 3. Logical Link Control Alternatives

Service	Type 1	Type 2	Type 3
Basic Service	Connectionless	Connection	ACKed connectionless
Acknowledgments	No	Yes	Yes
Error Recovery	No	Yes	Yes
Flow Control	No	Yes	No

Figure 6.
10BROAD36 Model
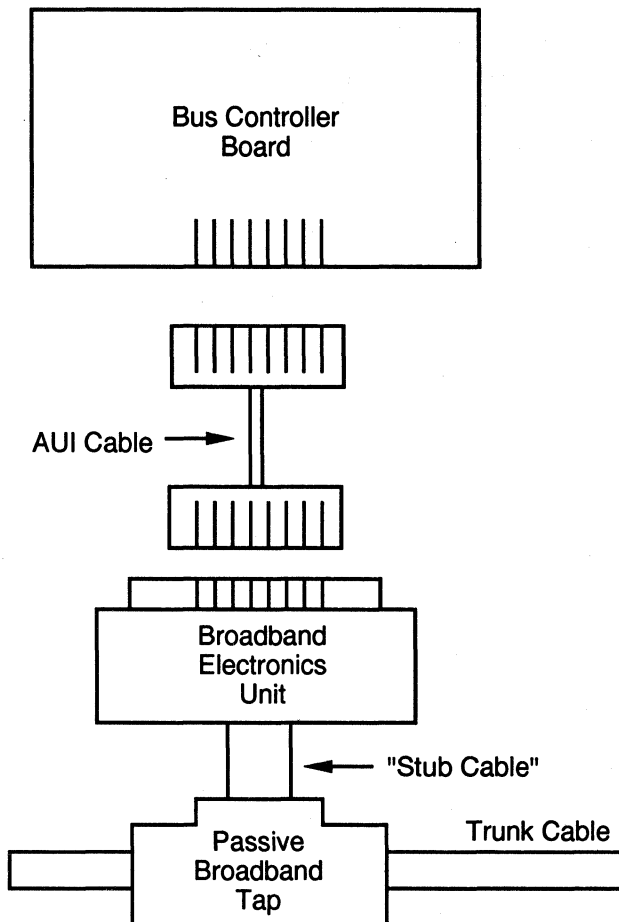
A 10BROAD36 broadband 802.3 implementation uses much of
the same hardware as baseband 802.3 LANs.

One team, championed by AT&T and Hewlett-Packard, is
supporting a technology called 100BASE-VG (voice grade). This
technology is geared to operate on existing voice grade wiring
(EIA/TIA-568 Level 3) designed to operate at 10M bps. The more
commonly used medium in LAN environments is EIA/TIA-568
Level 5, which is designed to operate at 100M bps.

The protocol architecture differs significantly from conven-
tional Ethernet CSMA/CD, in that this system operates using dif-
ferent priority levels which are administered by the hubs. This is
clearly a departure from the current distributed nature of Ethernet
channel access arbitration.

The second team, spearheaded by 3Com, SynOptics, Sun Mi-
crosystems, and others, is trying to protect its customers as well
as its own investment in standard Ethernet protocols. This ap-
proach, known as 100BASE-X, employs the Level 5 cable and
conventional CSMA/CD protocols.

A significant advantage of the 100BASE-X approach is the
ability to combine 10M bps and 100M bps connections using
dual-speed adapters and hubs. The similarity of the protocols be-
tween the backbone and the subnets should yield lower imple-
mentation risks.

As one might expect, the IEEE is under a great deal of pres-
sure to adopt one of these approaches—quickly. Which one will
prevail? For the moment, all bets are off!

IEEE 802.4 (Token Bus)

The 802.4 Token Bus specification has been adopted by ISO as
the 8802-4 International Standard. Although the initial broadband
implementations of the token bus appeared to be highly flexible
and desirable in terms of the generic manufacturing requirements,
a number of difficulties have arisen. First, the industry is finding
that migration from the early versions of the Manufacturing Au-
tomation Protocol (MAP) suite (Version 2.x) to current specifica-
tions (Version 3.0) is less than facile. It has become a manager's
nightmare for any number of reasons.

For instance, fewer and fewer people are interested in broad-
band implementations, primarily due to the difficulty in design,
installation, and maintenance. Additionally, the apparent benefits
of broadband networks in terms of the number of terminations,
geographic range, and bandwidth have been overtaken and ne-
gated by the introduction of medium access control bridges which
provide even greater capabilities—nearly transparently. These
bridges enable an organization to increase the traffic loading by
simply partitioning the network and eliminating the concern.
Couple these high-risk implementation issues with the scarcity of
products, difficulty in migration from MAP 2.x to 3.0, and soft
industry support, and one will find that the token bus presents a
quagmire of implementation risks that most managers would
rather avoid.

There is some hope on the horizon for the medium access
specification. Other physical medium specifications are being de-
veloped for both optical fiber and wireless approaches. Some dif-
ficulties lie ahead here since the dominant fiber specification in
the U.S. is the 62.5μm fiber specified by ANSI for the FDDI,
while in Japan and Europe, 50μm fiber is a more common imple-
mentation. In the final versions of this standard, both options may
be permitted.

The 802.4 Token Bus architecture has matured despite the un-
certainties presented by the MAP protocol suite. Standards for
medium access control, broadband media, carrierband media, and
optical fiber have been completed. Open projects include con-
formance testing, wireless (through the air) media, redundant me-
dia, twisted pair, and the potential for new and revised medium
access control.

IEEE 802.5 (Token-Ring)

The token-ring implementation which has received so much at-
tention since it was first approved in 1985 has undergone a variety
of changes and modifications over the past seven years.

Media Issues

The initial version of token-ring was a 4M bps implementation
which ran on shielded twisted pair (STP). The issues surrounding
STP have always been controversial. Telephony carriers avoid
shielded wire to the extent possible since the shielding introduces
capacitance changes and ultimately increases attenuation, thus re-
quiring more frequent repeater placement. LAN proponents, such
as IBM, feel differently. They contend that the shielding protects
the media from unwanted electromagnetic interference/radio fre-
quency interference (EMI/RFI) and that the distance between re-
peaters is not an issue since each station is its own repeater.

Considering the context of their respective positions, both
contenders are correct. In the case of LANs, the shielding does
buy some value. One thing we can be sure of, though, is that
where there is a requirement, someone will stand up to fill the
niche. Thus, when IBM introduced the 16M bps token-ring, run-
ning only on shielded wire, it was not surprising that other ven-
dors immediately introduced unshielded 16M bps implementa-
tions. In fact, the IEEE 802.5 working group has introduced a set
of guidelines for using UTP. Considering the work that the Elec-
tronic Industries Association (EIA) has done concerning intra-
building wiring (EIA/TIA-568), it is likely that shielded wire will

Table 4. IEEE Standards Status

IEEE No.	Year	Description	Status	ISO Equivalent
802	1990	Overview and architecture	Adopted	None
802.1a	1990	Conformance testing methodology	Adopted	None
802.1b	1992	LAN management	Adopted	None
802.1d	1990	MAC bridges	Adopted	None
802.1e	1990	System load protocol	Adopted	None
802.1i	1992	MAC bridge supplement for FDDI	Adopted	None
802.2	1989	Logical link control	Adopted	8802-2
802.3	1985	10BASE5 CSMA/CD	Adopted	8802-3
802.3a	1988	10BASE2 CSMA/CD	Adopted	8802-3
802.3b	1985	10BROAD36	Adopted	8802-3
802.3c	1985	Repeaters for 10M bps	Adopted	8802-3
802.3d	1987	Fiber Optic Inter Repeater Link (FOIRL)	Adopted	8802-3
802.3e	1987	1BASE5	Adopted	8802-3
802.3h	1990	Layer management	Adopted	None
802.3i	1990	System considerations for 10BASE-T	Adopted	None
802.3k	1992	Layer management for 10M bps repeaters	Adopted	None
802.3l	1992	10BASE-T MAU protocol implementation conformance statement (PICS)	Adopted	None
1802.3	1991	Conformance testing	Adopted	None
802.4	1985	Token passing bus	Adopted	8802-4
802.4b	1992	Enhancements for physical layer diversity— Redundant media control unit	Adopted	None

diminish in importance. Once can safely expect to see UTP become the dominant medium, even in the "blue world" of IBM.

Other media-related issues that have been explored by the 802.5 group are the use of Optical Fiber Station Attachment equipment and redundant media for backup. The latter has yielded a specification for "Dual Ring Operation with Wrap-back Configuration." This technique is similar to that used in the ANSI FDDI dual ring.

Token-Passing and Multiring Protocol Issues

With the 16M bps ring, IBM introduced a version of the token-passing protocol called Early Token Release (ETR). ETR makes more efficient use of the available bandwidth on physically large rings operating with particularly small packets. In earlier versions of the token-passing protocol, a new free token could not be released by the sending station until it recognized the address in its own packet coming back around the ring to itself. If the packet was small, and the ring was large, there was a great deal of wasted "time" on the medium. Using ETR, a sending station can release the free token immediately upon completing its transmission. The empty time slots on the ring can now be used by other parties. When coupled with the 16M bps ring, this new protocol appears to have significant advantages in terms of performance.

Another area of interest in the token-passing world is the controversy on medium access control bridges. While the Ethernet proponents prefer a minimum spanning tree approach, many token-ring developers prefer source routing bridges. These approaches have been evaluated by both the 802.3 and 802.5 committees. The IEEE has adopted spanning tree bridges as the 802.1d standard, but permits source routing bridges provided the two bridges can interoperate.

LAN Interconnection

As LANs proliferate, it is becoming more important that standard techniques for interconnection be adopted.

IEEE 802.3 Physical Layer Relays

In the case of the IEEE 802.3 CSMA/CD LANs, intra-LAN segment connection standards are well developed and mature. These physical layer relays are implemented as repeaters which regenerate the signals from one segment for retransmission to the next. The unique aspect of these repeaters is that they must be capable of retransmitting collisions as well as data frames. Unlike Data Link Layer relays (or source routing or MAC bridges), repeaters are not addressable. Since all segments are part of a unified LAN,

Table 4. IEEE Standards Status (Continued)

IEEE No.	Year	Description	Status	ISO Equivalent
802.5	1985	Token passing ring	Adopted	None
802.5a	1989	Station management revision	Adopted	None
802.5b	1991	4M bps over unshielded twisted pair	Adopted	None
802.5e	1992	Management entity specification	Adopted	None
802.5f	1992	16M bps operation	Adopted	None
802.5g	—	Conformance testing	Imminent adoption	None
802.5h	1992	ACK'd connectionless LLC	Adopted	None
802.5i	1992	Early token release	Adopted	None
802.5j	—	Optional fiber station attachment	Imminent adoption	None
802.6	1990	Distributed Queue Dual Bus Subnet	Adopted	None
802.7	1989	Recommended practices for RF broadband LANs	Adopted	None
802.8	—	Recommended practices for optical fiber	Imminent adoption	None
802.9	—	Integrated voice and data	In progress	None
802.10	1992	Interoperable LAN/MAN security and secure data exchange	Adopted	None
802.11	—	Wireless LAN access method	In progress	None

the nature of the shared channel must be preserved by broadcasting all information to all terminated devices.

The latest specifications for repeaters are contained in the IEEE 802.3C supplement (1992). Unlike the earlier version of this supplement (1989), this specification provides rich detail on coaxial cable, AUI, and optical fiber repeater interfaces. It is important to note that these repeater specifications pertain only to the 10BASE5 and 10BASE2 implementations. Other repeaters for 1BASE5, 10BASE-T, and 10BROAD36 are beyond the scope of this specification.

In addition to the functions described above, repeaters as specified in the 802.3C supplement provide "collision isolation" between segments. Thus, if conditions on a given segment are causing the extensive proliferation of collisions, the rest of the LAN can be protected from this anomaly. The repeater will count the number of collisions from the source segment, and isolate it from the next segment until it is stabilized.

IEEE 802.4 Physical Layer Relay

The issues of signal attenuation in a broadband LAN are normally resolved in two ways. First, the maximum placement of a device from the head-end provides a maximum boundary on signal loss in the context of attenuation. Second, since many stations may be connected to the bus, each resulting in a specific "insertion loss," amplifiers are often required to ensure that the total loss does not exceed specifications.

The IEEE 802.4 broadband bus specification defines a "Regenerative Repeater Machine" (RRM) as an optional component which is present only in special repeater stations such as the head-end. Since broadband systems are analog, amplifiers are usually

required to boost signal strength. Regenerative repeaters actually re-create a new signal in accordance with the amplitude and timing specifications for the original signal.

A regenerative repeater is also defined for the singlechannel carrierband system. Since the latter is not a multichannel broadband bus (a medium supporting multiple frequency-derived channels such as Community Antenna TeleVision—CATV), a headend is not required to facilitate this function. Physical placement of these devices is a function of the number and placement of user devices on the network. There are no explicit maximum terminations defined in the specification, but the standard suggests that 30 may be an appropriate user limitation.

IEEE 802.5 Physical Layer Relays

The nature of a token-passing ring obviates the necessity for repeaters, since each station's ring interface performs repeater functions. The maximum attenuation of a signal is thus guaranteed by limiting the distance between any two devices in the ring. As with 802.3, the issues of overall length of the ring impact protocol performance as opposed to signal attenuation.

Data Link Layer Relays

Interconnection of similar but separate LANs has resulted in the need for specifications on medium access control bridges. MAC bridges are hardware/software implementations that are limited to resolving the MAC sublayer differences between two or more interconnected LANs. No further higher-layer protocol intervention is required, and they are often transparent to the user in terms of delay and performance.
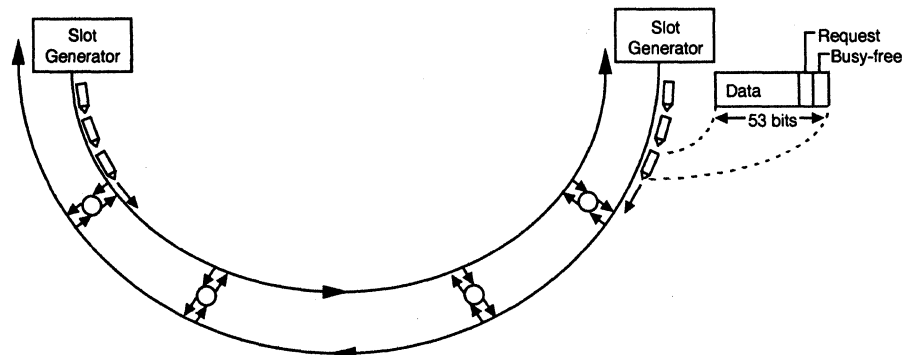
Figure 7.
IEEE 802.6 MAN Distributed
Queue Dual Bus (DQDB)

The nodes in the DQDB network
form a dual "open ring."

MAC bridge specifications have been addressed by the IEEE 802 working groups. The 802.3 and 802.5 teams have developed two significantly different approaches, but even these will interoperate.

The current approaches are the Minimum Spanning Tree for bus implementations, and the Source Routing bridge for interconnected rings. The essential difference between the two lies in that in the bus environment, only one path between any two devices exists. The bridges learn the LAN segment and node addresses and filter packets accordingly as required. Provision for multiple alternative paths is provided in the interconnected ring environment, which, in turn, yields a requirement for a routing protocol. This routing protocol is facilitated by adding "routing information" (RI) fields to the packet header. The RI field contains all of the source node routing information necessary for the bridge to determine which path is to be adopted for a specific packet.

There are certainly advantages and disadvantages to both of these approaches, but the common goals are to provide global, transparent interconnection. Global in the sense that any device on any LAN can share resources with any device on any other LAN; transparent in the sense that performance must be adequate to ensure that access to remote resources is provided rapidly and accurately. This guarantees that users do not perceive a difference between local and global objects.

IEEE 802.2 (Logical Link Control)

The IEEE 802.2 LLC specifications include those Data Link Layer functions that are common to all 802 LAN MAC sublayer alternatives. Three basic service types are provided:

Type 1 (Connectionless): This service provides a "best efforts" delivery mechanism between the origin and destination nodes. No call or logical circuit establishment procedures are invoked. Each packet is treated as an independent entity by the network. There are no flow control or acknowledgment mechanisms. If the packet arrives at the destination, all well and good. If not, it is the responsibility of the higher-layer protocols to resolve the problem through time-outs and retransmissions.

Type 2 (Connection-Oriented): Like many wide area network protocols, this service requires that a logical circuit or call be established for the duration of the exchange between the origin and destination nodes. Packets usually travel in sequence and are not routed as independent entities. Positive acknowledgments and flow control mechanisms are an integral part of this service.

Type 3 (ACKed Connectionless): No circuit is established in this service variation, but acknowledgments are required from the destination node. This type of service adds additional reliability to Type 1, but without the potentially excessive overhead of Type 2.

Specific LAN types lend themselves to different types of service. These services are generally combined in "service classes" which are oriented to different operating environments. Table 3 illustrates the LLC variations as they apply to the different MAC implementations.

IEEE 802.6 (Metropolitan Area Network)

The IEEE 802.6 MAN is a fourth MAC alternative that is intended to cover a greater geographic area than the conventional LAN. Earlier plans called for this to be a CATV network, while later proposals focused upon a high-speed slotted ring. The specification that was finally adopted is called the "Distributed Queue Dual Bus" (DQDB). It has been developed under the auspices of the Australian Postal Telephone and Telegraph (PTT) or "Telecom Australia."

The DQDB is characterized by its very high transmission rates of up to 155M bps, rapid access mechanisms, and preallocated time slots for isochronous (time-critical) traffic. This makes the 802.6 MAN an ideal candidate for digitized voice or video traffic. It has been designed to support 512 nodes over a distance of 160 kilometers, but all of these design metrics can be extended considerably. It is primarily used for interconnection of LANs and to support high-density "bit-mapped" traffic such as graphics or imagery. The DQDB is also important in that it is the only 802 LAN that provides "direct" compatibility with high-speed switched data services as well as Broadband ISDN. (Note that the term "broadband" in this context denotes high-capacity digital services, as opposed to frequency-division multiplexed analog CATV.)

As illustrated in Figure 7, the nodes in the DQDB network form a dual "open ring" where they turn on available request bits in fixed time slots that have data in them. When available slots appear on the other bus, they transmit after correlating their requests with the number of available slots. The correlation process is accomplished by observing the number of request bits that have been turned on prior to receiving an available request bit. As empty slots appear, the request counter is decremented until there are no outstanding requests. The next empty slot is effectively scheduled for this node.

Other IEEE 802 Activities

The IEEE 802 committees have sponsored a number of other related activities. These projects are staffed by Technical Advisory Groups (TAGs). They are not developing different access methods, but rather guidelines and standards that can be applied "across the board" of MAC implementations.

IEEE 802.7 (Broadband TAG): This group has developed a standard specification that deals with the Physical Layer issues of broadband LANs. Topics covered include frequency allocations, design guidelines, and installation procedures and methodology. These issues apply to both the 10BROAD36 CSMA/CD and the 802.4 token-passing bus.

IEEE 802.8 (Fiber Optic TAG): This working group is responsible for defining fiber types, installation issues, connectors, and tapping and splicing procedures. The guidelines developed by this TAG are applicable to each of the MAC implementations. This TAG also coordinates its activities with the EIA-568 Intrabuilding Wiring Committee.

IEEE 802.9 (Integrated Voice/Data): The IVD TAG actively addresses the myriad issues faced in interconnection of LANs via ISDN networks, as well as the requirements to provide for voice transmission in the LAN environment itself.

IEEE 802.10 (Security and Privacy TAG): This working group is responsible for developing guidelines for security and privacy mechanisms in LAN environments. They interface with other industry working groups.

IEEE 802.11 (Wireless Access Method and Physical Layer Specifications): This working group is developing standards for wireless LANs and has been considering the following.

- Infrared transmission (line of sight).

- Power-grid transmission (over power lines).

- Spread spectrum transmission (code-division multiplexing).

- Microwave transmission (at high frequencies, e.g., 18GHz).

ANSI Fiber Distributed Data Interface (FDDI)

The FDDI network is a 100M bps token-passing ring that was developed by the American National Standards Institute (ANSI). It has been adopted as an ISO standard 9314. While it is not an IEEE 802 LAN, it has many similarities. The Data Link Layer is divided into two sublayers, the upper half of which is the 802 Logical Link Control. The lower half, FDDI MAC, is very similar to the 16M bps IEEE 802.5 token-ring.

Like the IEEE 802.6 MAN, it is designed to interconnect LANs over a wider geographic area; however, current versions do not provide the guarantees necessary for isochronous service. There are a number of wiring rules associated with the FDDI ring. Some of these are based on limitations imposed upon us by the laws of physics, while others are related to performance issues.

Limitations associated with laws of physics include the following:

- Maximum of 2 kilometers between active nodes, due to attenuation.

- Maximum of three bypassed nodes, due to attenuation.

- Maximum of 4500-byte packet size, due to clock skew.

Performance limitations include:

- Maximum of 500 attached nodes, due to token seizure delays.

- Maximum of 100 meters in overall length due to token rotational delay.

As with the 802.6 MAN, these performance limitations are baseline criteria—not absolute limits.

The FDDI ring is similar to the token-ring in that it uses a similar frame structure, supports the 48-bit addresses of the IEEE specifications, and uses the same 32-bit cyclic redundancy check (CRC). The same hardware acknowledgment bits used in the 802 token-passing ring are also employed in the FDDI ring, while

control is completely distributed as it is in the 802.4 token-passing bus. As in the case of the 16M bps token-ring, the token is released immediately after transmitting (Early Token Release).

Physical layer issues associated with light-emitting-diodes on multimode optical fiber require that a unique coding scheme 4B/5B be used. For every four bits of information, five bits must be transmitted. This results in 125M bps for a 100M bps ring.

The FDDI ring employs a dual ring structure which provides a "wrap-back" in the event of a break in the ring. This is similar to the "self healing" reconfiguring token-ring.

Emerging Developments in FDDI

At the present time, FDDI implementations are being developed to operate on unshielded twisted pair. This is envisioned as a "drop" medium from the wiring closet to the work area. While UTP is considerably less expensive than fiber, distances will be limited. These implementations are called twisted-pair DDI (TP-DDI) and copper DDI (CDDI).

A new version of FDDI is being developed. FDDI II is designed to support isochronous communications providing guaranteed transmission capabilities for applications such as digitized speech. The same technology will also support compressed video. It is not clear at the moment how this apparent overlap with the IEEE 802.6 DQDB MAN will be resolved. As we quoted earlier, "The nice thing about standards is you have so many to choose from."

Synchronous Optical Network (Sonet)

Sonet is a major development that will ultimately provide a 100% digital fiber transport network. While by no means a LAN, Sonet will provide us with LAN interconnection capabilities that will outperform anything on the market today. Unfortunately, our best projections for Sonet do not show any significant penetration before 1994—at best. Sonet standards have been defined in three phases.

Sonet Phase I: This phase of Sonet was released in 1988. It defined the optical interfaces, data rates from T1 (1.544M bps) to OC-48 (2.5G bps), as well as channel allocations, basic features, and overhead.

Sonet Phase II: This phase of the Sonet standard included a number of new elements.

- Electrical interface

- Additional payload mapping

- Optical parameters and specifications

- Maintenance functions

- Data communications functions

- Generic message structures

- Equipment specifications

Sonet Phase III: Released in 1990, this phase of the standards defined specific message sets for different operating scenarios.

Before deploying Sonet, a thorough analysis must be performed to determine precisely what expected benefits may accrue. A variety of issues ranging from carrier deployment schedules to harmonization with companies' strategies will all influence this decision. It is important to recognize that Sonet is going to be there, but because of its elusive nature, it is best not to couple it too tightly to organizational objectives.

Summary

The status of LAN standards is ever changing. From the early days of proprietary implementations and pioneering standards development, we have now reached a point where numerous standards bodies are building upon each other's work.

The IEEE 802 LAN standards have evolved and matured significantly since their development in the early 1980s. Table 4 lists all of the current IEEE 802 standards and activities, as well as their status. It is essential that we do not view this maturation process as at an end. They will continue to evolve, and as new technologies and requirements develop, new standards will follow. The utopian environment would be for standards development to lead product development, but it is unrealistic to believe that in an environment as volatile as local area networking, vendors will wait patiently while users clamor for more and better products.

The IEEE will be faced with a continuing challenge to ensure that as new requirements and products evolve, the standards also evolve. This challenge will also be coupled with a requirement that migration from prior implementations is as painless as possible—both in terms of development risk and cost. ∎

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LAN Standards

In this report:

Datapro Summary

No single technological trend other than the development and proliferation of the PC has had the impact upon our work habits and styles as have local area networks. It was not that long ago when we viewed PCs as sophisticated replacements for typewriters. Networking PCs was something ever distant—the cost of networking was prohibitive. But those costs have plummeted. An Ethernet connection, which in 1982 cost approximately $2,000, is less than $300 today. The development of LAN standards has fueled PC networking even more than the technology itself.

Introduction (A Little History)

During the middle-to-late 1970s, a small company in Texas developed a capability to provide access to shared DASDs (direct access storage device-disk) from microprocessor workstations located within a reasonable distance from the DASD. The company was Datapoint Corp. and the technology was Arcnet—Attached Resource Computer Network. At about the same time, Xerox Corp. was developing its experimental Ethernet. These were the first LANs to be offered as commercial products.

In the 1980s, with the near demise of Datapoint, and Xerox's alliance with Digital Equipment Corp. and Intel, the IEEE had little choice when it adopted an "Ethernet-like" approach for its local network standard. Other organizations, such as General Motors and IBM, had their own ideas about what the "ideal" LAN should look like. The result was a family of LAN standards to be known as the IEEE Project 802 LAN standards.

Despite these developments, Arcnet did not quite disappear. Vendors that had acquired the licenses continued to make Arcnet interfaces, but now focused on the PC as the workstation. Arcnet continues to enjoy a useful life as a mature and highly functional proprietary implementation. In fact, there are implementations of Arcnet that operate at 20M bps, an order of magnitude greater than the original 2.5M bps LAN. Efforts are under way to influence standards bodies to adopt this approach as an alternative, but it is not yet clear what the outcome will be.
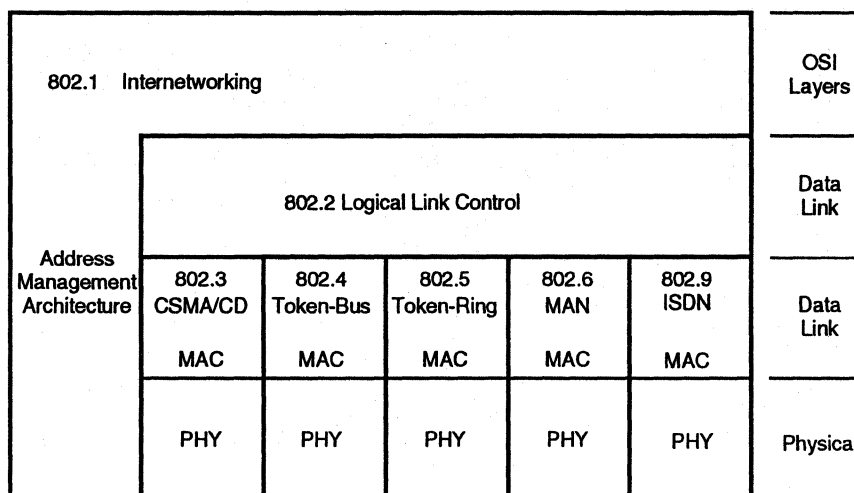
With the ever increasing popularity of LANs, new requirements have developed calling for higher-speed networks of greater geographic range. In response to these requirements, vendors have developed alternatives to the standard implementations, and standards bodies such as ANSI have produced FDDI (Fiber Distributed Data Interface) while the IEEE has finally adopted its IEEE 802.6 Metropolitan Area Network (MAN).

The bottom line is that while there are currently a fair number of standard implementations, there are also proprietary implementations from leading vendors which, while not "standard," may suit one's needs very well. As long as technology continues to improve, entrepreneurs will continue to come up with "better ways." Some of these "better ways" will fade quickly after initial flurries of excitement, while others will pave the way for new and better standards. Standards are not *static*, and the network architect must realize that there will always be a better solution tomorrow. Of course, if

—By Michael L. Rothberg
President
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802.1 Internetworking						OSI Layers
Address Management Architecture	802.2 Logical Link Control					Data Link
	802.3 CSMA/CD	802.4 Token-Bus	802.5 Token-Ring	802.6 MAN	802.9 ISDN	Data Link
	MAC	MAC	MAC	MAC	MAC	
	PHY	PHY	PHY	PHY	PHY	Physical

one continues to wait for the better solution, no solution will ever be implemented.

It is essential to also realize that there are a variety of competing forces in the standards development world—each with their own "agenda" (hidden or unhidden). The result is often a "less than perfect" compromise. It is often said that the two things you really do not want to watch being made (if you're going to be involved with them) are sausages and computer network standards.

Overview of IEEE 802 Standards

The IEEE 802 standards essentially address only the two lower layers of the Open Systems (OSI) Reference Model.

The Physical Layer corresponds to the OSI Physical Layer, while the OSI Data Link Layer is divided into two "sublayers": Medium Access Control (MAC) and Logical Link Control (LLC). The MAC sublayer addresses the specific procedural issues associated with distributed arbitration of channel access.

The LLC sublayer provides a mechanism accommodating those functions of wide area network Data Link protocols that pertain to LAN management. Unlike the wide-area Data Link protocols such as High-level Data Link Control (HDLC), which address specific nodes, LLC protocol data units only contain service access points or internal memory addresses of software entities. Physical node addresses and error-detection are handled by the MAC sublayer.

There are four basic access methods defined, as well as a subset of higher Data Link Layer functions. In addition, there are several working groups whose activities are focused on specific technologies which are applicable across a broad range of the access methods.

The Carrier Sense Multiple Access with Collision Detection (CSMA/CD) method was the first to be developed by the IEEE, and was modeled after the Digital/Intel/Xerox (DIX) Ethernet. While many people refer to the 802.3 specification as "Ethernet," the two are not really compatible. There are a number of differences in the Physical and Medium Access implementations, but these have usually been resolved through "interface agreements" and special-purpose bridges. Since it is more difficult to change tradition than to accept it, we will continue to use the terms Ethernet and IEEE 802.3 interchangeably. Table 1 defines the differences between Ethernet and IEEE 802.3 implementations.

The 802.4 specifications were developed primarily in response to requirements for the "deterministic performance" of token-passing, coupled with the facility of bus-oriented cabling. The employment of broadband technology provided the additional benefits of increased bandwidth, geographic coverage, and numbers of terminations.

The 802.5 token-ring specification was developed under the "guidance" of IBM, and reflected the emerging "blue" perspective on local area networking. While the initial versions of the network provided less capacity than

Table 1. Ethernet/IEEE 802.3 Differences

Feature	Ethernet Version 1	Ethernet Version 2	IEEE 802.3
Specification	1980 Blue Book	1982 Blue Book	1983, 1985
Transceiver Cable	3 pairs AWG 22	4 pairs AWG 20	4 pairs AWG 20
Grounding at Host	Inner/outer shield common at backshell & pin 1	Same as Version 1	Inner shield to backshell; outer to pin 4
Electrical Signal	0 v to negative	+ & - signal	+ & - signal
Signal Quality Error (SQE)	None; no heartbeat	Yes; heartbeat	Yes; heartbeat
Repeater Specification	None	None	Multiple collision protection
Jabber Control	None	Yes	Yes
Type/Length Field	Type (>1500)	Type (>1500)	Length (<1500)
Coaxial Cable	50Ω Double shield	Same	Same

Figure 2.
IEEE Standards Variations

802.2 Logical Link Control –	Type 1 Connectionless
	Type 2 Connection Oriented
	Type 3 ACK'ed Connectionless

There are variations within each of the IEEE 802 standards.

802.3 CSMA/CD		802.4 Token-Bus		802.5 Token-Ring	802.6 Metropolitan Area Network
Base-band	Broad-band	Broad-band	Carrier Band	Baseband	DQDB 155M bps

802.3 CSMA/CD (Broadband):
Single Cable
Dual Cable

"Ethernet" 10M bps
"Cheapernet" 10M bps
Starlan 1M bps
Twisted Pair 10BASE-T

802.4 Token-Bus (Carrier Band):
1M bps
5M bps
10M bps

802.4 Token-Bus (Broadband):
5M bps
10M bps

802.5 Token-Ring:
1M bps
4M bps
16M bps

Figure 3.
10BASE5 Termination Hardware

The 10BASE5 version of IEEE 802.3 uses thick Ethernet coaxial cable and various termination hardware.

Ethernet, the expected improvements associated with deterministic performance and priority mechanisms yielded other benefits.

Over time, however, we have seen a wide variety of implementations emerge—each reflecting specific vendor's "better ideas." Some of these have been standardized, while others will likely become standards in the near future.

The chairman of the 802.3 working group, Don Loughry, spoke at an Interface Conference session with this author, and remarked that the "nice thing about standards is that you have so many to choose from." While this is certainly humorous, and may evoke some concern for the viability of so many variations, it does in fact insure that there will be a standard implementation to meet most user requirement scenarios.

With this backdrop, we will explore the specific 802 LAN standards.

IEEE 802.3 (CSMA/CD)

IEEE 802.3 standards are characterized by a shorthand notation which facilitates their description in as few words as possible. The notation is composed of three elements:
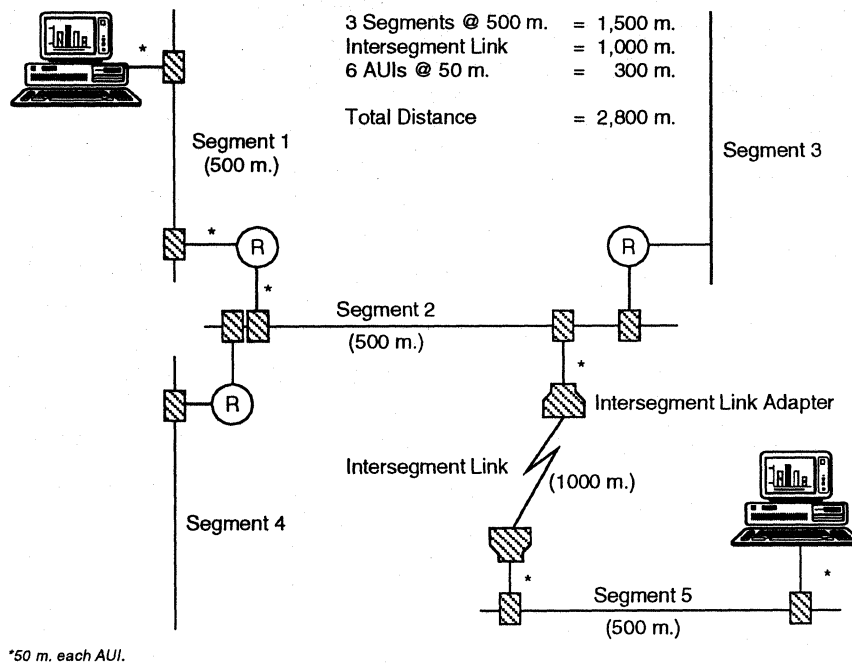
1. Megabits per second divided by 10^6

2. Baseband or Broadband

3. Meters per segment divided by 100

10BASE5

Thus, 10BASE5 means 10M bps, baseband, 500-meter segments. This was the first version of the specification to be developed, and most closely resembled the earlier Version 1 & 2 Ethernets (1980 & 1982 respectively). The 10BASE5 LAN employed the "thick Ethernet," 50-ohm coaxial cable. While this cable was difficult and relatively expensive to install, it provided significant advantages over other implementations in terms of distance and the number of terminations permitted for each segment.

Figure 4.
Multisegment CSMA/CD LAN

For a multisegment 802.3 LAN, the maximum distances between segments can vary; however, the maximum distance between any two communicating stations is limited to 3,000 meters.

3 Segments @ 500 m.	= 1,500 m.
Intersegment Link	= 1,000 m.
6 AUIs @ 50 m.	= 300 m.
Total Distance	= 2,800 m.

Segment 1 (500 m.)

Segment 3

Segment 2 (500 m.)

Intersegment Link Adapter

Intersegment Link (1000 m.)

Segment 4

Segment 5 (500 m.)

50 m. each AUI.

The workstation contained an adapter board called the "bus controller" in Ethernet parlance. Attached to the bus controller was a multiconductor cable known as the Attachment Unit Interface (AUI) cable. This was in turn connected to a transceiver/tap assembly called the Medium Attachment Unit (MAU) which was connected to the Ethernet trunk cable employing a "vampire" tap.

When Ethernet products were first developed, this assemblage of components normally cost $1,500 to $2,000. Since LAN implementations are very sensitive to workstation termination costs, less expensive alternatives were required. This problem was resolved in two ways. First, vendors developed less expensive implementations (the old "better way" trick), which we will explore in a moment, and second, the natural momentum in declining semiconductor costs reduced these implementations to a fraction of their former selves.

Due to the sensitive timing issues associated with the performance of the CSMA/CD protocols, limits were imposed upon the overall length of a multisegment LAN, as well as the maximum signaling rate. A typical large-scale CSMA/CD LAN is limited to a distance of 2,800 meters between any two communicating stations. This is often implemented by using three 500-meter segments and a 1,000-meter intersegment link. An important distinction between a link and a segment should be noted. Segments may have workstations attached, while links are simply media used to extend the overall distance of the LAN.

Figure 4 illustrates a 10BASE5 LAN with the maximum distance between two workstations. Other constraints associated with 10BASE5 LANs concern the number of devices that can be terminated on the trunk cable. Up to 100 devices can be placed on a 500-meter segment, with a maximum of 1,024 devices on the entire network. This limitation can be circumvented through the use of bridges, which partition a LAN into several connected, but independent LANs—thus yielding the maximum length and number of workstations for each.

10BASE2

10BASE2 (also known as "thin Ethernet" or "cheapernet") employs a thin flexible coaxial cable (RG-58) which connects to the adapter board in the workstation by means of a BNC "T" connector. In earlier implementations, the transceiver functions were "on-board," but in the interests of using the bus controller for either implementation, a variety of MAUs and bus controllers has been developed which provides options for both 10BASE5 "vampire" taps, attachment unit interface cables, and 10BASE2 BNC connectors.

The standard 10BASE2 LAN can only support 30 terminations on each coaxial cable segment of 185 meters. While this may seem like a major constraint, it is often adequate for most moderate workarea environments. Where a requirement exists for interconnecting multiple workareas, or workareas with multiple 10BASE2 segments, a backbone 10BASE5 segment can be employed to provide intersegment connectivity. Figure 5 illustrates this type of configuration.
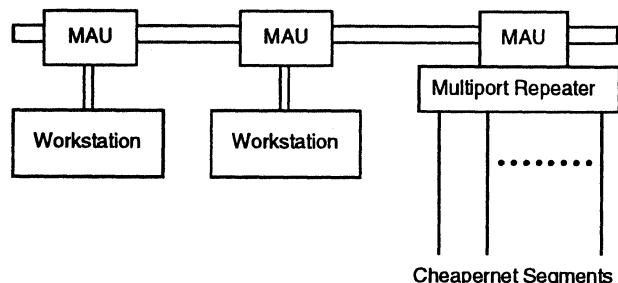
1BASE5

This standard option was designed by AT&T to accommodate its earlier Starlan products. It operates at 1M bps and as such is often most useful for small workareas or low traffic environments. 1BASE5 also employs inexpensive twisted-pair interconnected through a hierarchical system of concentrator hubs. The hubs emulate a bus configuration by broadcasting all data and collision information on all ports.

10BASE-T

One of the most exciting developments on the local network scene has been the development of the 10M bps unshielded twisted-pair (UTP) Ethernet. Some well-known products claiming compliance with this standard are Synoptics' LattisNet and AT&T's Starlan 10. It is important to note that these implementations are limited to approximately 100-meter segments due to the greater attenuation and signaling difficulties of twisted-pair. This should not present any unusual problems since these networks can be

Figure 5.
10BASE5/10BASE2 Interconnectivity

Cheapernet Segments

In environments with multiple workareas, or workareas
with multiple 10BASE2 LAN segments, a backbone
10BASE5 segment can be used to provide intersegment
connectivity.

concatenated and interconnected with 10BASE2 and 10BASE5 implementations.

It is imperative however, that organizations planning these networks have their existing twisted-pair certified for both attenuation and capacitance before making any assumptions on its salvagability. Like other star-wired LANs, these systems use concentrators to interconnect multiple stations and emulate the bus operation.

10BROAD36

The 10BROAD36 implementation uses much of the same hardware as the baseband implementations. The essential difference is the substitution of a broadband electronics unit and a passive broadband tap for the baseband MAU. This enables an organization to use its existing bus controller boards in the workstations for connection to either a baseband or broadband system. The primary functions of the broadband electronics unit are to create the frequency derived channels of 14MHz for data and 4MHz for collision consensus. It also converts the signals from the baseband coded signal of the AUI to the analog signal necessary on the broadband channel.

Workstations can be placed up to 1,800 m. from the "head-end" of the broadband cable plant. By placing the head-end in the center of the configuration, workstations can be installed up to 3,600 meters from each other.

IEEE 802.3 Status

Within the IEEE 802.3 group, the following standards have been completed as of this date:

- 10BASE5
- 10BASE2
- 10BASE-T
- 10BROAD36
- 1BASE5
- 10BASE5 Repeater Specifications
- Layer Management Supplement

IEEE 802.4 (Token Bus)

The 802.4 Token Bus specification has been adopted by ISO as 8802-4 International Standard. Although the initial broadband implementations of the token bus appeared to be highly flexible and desirable in terms of the generic manufacturing requirements, a number of difficulties have

arisen. First, the industry is finding that migration from the early versions of the Manufacturing Automation Protocol suite (Version 2.x) to current specifications (Version 3.0) is less than facile. It has become a manager's nightmare for any number of reasons.

For instance, fewer and fewer people are interested in broadband implementations primarily due to the difficulty in design, installation, and maintenance. Additionally, the apparent benefits of broadband networks in terms of the number of terminations, geographic range, and bandwidth, have been overtaken and negated by the introduction of medium access control bridges which provide even greater capabilities—nearly transparently. These bridges enable an organization to increase the traffic loading by simply partitioning the network and eliminating the concern. Couple these high-risk implementation issues with the scarcity of products, difficulty in migration from MAP 2.x to 3.0, and soft industry support, and one will find that the token bus presents a quagmire of implementation risks that most managers would rather avoid.

There is some hope on the horizon for the medium access specification. Other physical medium specifications are being developed for both optical fiber and wireless approaches. Some difficulties lie ahead here since the dominant fiber specification in the U.S. is the 62.5-um. fiber specified by ANSI for the Fiber Distributed Data Interface, while in Japan and Europe, 50-um. fiber is a more common implementation. In the final versions of this standard, both options may be permitted.

The 802.4 Token Bus architecture has matured despite the uncertainties presented by the MAP protocol suite. Standards for medium access control, broadband media, carrier band media, and optical fiber have been completed. Open projects include conformance testing, wireless (through the air) media, redundant media, twisted-pair, and the potential for new and revised medium access control.

IEEE 802.5 (Token-Ring)

The token-ring implementation which has received so much attention since it was first approved in 1985 has undergone a variety of changes and modifications over the past seven years.

Media Issues

The initial version of token-ring was a 4M bps implementation which ran on shielded twisted-pair (STP). The issues surrounding shielded twisted-pair have always been controversial. Telephony carriers avoid shielded wire to the extent possible since the shielding introduces capacitance changes and ultimately increases attenuation, thus requiring more frequent repeater placement. The LAN proponents, such as IBM, feel differently. They contend that the shielding protects the media from unwanted EMI/RFI and that the distance between repeaters is not an issue since each station is its own repeater.

Considering the context of their respective positions, both contenders are correct. In the case of LANs, the shielding does buy some value. One thing we can be sure of, though, is that were there is a requirement, someone will stand up to fill the niche. Thus, when IBM introduced the 16M bps ring, running only on shielded wire, it was not surprising that other vendors immediately introduced unshielded 16M bps implementations. In fact, the IEEE 802.5 working group has introduced a set of guidelines for using unshielded twisted-pair. Considering the work that

Table 2. 802.3 10BASE5/10BASE2 Differences

Feature	10BASE5	10BASE2
Name	802.3 "Ethernet"	Cheapernet, thin or thinwire Ethernet
Type of Cable	50Ω thick dual shield	50Ω RG-58
Maximum Segment Length	500 meters	185 meters
Spacing of Devices on Cable	2.5 meters minimum	0.5 meters minimum
Maximum Number of Taps for a Segment	100	30
Maximum Number of Full Repeaters in a Path Between Two Stations	2	2
Type of Taps	Vampire	BNC "T" connector for "daisy chaining"

the Electronic Industries Association (EIA) has done concerning intrabuilding wiring, it is likely that their specifications for unshielded wire will be candidates for the 16M bps ring.

Other media related issues that have been explored by the 802.5 group are the use of Optical Fiber Station Attachment equipment and redundant media for backup. The latter has yielded a specification for "Dual Ring Operation with Wrap-back Configuration." This technique is similar to that used in the ANSI FDDI dual ring.

Token-Passing and Multi-Ring Protocol Issues

With the 16M bps ring, IBM introduced a version of the token-passing protocol called Early Token Release (ETR). ETR makes more efficient use of the available bandwidth on physically large rings operating with particularly small packets. In earlier versions of the token-passing protocol, a new free token could not be released by the sending station until it recognized the address in its own packet coming back around the ring to itself. If the packet was small, and the ring was large, there was a great deal of wasted "time" on the medium. Using ETR, a sending station can release the free token immediately upon completing its transmission. The empty time slots on the ring can now be used by other parties. When coupled with the 16M bps ring, this new protocol appears to have significant advantages in terms of performance.

Another area of interest in the token-passing world is the controversy on medium access control bridges. While the Ethernet proponents prefer a minimum spanning tree approach, many token-ring developers prefer source routing bridges. These approaches have been evaluated by both the 802.3 and 802.5 committees. The IEEE has adopted spanning tree bridges as the 802.1D standard, but permits source routing bridges provided the two bridges can interoperate.

IEEE 802.5 Status

Presently, the following completed standards are available from the 802.5 working group:

- ANSI/IEEE 802.5 Token-Passing Ring (1989)
- 802.5A Station Management Functions Revision
- 802.5B Unshielded Twisted-Pair
- 802.5C Reconfiguring Dual Ring Specifications (Redundant Media)
- 802.5E Management Entity Specification
- 802.5F 16M bps Operation
- 802.5H Acknowledged Connectionless Logical Link Control
- 802.5I Early Token Release

The list of ongoing open projects includes:

- 802.5D Multi-Ring Configurations
- 802.5G Conformance Testing
- 802.5J Optical Fiber Station Attachment

LAN Interconnection

As LANs proliferate, it is becoming more important that standard techniques for interconnection be adopted.

IEEE 802.3 Physical Layer Relays

In the case of the IEEE 802.3 CSMA/CD LANs, intra-LAN segment connection standards are well developed and mature. These physical layer relays are implemented as repeaters which regenerate the signals from one segment for retransmission to the next. The unique aspect of these repeaters is that they must be able to retransmit collisions as well as data frames. Unlike Data Link Layer relays (or source routing or MAC bridges), repeaters are not addressable. Since all segments are part of a unified LAN, the nature of the shared channel must be preserved by broadcasting all information to all terminated devices.

The latest specifications for repeaters are contained in the IEEE 802.3C supplement (1992). Unlike the earlier version of this supplement (1989), this specification provides rich detail on coaxial cable, AUI, and optical fiber repeater interfaces. It is important to note that these repeater specifications pertain only to the 10BASE5 and 10BASE2 implementations. Other repeaters for 1BASE5, 10BASE-T, and 10BROAD36 are beyond the scope of this specification.

In addition to the functions described above, repeaters as specified in the 802.3C supplement provide "collision isolation" between segments. Thus, if conditions on a given segment are causing the extensive proliferation of collisions, the rest of the LAN can be protected from this anomaly. The repeater will count the number of collisions from the source segment, and isolate it from the next segment until it is stabilized.

IEEE 802.4 Physical Layer Relay

The issues of signal attenuation in a broadband LAN are normally resolved in two ways. First, the maximum placement of a device from the head-end provides a maximum bound on signal loss in the context of attenuation. Second, since many stations may be connected to the bus, each resulting in a specific "insertion loss," amplifiers are often required to assure that the total loss does not exceed specifications.

Figure 6.
10BROAD36 Model
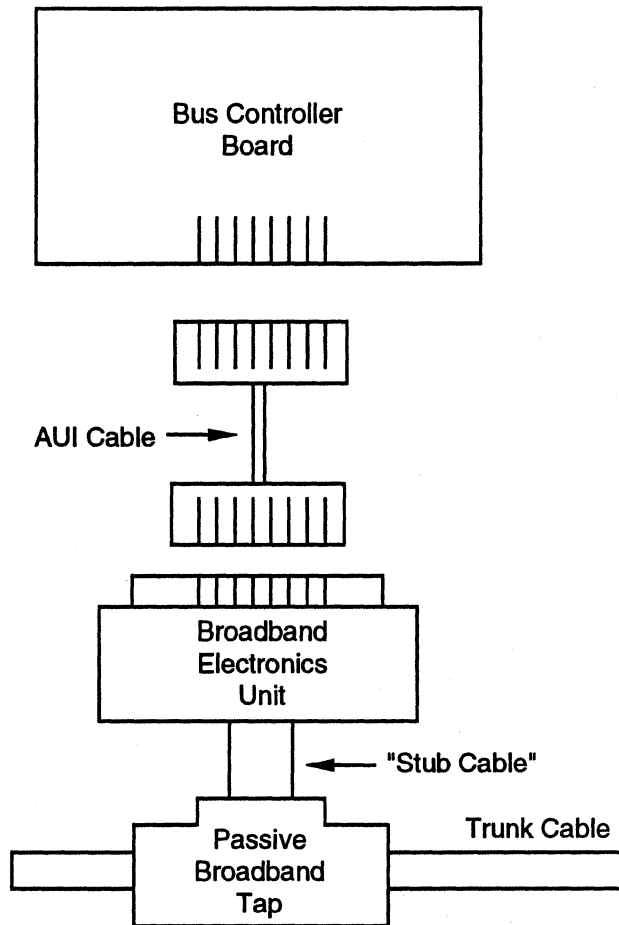
A 10BROAD36 broadband 802.3 implementation uses
much of the same hardware as baseband 802.3 LANs.

The IEEE 802.4 broadband bus specification defines a
"Regenerative Repeater Machine" (RRM) as an optional
component which is present only in special "repeater" sta-
tions such as the "head-end." Since broadband systems are
analog, amplifiers are usually required to boost signal
strength. Regenerative repeaters actually recreate a new
signal in accordance with the amplitude and timing speci-
fications for the original signal.

A regenerative repeater is also defined for the single-
channel carrierband system. Since the latter is not a multi-
channel broadband bus (a medium supporting multiple
frequency-derived channels such as Community Antenna
TeleVision—CATV), a head-end is not required to facili-
tate this function. Physical placement of these devices is a
function of the number and placement of user devices on
the network. There are no explicit maximum terminations
defined in the specification, but the standard suggests that
30 may be an appropriate user limitation.

IEEE 802.5 Physical Layer Relays

The nature of a token-passing ring obviates the necessity
for repeaters, since each station's ring interface performs
repeater functions. The maximum attenuation of a signal
is thus guaranteed by limiting the distance between any

two devices in the ring. As with 802.3, the issues of overall
length of the ring impact protocol performance as opposed
to signal attenuation.

Data Link Layer Relays

Interconnection of similar but separate LANs has resulted
in the need for specifications on Medium Access Control
bridges. MAC bridges are hardware/software implementa-
tions that are limited to resolving the MAC sublayer differ-
ences between two or more interconnected LANs. No fur-
ther higher layer protocol intervention is required, and
they are often transparent to the user in terms of delay and
performance.

MAC bridge specifications have been addressed by the
IEEE 802 working groups. The 802.3 and 802.5 teams
have developed two significantly different approaches, but
even these will interoperate.

The current approaches are the Minimum Spanning
Tree for bus implementations, and the Source Routing
bridge, or "Brouter" as it has come to be known, for inter-
connected rings. The essential difference between the two
lies in that in the bus environment, only one path between
any two devices exists. The bridges learn the LAN segment
and node addresses and filter packets accordingly as re-
quired. Provision for multiple alternative paths is pro-
vided in the interconnected ring environment which in
turn yields a requirement for a routing protocol. This rout-
ing protocol is facilitated by adding "routing information"
(RI) fields to the packet header. The RI field contains all of
the source node routing information necessary for the
bridge to determine which path is to be adopted for a spe-
cific packet.

There are certainly advantages and disadvantages to
both of these approaches, but the common goals are to pro-
vide global, transparent interconnection. Global in the
sense that any device on any LAN can share resources with
any device on any other LAN; transparent in the sense that
performance must be adequate to assure that access to re-
mote resources is provided rapidly and accurately. This
guarantees that users do not perceive a difference between
local and global objects.

IEEE 802.2 (Logical Link Control)

The IEEE 802.2 Logical Link Control (LLC) specifications
include those Data Link Layer functions that are common
to all 802 LAN MAC sublayer alternatives. Three basic
service types are provided:

Type 1 (Connectionless): This service provides a "best
efforts" delivery mechanism between the origin and desti-
nation nodes. No call or logical circuit establishment pro-
cedures are invoked. Each packet is treated as an indepen-
dent entity by the network. There are no flow control nor
acknowledgment mechanisms. If the packet arrives at the
destination, all well and good. If not, it is the responsibility
of the higher-layer protocols to resolve the problem
through time-outs and retransmissions.

Type 2 (Connection-Oriented): Like many wide area net-
work protocols, this service requires that a logical circuit
or call be established for the duration of the exchange be-
tween the origin and destination nodes. Packets usually
travel in sequence and are not routed as independent enti-
ties. Positive acknowledgments and flow control mecha-
nisms are an integral part of this service.

Table 3. Logical Link Control Alternatives

Service	Type 1	Type 2	Type 3
Basic Service	Connectionless	Connection	ACKed connectionless
Acknowledgments	No	Yes	Yes
Error Recovery	No	Yes	Yes
Flow Control	No	Yes	No

Type 3 (ACKed Connectionless): No circuit is established in this service variation, but acknowledgments are required from the destination node. This type of service adds additional reliability to Type 1, but without the potentially excessive overhead of Type 2.

Specific LAN types lend themselves to different types of service. These services are generally combined in "service classes" which are oriented to different operating environments. Table 3 illustrates the LLC variations as they apply to the different MAC implementations.

IEEE 802.6 (Metropolitan Area Network)

The IEEE 802.6 MAN is a fourth MAC alternative that is intended to cover a greater geographic area than the conventional LAN. Earlier plans called for this to be a CATV network, while later proposals focused upon a high-speed slotted ring. The specification that was finally adopted is called the "Distributed Queue Dual Bus" (DQDB). It has been developed under the auspices of the Australian Postal Telephone and Telegraph (PTT) or "Telecom Australia."

The DQDB is characterized by its very high transmission rates of up to 155M bps, rapid access mechanisms, and preallocated time slots for isochronous (time critical) traffic. This makes the 802.6 MAN an ideal candidate for digitized voice or video traffic. It has been designed to support 512 nodes over a distance of 160 kilometers, but all of these design metrics can be extended considerably. It is primarily used for interconnection of LANs and to support high-density "bit-mapped" traffic such as graphics or imagery. The DQDB is also important in that it is the only 802 LAN that provides "direct" compatibility with high-speed switched data services as well as Broadband ISDN. (Note that the term "broadband" in this context denotes high-capacity digital services, as opposed to frequency division multiplexed analog CATV.)

As illustrated in Figure 7, the nodes in the DQDB network form a dual "open ring" where they turn on available request bits in fixed time slots that have data in them. When available slots appear on the other bus, they transmit after correlating their requests with the number of available slots. The correlation process is accomplished by observing the number of request bits that have been turned on prior to receiving an available request bit. As empty

slots appear, the request counter is decremented until there are no outstanding requests. The next empty slot is effectively scheduled for this node.

Other IEEE 802 Activities

The IEEE 802 committees have sponsored a number of other related activities. These projects are staffed by Technical Advisory Groups (TAGs). They are not developing different access methods, but rather guidelines and standards that can be applied "across the board" of MAC implementations.

IEEE 802.7 (Broadband TAG): This group has developed a standard specification that deals with the Physical Layer issues of broadband LANs. Topics covered include frequency allocations, design guidelines, and installation procedures and methodology. These issues apply to both the 10BROAD36 CSMA/CD and the 802.4 token-passing bus.

IEEE 802.8 (Fiber Optic TAG): This working group is responsible for defining fiber types, installation issues, connectors, and tapping and splicing procedures. The guidelines developed by this TAG are applicable to each of the MAC implementations. This TAG also coordinates its activities with the EIA-568 Intra-building Wiring Committee.
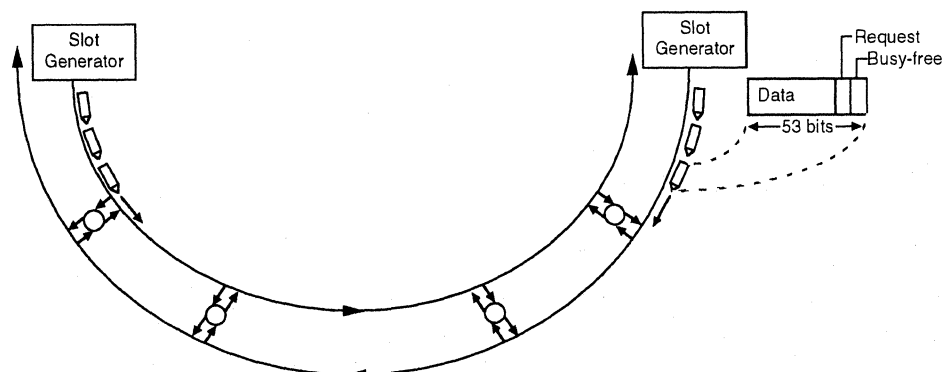
IEEE 802.9 (Integrated Voice/Data): The IVD TAG actively addresses the myriad issues faced in interconnection of LANs via ISDN networks, as well as the requirements to provide for voice transmission in the LAN environment itself.

IEEE 802.10 (Security and Privacy TAG): This working group is responsible for developing guidelines for security and privacy mechanisms in LAN environments. They interface with other industry working groups.

IEEE 802.11 (Wireless Access Method and Physical Layer Specifications): This working group is developing standards for wireless LANs and has been considering the following:

Figure 7.
IEEE 802.6 MAN Distributed Queue Dual Bus (DQDB)

The nodes in the DQDB network form a dual "open ring."

- Infrared transmission (line of sight)
- Power-grid transmission (over power lines)
- Spread spectrum transmission (code division multiplexing)
- Microwave transmission (at high frequencies, e.g., 18GHz)

ANSI Fiber Distributed Data Interface (FDDI)

The FDDI network is a 100M bps token-passing ring that was developed by the American National Standards Institute (ANSI). It has been adopted as an ISO standard 9314. While it is not an IEEE 802 LAN, it has many similarities. The Data Link Layer is divided into two sublayers, the upper half of which is the 802 Logical Link Control. The lower half, FDDI MAC, is very similar to the 16M bps IEEE 802.5 token-ring.

Like the IEEE 802.6 MAN, it is designed to interconnect LANs over a wider geographic area; however, current versions do not provide the guarantees necessary for isochronous service. There are a number of wiring rules associated with the FDDI ring. Some of these are based on limitations imposed upon us by the laws of physics, while others are related to performance issues.

Limitations associated with physics include:

- Maximum of 2 kilometers between active nodes, due to attenuation
- Maximum of three bypassed nodes, due to attenuation
- Maximum of 4500-byte packet size, due to clock skew

Performance limitations include:

- Maximum of 500 attached nodes, due to token seizure delays
- Maximum of 100 meters in overall length due to token rotational delay

As with the 802.6 MAN, these performance limitations are baseline criteria—not absolute limits.

The FDDI ring is similar to the token-ring in that it uses a similar frame structure, supports the 48-bit addresses of the IEEE specifications, and uses the same 32-bit cyclic redundancy check (CRC). The same hardware acknowledgment bits used in the 802 token-passing ring are also employed in the FDDI ring, while control is completely distributed as it is in the 802.4 token-passing bus. As in the case of the 16M bps token-ring, the token is released immediately after transmitting (Early Token Release).

Physical layer issues associated with light-emitting diodes on multimode optical fiber require that a unique coding scheme 4B/5B be used. For every four bits of information, five bits must be transmitted. This results in 125M bps for a 100M bps ring.

The FDDI ring employs a dual ring structure which provides a "wrap-back" in the event of a break in the ring. This is similar to the "self healing" reconfiguring token-ring.

Emerging Developments in FDDI

At the present time, FDDI implementations are being developed to operate on shielded twisted-pair. This is envisioned as a "drop" medium from the wiring closet to the

workarea. While shielded twisted-pair is currently less expensive than fiber, distances will be limited. Others are experimenting with unshielded twisted-pair for the same application. These implementations are called TPDDI (twisted-pair DDI) and CDDI (copper DDI).

A new version of FDDI is being developed. FDDI II is designed to support isochronous communications providing guaranteed transmission capabilities for applications such as digitized speech. The same technology will also support compressed video. It is not clear at the moment how this apparent overlap with the IEEE 802.6 DQDB MAN will be resolved. As we quoted earlier, "The nice thing about standards is you have so many to choose from."

Synchronous Optical Network (SONET)

SONET is a major development that will ultimately provide a 100% digital fiber transport network. While by no means a LAN, SONET will provide us with LAN interconnection capabilities that will outperform anything on the market today. Unfortunately, our best projections for SONET do not show any significant penetration before 1994—at best. SONET standards have been defined in three phases.

SONET Phase I: This phase of SONET was released in 1988. It defined the optical interfaces; data rates from T1 (1.544M bps) to OC-48 (2.5G bps); as well as channel allocations, basic features, and overhead.

SONET Phase II: This phase of the SONET standard included a number of new elements.

- Electrical interface
- Additional payload mapping
- Optical parameters and specifications
- Maintenance functions
- Data communications functions
- Generic message structures
- Equipment specifications

SONET Phase III: Released in 1990, this phase of the standards defined specific message sets for different operating scenarios.

Before deploying SONET, a thorough analysis must be performed to determine precisely what expected benefits may accrue. A variety of issues ranging from carrier deployment schedules to harmonization with companies' strategies will all influence this decision. It is important to recognize that SONET is going to be there, but because of its elusive nature, it is best not to couple it too tightly to organizational objectives.

Summary

The status of LAN standards is ever changing. From the early days of proprietary implementations and pioneering standards development, we have now reached a point where numerous standards bodies are building upon each other's work.

The IEEE 802 LAN standards have evolved and matured significantly since their development in the early 1980s. It is essential that we do not view this maturation process as at an end. They will continue to evolve, and as

new technologies and requirements develop, new standards will follow. The utopian environment would be for standards development to lead product development, but it is unrealistic to believe that in an environment as volatile as local area networking, vendors will wait patiently while users clamor for more and better products.

The IEEE will be faced with a continuing challenge to assure that as new requirements and products evolve, the standards also evolve. This challenge will also be coupled with a requirement that migration from prior implementations is as painless as possible—both in terms of development risk and cost. ■

This report was prepared exclusively for Datapro by Michael L. Rothberg. Mr. Rothberg is president of Applied Network Solutions, Inc., a Somerset, NJ, firm specializing in designing, developing, and implementing local and wide area computer networks for government and commercial clients and providing market and product planning services for communications suppliers.

Prior to founding the company in 1981, Mr. Rothberg was a vice president of the Chase Manhattan Bank, NA, where he pioneered the application of digitized speech and local networking technology to support banking applications. He is a frequent contributor to trade publications and is a Datapro advisor.

IEEE 802 Standards for Local Area Networking

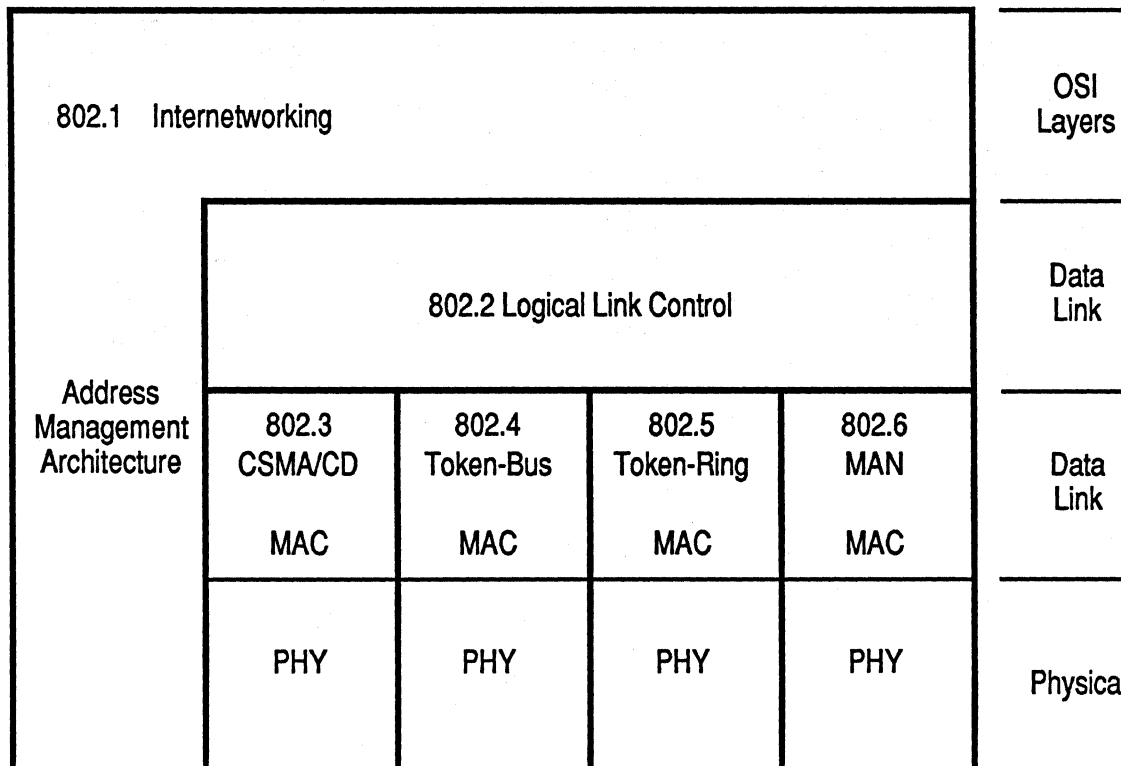## In this report:

Synopsis

Editor's Note

The local area network market is one of the fastest-growing segments of the computer and communications industry. Developing standards have helped to fuel the growth of this market. The IEEE 802 standards body is chartered to define the standards for local area networking, and this report provides an overview of the IEEE 802 LAN standards, some of which are not yet final.

Report Highlights

The Institute of Electrical and Electronics Engineers (IEEE) began Project 802 in February 1980 in an attempt to establish standards in advance of the local area network (LAN) market. The IEEE 802 Committee has defined interface and protocol specifications for logical link control and access methods for various LAN topologies. The project has maintained an open-door policy, and from 20 to 300 people have participated in any one working group. Most of the participants work for a computer or network components vendor, and many have a communications or marketing background.

Since the project's commencement, it has been under intense scrutiny by the computer industry, because the resulting set of standards has—and will continue to have—a significant impact on the growing LAN market. This report will help you to understand the IEEE/ISO LAN standards; compare the differences among the various options and alternatives; recognize how the standards evolved from inception to the present; and understand standard approaches to interconnecting LANs.

Figure 1.
IEEE Project 802 Working Groups

					OSI Layers
802.1 Internetworking					
Address Management Architecture	**802.2 Logical Link Control**				Data Link
	802.3 CSMA/CD **MAC**	**802.4 Token-Bus** **MAC**	**802.5 Token-Ring** **MAC**	**802.6 MAN** **MAC**	Data Link
	PHY	**PHY**	**PHY**	**PHY**	Physical

The IEEE 802 standards address the two lower layers (Physical, Data Link) of the OSI Reference Model.

Introduction (A Little History)

During the mid-to-late 1970s, a small company in Texas developed a capability to provide access to shared direct access storage devices (DASDs) from microprocessor workstations located within a reasonable distance from the DASD. The company was Datapoint Corp. and the technology was Arcnet—Attached Resource Computer Network. At about the same time, Xerox Corp. was developing its experimental Ethernet. These were the first local area networks (LANs) to be offered as commercial products.

In the 1980s, with the near demise of Datapoint, and Xerox' alliance with Digital and Intel, the IEEE had little choice when it adopted an "Ethernet-like" approach for its local network standard. Other organizations such as General Motors and IBM had their own ideas about what the "ideal" LAN should look like. The result was a family of LAN standards to be known as the IEEE Project 802 LAN standards.

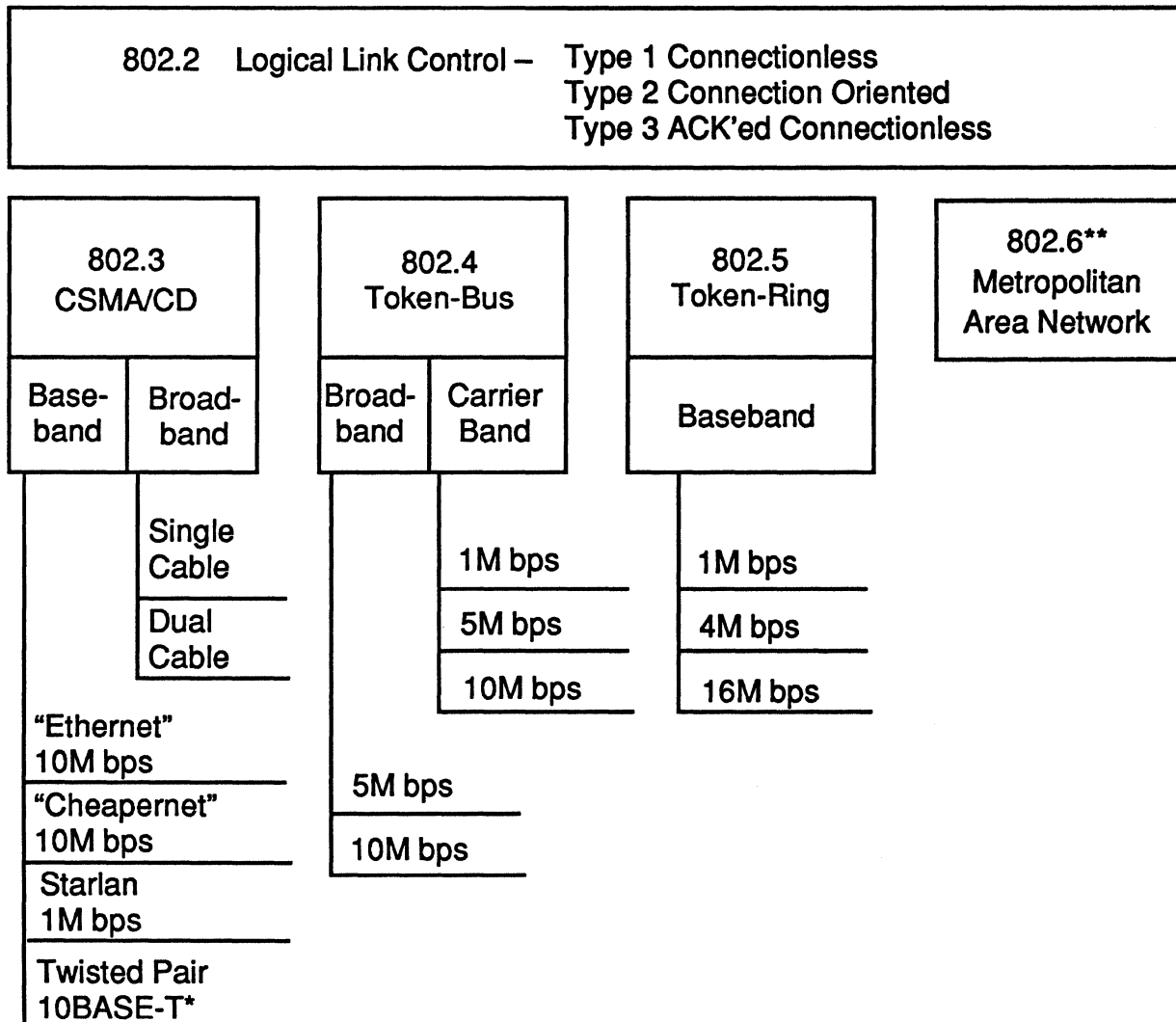Despite these developments, Arcnet did not disappear. Vendors that had acquired the licenses continued to make Arcnet interfaces, but now focused on the PC as the workstation. Arcnet continues to enjoy a useful life as a mature and highly functional proprietary LAN implementation.

With the ever-increasing popularity of LANs, new requirements have developed for higher speed networks of greater geographic range. In response, vendors have developed alternatives to the standard implementations, and standards bodies such as ANSI have produced the Fiber Distributed Data Interface (FDDI), among others.

The bottom line is that while there are currently a fair number of standard LAN implementations, there are also proprietary implementations from leading vendors, which, while not "standard," may suit one's needs very well. As long as technology continues to improve, entrepreneurs will continue to come up with "better ways." Some of these better ways will fade quickly after initial flurries of excitement, while others will pave the way for new and better standards.

Figure 2.
IEEE Standards Variations

802.2 Logical Link Control –	Type 1 Connectionless
	Type 2 Connection Oriented
	Type 3 ACK'ed Connectionless

802.3 CSMA/CD		802.4 Token-Bus		802.5 Token-Ring	802.6** Metropolitan Area Network
Base-band	Broad-band	Broad-band	Carrier Band	Baseband	
	Single Cable		1M bps	1M bps	
	Dual Cable		5M bps	4M bps	
			10M bps	16M bps	
"Ethernet" 10M bps		5M bps			
"Cheapernet" 10M bps		10M bps			
Starlan 1M bps					
Twisted Pair 10BASE-T*					

*Imminent adoption expected.
**In process.

There are variations within each of the IEEE 802 standards.

Standards are not static, and the network architect must realize that there will always be a better solution tomorrow. Of course, if one continues to wait for the better solution, no solution will ever be implemented.

It is also essential to realize that a variety of forces competes in the standards development world—each with its own agenda (whether hidden or unhidden). The result is often a less than perfect compromise. It is often said that "the two things you really don't want to watch being made [if you're going to be involved with them] are sausages and computer network standards."

Overview of the IEEE 802 Standards

The IEEE 802 standards essentially address only the two lower layers of the Open Systems Interconnection (OSI) Reference Model.

The Physical Layer corresponds to the OSI Physical Layer, while the OSI Data Link Layer is divided into two sublayers: Medium Access Control (MAC) and Logical Link Control (LLC). The

Medium Access Control sublayer addresses the specific procedural issues associated with distributed arbitration of access to the channel. The Logical Link Control sublayer provides a mechanism accommodating those functions of wide area network Data Link protocols that pertain to LAN link management. Unlike the wide area Data Link protocols such as High-level Data Link Control (HDLC), which addresses specific nodes, LLC frames contain only service access points or internal memory addresses of software entities. Physical node addresses are handled by the MAC sublayer.

There are four basic access methods with published standards, as well as a subset of higher Data Link Layer functions. In addition, there are several working groups whose activities are focused on specific technologies which are applicable across a broad range of the access methods.

The carrier sense multiple access with collision detection (CSMA/CD) method was the first to be developed by the IEEE and was modeled after the Digital/Intel/Xerox (DIX) Ethernet. Although there are differences between the Ethernet and 802.3, manufacturers now typically produce hardware that can support both, so that effectively the two are compatible. Differences in the packet format are resolved in firmware for a particular implementation. We will continue to use the terms Ethernet and IEEE 802.3 interchangeably. Table 1 defines the differences between Ethernet and IEEE 802.3 implementations.

The 802.4 specifications were developed primarily in response to requirements for the deterministic performance of token passing, coupled with the facility of bus-oriented cabling. The use of broadband technology provided the additional benefits of increased bandwidth, geographic coverage, and numbers of terminations.

The 802.5 token-ring specification was developed under the "guidance" of IBM and reflected the emerging "blue" perspective on local area networking. While the initial versions of the network provided less capacity than Ethernet, the expected improvements due to deterministic performance and priority mechanisms yielded other benefits.

With time, however, we have seen a wide variety of implementations emerge—each reflecting a specific application arena. Some of these have been standardized, while others will likely become standards in the near future.

Figure 3.
10BASE5 Termination Hardware
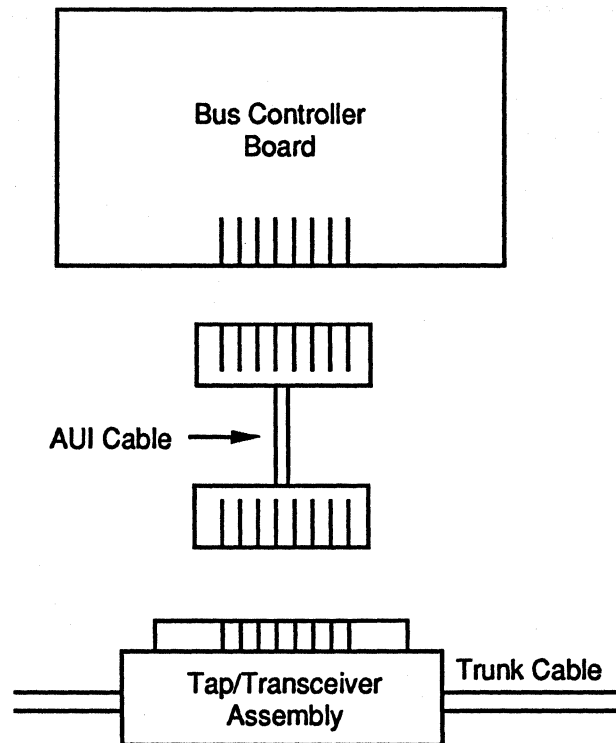
The 10BASE5 version of IEEE 802.3 uses thick Ethernet coaxial cable and various termination hardware.

Work began recently in several new technology areas including integrated voice and data (IEEE 802.9—IVD), security standards for interoperable LANs (IEEE 802.10—SILS), and wireless LANs (IEEE 802.11—WLAN). Preliminary work continues on the use of fiber optics by the Fiber Optic Technical Advisory Group (IEEE 802.8—FOTAG).

With this backdrop, we will explore the specific 802 LAN standards.

IEEE 802.3 (CSMA/CD)

IEEE 802.3 standards are characterized by a shorthand notation which facilitates their description in as few words as possible. The notation (e.g., 10BASE5) is composed of three elements:

- 10—megabits per second

- BASE—baseband (or BROAD for broadband)

- 5—meters per segment divided by 106

With standards adopted more recently, such as 10BASE-T, IEEE has tried to be more descriptive

Table 1. Ethernet/IEEE 802.3 Differences

Feature	Ethernet Version 2	IEEE 802.3
Specification	1982 Blue Book	1985, 1989
Transceiver cable	4 Pairs AWG 20	4 Pairs AWG 20
Grouding at host	Inner/Outer shield common at backshell & pin 1	Inner shield to pin 4; outer backshell
Signal Quality Error (SQE)	Yes, Heartbeat	Yes, Heartbeat
Repeater specification	None	Multiple collision protection
Jabber control	Yes	Yes
Type/length field	Type (>1500)	Length (<1500)
Coaxial cable	50-ohm Double shielded	50-ohm Double shielded

with its notation. For example, the "T" in the 10BASE-T standard is short for "twisted-pair wiring."

10BASE5

Using the formula, 10BASE5 means 10M bps, baseband, 500-meter segments. This was the first version of the specification to be developed, and it most closely resembled the earlier Ethernet Versions 1 and 2 (1980 and 1982, respectively). The 10BASE5 LAN employed the "thick Ethernet" 50-ohm coaxial cable. While this cable is difficult and relatively expensive to install, it provides significant advantages over other implementations in terms of distance and the number of terminations permitted for each segment.

The workstation contains an adapter board, called the "bus controller" in Ethernet parlance. Attached to the bus controller is a multiconductor cable known as the Attachment Unit Interface (AUI) cable. This, in turn, is connected to a transceiver/tap assembly called the Medium Attachment Unit (MAU), which is connected to the Ethernet trunk cable employing a "vampire" tap.

When Ethernet products were first developed, this assemblage of components normally cost $1,500 to $2,000. Since LAN implementations are very sensitive to workstation termination costs, less expensive alternatives were required. This problem was resolved in two ways. First, vendors developed less expensive implementations (the old "better way" trick), which we will explore in a moment; and second, the natural momentum in declining semiconductor costs reduced these implementations to a fraction of their former costs.

Due to the sensitive timing issues associated with the performance of the CSMA/CD protocols, limits were imposed upon the overall length of a multisegment LAN, as well as the maximum signaling rate. A typical large-scale CSMA/CD LAN is limited to a distance of 3,000 meters between any two communicating stations. This is often implemented by using three 500-meter segments, two 500-meter link segments, and up to ten 50-meter AUI cables. An important distinction between a link and a segment should be noted. Segments can have workstations attached, while links are simply media used to extend the overall distance of the LAN.

Figure 4 illustrates a 10BASE5 LAN with the maximum distance between two workstations. Other constraints associated with 10BASE5 LANs concern the number of devices that can be terminated on the trunk cable. Up to 100 devices can be placed on a 500-meter segment, with a maximum of 1,024 devices on the entire network. This limitation can be circumvented through the use of bridges, which partition a LAN into several connected, but independent LANs—thus yielding the maximum length and number of workstations for each.

10BASE2

10BASE2 (also known as "thin Ethernet or "Cheapernet") employs a thin flexible coaxial cable (RG-58) that connects to the bus controller board in the workstation by means of a BNC "T" connector. In earlier implementations, the transceiver functions were onboard, but in the interests

Figure 4.
Multisegment CSMA/CD LAN

3 Segments @ 500 m.	= 1,500 m.
Intersegment Link	= 1,000 m.
6 AUIs @ 50 m.	= 300 m.
Total Distance	= 2,800 m.
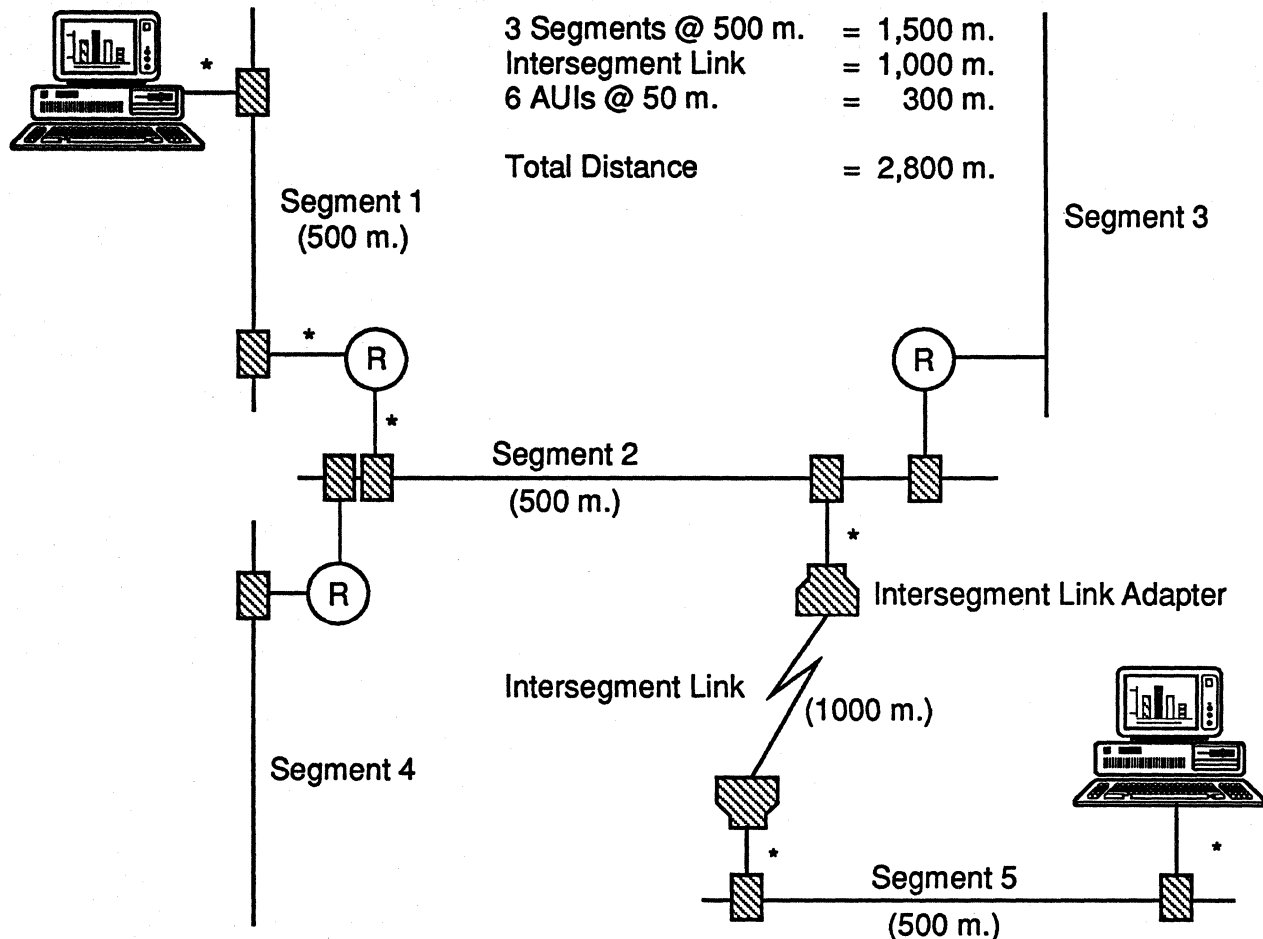
*50 m. each AUI.

For a multisegment 802.3 LAN, the maximum distances between segments can vary; however, the maximum distance between any two communicating stations is limited to 3,000 meters.

of using the bus controller for either implementation, MAUs and bus controllers have been developed which provide options for both 10BASE5 "vampire" taps and 10BASE2 BNC connectors. More recently, board manufacturers commonly provide boards with built-in transceivers that can be switched on or off by the component manufacturer for a particular application.

The standard 10BASE2 LAN can support only 30 terminations on each coaxial cable segment of 185 meters. While this may seem like a major constraint, it is often adequate for most work area environments. Where a requirement exists for interconnecting multiple work areas, or work areas with multiple 10BASE2 segments, a backbone 10BASE5 segment can be employed to provide intersegment connectivity. Figure 5 illustrates this type of configuration.
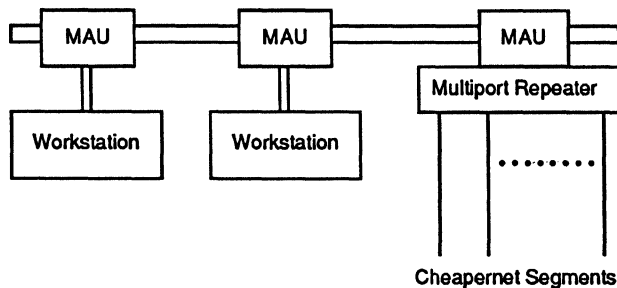
1BASE5
This standard approach was contributed by AT&T to accommodate its earlier Starlan products. It operates at 1M bps, and as such is often most useful for small work areas or low traffic environments. 1BASE5 also employs inexpensive twisted-pair wire interconnected through a hierarchical system of concentrator hubs. The hubs emulate a bus configuration by broadcasting all data and collision information on all ports.

10BASE-T
One of the most exciting developments on the local network scene has been the development of the 10M bps unshielded twisted-pair (UTP) Ethernet. This implementation has now received final approval from the IEEE. One of the best-known products to claim compliance with this standard is

Figure 5.
10BASE5/10BASE2 Interconnectivity

In environments with multiple work areas, or work areas with multiple 10BASE2 LAN segments, a backbone 10BASE5 segment can be used to provide intersegment connectivity.

SynOptics' LattisNet. There are now several major manufacturers producing products meeting this standard (including AT&T, HP, Digital, and 3Com); in fact, virtually every vendor active in the Ethernet market now offers 10BASE-T products.

It is important to note that these implementations will be limited to 100-meter segments due to the greater attenuation and signaling difficulties of twisted pair. This should not present any unusual problems since these networks' connections usually only have to reach to the "communications closet." From there, FOIRL and coax can be used to concatenate and interconnect LANs with standards such as 10BASE2.

It is imperative, however, that organizations planning these networks have their existing twisted-pair wire certified for both attenuation and capacitance before making any assumptions on its salvageability.

Like the AT&T Starlan, this system uses a hub concentrator to interconnect multiple stations and emulate the bus operation.

10BROAD36

The 10BROAD36 implementation uses much of the same hardware as the baseband implementations. The essential difference is the substitution of a broadband electronics unit and a passive broadband tap for the baseband MAU. This enables an organization to use its existing bus controller boards in the workstations for connection to either a baseband or broadband system. In recent years, this standard is being used less frequently.

The primary functions of the broadband electronics unit are to create the frequency-derived

channels of 14MHz for data and 4MHz for collision consensus. It also converts the signals from the baseband-coded signal of the AUI to the analog signal necessary on the broadband channel.

Workstations can be placed up to 1,800 meters from the "head-end" of the broadband cable plant. By placing the head-end in the center of the configuration, workstations can be installed up to 3,600 meters from each other.

IEEE 802.3 Standards Status

Within the IEEE 802.3 group, the following standards have been completed as of this date:

- CSMA/CD Medium Access Control Layer
- 10BASE5 Medium
- 10BASE2 Medium
- 10BROAD36 Medium
- Repeater Specifications
- Fiber Optic Inter Repeater Link (supports distances up to one kilometer)
- Layer Management
- 10BASE-T
- ATS for AUI Conformance Testing

Several projects remain open, with adoption expected imminently on some:

- Conformance Testing
- Maintenance
- 10BASE-F (Fiber Optics Task Force)
- Hub Management

IEEE 802.4 (Token Bus)

The 802.4 Token Bus working group wrestled with the issues of coordinating both IEEE and ISO standards development activities. Although the initial broadband implementations of the token bus appeared to be highly flexible and desirable in terms of the generic manufacturing requirements, a number of difficulties arose.

First, the industry found that migration from the early versions of the Manufacturing Automation Protocol (MAP) suite (Version 2.1) to current specifications (Version 3.0) is less than facile. It has become a manager's nightmare for a number of reasons.

For instance, fewer and fewer people are interested in broadband implementations primarily

due to the difficulty in design, installation, and maintenance. Additionally, the apparent benefits of broadband networks, in terms of the number of terminations, geographic range, and bandwidth, have been overtaken and negated by the introduction of Medium Access Control bridges that provide even greater capabilities for baseband networks—nearly transparently. These bridges enable an organization to increase the traffic loading by simply partitioning the network and eliminating the concern. Couple these high-risk implementation issues with the scarcity of products, difficulty in migration from MAP 2.1 to 3.0, and soft industry support, and one will find that the token bus presents a quagmire of implementation risks that most managers would rather avoid.

There is some hope on the horizon for the medium access specification. Other broadband physical medium specifications are being developed for optical fiber. Some difficulties lie ahead here since the dominant fiber specification in the U.S. is the 62.5μm fiber specified by ANSI for the Fiber Distributed Data Interface. In Japan and Europe, 50μm fiber is a more common implementation. In the final versions of this standard, both options are permitted—62.5μm is the standard and 50μm is allowed.

The 802.4 Token Bus architecture has matured despite the uncertainties presented by the MAP protocol suite. Standards for medium access control, broadband media, carrier-band media, and optical fiber have been completed. Open projects include conformance testing.

IEEE 802.5 (Token-Ring)

The token-ring implementation, which has received so much attention since it was first approved in 1985, has undergone a variety of modifications, and completion of essential specifications.

Media Issues

The initial version of the ring was a 4M bps implementation which ran on shielded twisted-pair wire. The issues surrounding shielded twisted pair have always been controversial. Telephony carriers avoid shielded wire to the extent possible, since the shielding introduces capacitance changes and ultimately increases attenuation, thus requiring more frequent repeater placement. The LAN proponents, such as IBM, feel differently. They contend that the shielding protects the media from unwanted EMI/RFI and that the distance between repeaters is not an issue since each station is its own repeater. The company using shielded wiring must decide if lower attentuation is worth the extra cost associated with a thicker (i.e., harder to install) and more expensive wire.

Considering the context of their respective positions, both contenders are correct. In the case of LANs, however, the shielding does buy some value. One thing we can be sure of is that where there is a requirement, someone will stand up to fill the niche. Thus, when IBM introduced the 16M bps token-ring network, running only on shielded wire, it was not surprising that other vendors immediately introduced unshielded wire 16M bps implementations. It is reasonably certain that in due time, the IEEE 802.5 working group will introduce a specification for unshielded twisted-pair wire. Considering the work that the Electronic Industries Association (EIA) has done concerning intrabuilding wiring (PN-1907), it is likely that the EIA specifications for unshielded wire will be candidates for the 16M bps ring.

Other media-related issues being explored by the 802.5 group are the use of Optical Fiber Station Attachment equipment and redundant media for backup (reconfiguring dual rings).

Token-Passing and Multi-Ring Protocol Issues

Recently, IBM introduced a new version of the token-passing protocol called "Early Token Release." This new protocol is intended to make more efficient use of the available bandwidth on physically large rings operating with particularly small packets. In earlier versions of the token-passing protocol, a new free token could not be released by the sending station until it recognized the address in its own packet coming back around the ring to itself. If the packet was small, and the ring was large, there was a great deal of wasted time on the medium.

Using Early Token Release, a sending station can release the free token immediately upon completing its transmission. The empty time slots on the ring can now be used by other parties. When coupled with the 16M bps ring, this new protocol appears to have significant advantages in terms of performance.

Figure 6.
10BROAD36 Model
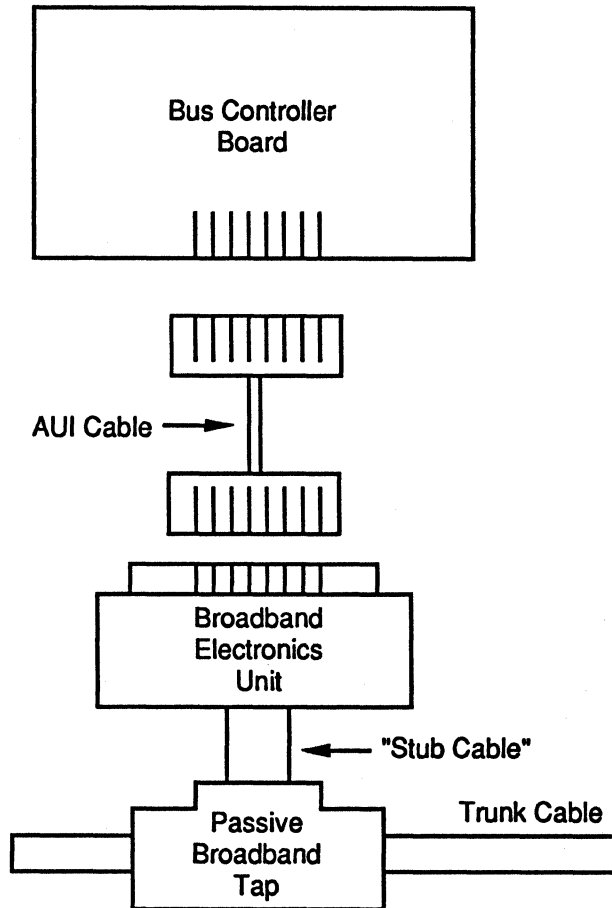
A 10BROAD36 broadband 802.3 implementation uses much of the same hardware as baseband 802.3 LANs.

Another area of interest in the token-passing world is the controversy on Medium Access Control Bridges. While Ethernet proponents prefer a minimum spanning-tree approach, many token-ring developers prefer source routing bridges. The 802 spanning tree bridge is an approved standard.

A discussion of Medium Access Control Bridges can be found in the Data Link Layer Repeaters section.

802.5 Standards Status

Presently, the following completed standards are available from the 802.5 working group:

- ANSI/IEEE 802.5 Token-Passing Ring (1985)
- 802.5A Station Management Functions Revision
- 802.5E Management Entity Specification

- 802.5F 16M bps Operation
- 802.5H Acknowledged Connectionless Logical Link Control
- 802.5I Early Token Release
- ANSI/IEEE 802.5 (1989)
- 802.5B Unshielded Twisted-Pair (being published)
- 802.5C Reconfiguring Dual Ring Specifications (being published) (redundant media)

The list of ongoing open projects includes:

- 802.5D Multi-Ring Configurations
- 802.5G Conformance Testing
- 802.5J Optical Fiber Station Attachment
- UTP 4/16 megabits per second

IEEE 802.6 (Metropolitan Area Network)

The IEEE 802.6 Metropolitan Area Network is a fourth MAC alternative that has been defined by the IEEE. Early plans for this moderate geographic area service focused on CATV-type networks, while later proposals revolved around a slotted ring concept. Current specifications call for a Queued Packet Synchronous Switch, which is a hybrid approach. It has been developed under the auspices of the Australian Postal, Telephone, and Telegraph administration and appears to be gaining general acceptance. The standard is approved.

IEEE 802.9 (Integrated Voice & Data LAN)

Topics under consideration by this working group include MAC frame delimiting, TDM frame formats, 20M bps PMD, and Layer Management. Both medium (4M bps) and higher speed Physical Layer standards are being investigated. Voting on a relatively "mature" specification is expected this summer.

IEEE 802.10 (Standard for Interoperable LAN Security)

This group is making progress on defining an architectural model for implementing interoperable LAN security. Licensing terms for the use of patented public key technology are being studied. Group 802.10B is working on secure data exchange. Group 802.10C is studying Key Management. The group is not predicting a standards ballot in the immediate future.

Table 2. 802.3 10BASE5/10BASE2 Differences

Feature	10BASE5	10BASE2
Name	802.3 "Ethernet"	Cheapernet, THIN Ethernet, THINWIRE Ethernet, etc.
Type of cable	50Ω Thick dual shield	50Ω RG-58
Maximum segment length	500 m.	185 m.
Spacing of devices on cable	2.5 m. minimum	0.5 m. minimum
Maximum number of taps for a segment	100	30
Maximum number of full repeaters in a path between two stations	2	2
Type of taps	Vampire or coax	BNC "T" connector for "daisy chaining"

IEEE 802.11 (Wireless Local Area Network)

Interest in this standard comes from all over the world including Japan, Canada, and Europe. The group has started on specifications for MAC and the Physical Layer, though a ballotable draft standard is still at least a year away. The work done by this group will be applicable to other MAC standards including 802.3, 802.4, and 802.5. Interest includes radio frequency and the infrared spectrum. The group hopes to have a standard in place by the end of 1992. The group is keeping other standards bodies, including T1P1, ETSI, and ECMA, informed of its progress.

Local Area Network Interconnection

As LANs proliferate, it is becoming more important that standard techniques for interconnection be adopted.

IEEE 802.1 Higher Layer Interface

Data Link Layer Repeaters

Interconnection of similar but separate LANs has resulted in the need for specifications on Medium Access Control bridges. MAC bridges are hardware/software implementations that are limited to resolving the MAC sublayer differences between two or more interconnected LANs. No further higher layer protocol translation is required, and they are often transparent to the user in terms of delay and performance.

MAC bridge specifications have been addressed by the IEEE 802 working groups. The 802.10, 802.1, and 802.5 teams have developed significantly different approaches, but even these

are beginning to converge. It is likely that within the next year, we will see more mature guidance in this area.

The current approaches are the Minimum Spanning Tree for bus implementations and the Source Routing bridge for interconnected rings.

The essential difference is that in the bus environment, only one path between any two devices exists. The bridges learn the LAN segment and node addresses and filter packets accordingly as required. Provision for multiple alternative paths is provided in the interconnected ring environment, which, in turn, yields a requirement for a routing protocol. This routing protocol is facilitated by adding "routing information" (RI) fields to the packet header. The RI field contains all of the source node routing information necessary for the bridge to determine which path is to be adopted for a specific packet.

There are certainly advantages and disadvantages to both of these approaches, but the common goals are to provide global, transparent interconnection. Global in the sense that any device on any LAN can share resources with any device on any other LAN; transparent in the sense that performance must be adequate to ensure that access to remote resources is provided rapidly and accurately. This guarantees that users do not perceive a difference between local and global objects.

IEEE 802.3 Physical Layer Repeaters

In the case of the IEEE 802.3 CSMA/CD LANs, intra-LAN segment connection standards are well developed and mature. These physical layer relays

Table 3. Logical Link Control Alternatives

Service	Type 1	Type 2	Type 3
Basic Service	Connectionless	Connection	ACK'ed connectionless
Acknowledgments	No	Yes	Yes
Error Recovery	No	Yes	Yes
Flow Control	No	Yes	No

are implemented in the form of repeaters that re-generate the signals from one segment for retrans-mission to the next. The unique aspect of these repeaters is that they must be capable of retrans-mitting collisions as well as data frames. Unlike Data Link Layer relays (or MAC bridges), these repeaters are not addressable. Since all segments are part of a unified LAN, the nature of the shared channel must be preserved by broadcasting all in-formation to all terminated devices.

The latest specifications for repeaters are con-tained in the IEEE 802.3C supplement (1989). Un-like the earlier version of this supplement (1988), this specification provides rich detail on coaxial cable, AUI, and optical fiber repeater interfaces. Repeater specifications now pertain to all 10BASE implementations.

In addition to the functions described above, repeaters as specified in the 802.3C supplement can provide "partitioning" between segments. Thus, if conditions on a given segment are causing the extensive proliferation of collisions, the rest of the LAN can be protected from this anomaly. The repeater will count the number of collisions from the source segment and interrupt these from trans-mission to the next segment. This function is de-signed to address an abnormal situation such as a cable break or network card failure.

IEEE 802.4 Physical Layer Repeaters

The issues of signal attenuation in a broadband LAN are normally resolved in two ways. First, the maximum placement of a device from the head-end provides a maximum bound on signal loss in the context of attenuation. Second, since many sta-tions can be connected to the bus, each resulting in a specific "insertion loss," amplifiers are often re-quired to ensure that the total loss does not exceed specifications.

The IEEE 802.4 broadband bus specifications define a Regenerative Repeater Machine (RRM) as

an optional component that is present only in spe-cial repeater stations such as the head-end. Since broadband systems are analog, amplifiers are usu-ally used to boost signal strength. Regenerative re-peaters actually re-create a new signal in accordance with amplitude and time specifica-tions.

A regenerative repeater is also defined for the single-channel carrier-band system. Since the latter is not a multichannel broadband bus (a medium supporting multiple frequency-derived channels such as a Community Antenna Television [CATV] system), a head-end is not required to facilitate this function. Physical placement of these devices is a function of the number and placement of user de-vices on the network. There are no explicit maxi-mum terminations defined in the specification, but the standard suggests that 30 may be an appropri-ate user limitation.

IEEE 802.5 Physical Layer Repeaters

The nature of a token-passing ring obviates the ne-cessity for repeaters, since each station's ring inter-face performs repeater functions. The maximum attenuation of a signal is thus guaranteed by limit-ing the distance between any two devices in the ring. As with 802.3, the issues of overall length of the ring impact protocol performance as opposed to signal attenuation.

IEEE 802.2 Logical Link Control

The IEEE 802.2 Logical Link Control (LLC) speci-fications include those Data Link Layer functions that are common to all 802 LAN MAC sublayer alternatives. Three basic service types are pro-vided.

Type 1 (Connectionless)

This service provides a best-effort delivery mecha-nism between origin and destination nodes. No call

or logical circuit establishment procedures are invoked. Each packet is treated as an independent entity by the network. There are no flow control mechanisms or acknowledgments. If the packet arrives at the destination—all well and good. If not, it is the responsibility of the higher layers to resolve the problem through time-outs and retransmission.

Type 2 (Connection Oriented)

Like many wide area network protocols, this service requires that a logical circuit or call be established for the duration of the exchange between the origin and destination nodes. Packets usually travel in sequence and are not routed as independent entities. Positive acknowledgments and flow control mechanisms are an integral part of this service.

Type 3 (ACK'ed Connectionless)

No circuit is established in this service variation, but acknowledgments are required from the destination node. This type of service adds additional reliability to Type 1, but without the potentially excessive overhead of Type 2.

Specific LAN types lend themselves to different types of service. Table 3 illustrates the LLC variations as they apply to the different MAC implementations.

Summary

The IEEE 802 local area network standards have evolved and matured significantly since their development in the early 1980s. It is essential that we not view this maturation process as an end. The standards will continue to evolve, and as new technologies and requirements develop, new standards will follow. The ideal utopian environment would be for standards development to lead product development, but it is unrealistic to believe, in an environment as volatile as local area networking, that vendors will wait patiently while users clamor for more and better products.

The IEEE will be faced with a continuing challenge to ensure that as new requirements and products evolve, the standards also evolve. This challenge will also be coupled with a requirement that migration from prior implementations is as painless as possible—both in terms of development risk and cost. ■