FDDI: Current Issues and Future Plans

Key issues in several FDDI standard working groups include low-cost fiber, twisted-pair, SONET mapping, and FDDI follow-on LAN.

Raj Jain

RAJ JAIN is a senior consulting engineer at Digital Equipment Corporation.

Adapted with permission from "FDDI Handbook: High-Speed Networking with Fiber and Other Media," by Raj Jain, Addison-Wesley, Reading, MA, 1994.

Fiber Distributed Data Interface (FDDI) is a set of standards developed by the American National Standards Institute (ANSI) X3T9.5 Task Group. The timed token access method, used to share the medium among stations in this 100 Mb/s local area network (LAN), differs from the traditional token access method in that the time for the token to walk around the ring is accurately measured by each station and used to determine the usability of the token.

Older LANs (e.g., IEEE 802.3/Ethernet and IEEE 802.5/token ring networks) support only asynchronous traffic (Fig. 1). FDDI adds synchronous service (Fig. 2). Synchronous traffic consists of delay-sensitive traffic such as voice packets, which need to be transmitted within a certain time interval. Asynchronous traffic consists of data packets produced by various computer communication applications, such as file transfer and mail. These data packets can sustain reasonable delay, but are generally throughput sensitive in that higher throughput (bits or bytes per second) is more important than the time for bits to travel over the network.

An important feature of FDDI is its distributed nature, as reflected in its name. An attempt has been made to make all algorithms distributed in that control of the rings is not centralized. When any component fails, other components can reorganize and continue to function, including fault recovery, clock synchronization, token initialization, and topology control.

Regarding higher layer protocols, FDDI is compatible with IEEE 802 standards such as carrier sense multiple access with collision detection (CSMA/CD—loosely called Ethernet), token rings, and token bus. Applications running on these LANs can easily work over FDDI without any significant changes to upper layer software.

FDDI-II

Although the synchronous traffic service provided by FDDI guarantees a bounded delay, this delay can vary. For example, with a target token rotation time (TTRT) value of 165 ms on a ring with 10-μs latency, a station gets an opportunity to transmit the synchronous traffic every 10 μs at zero load, but it may have to wait 330 ms under heavy load. This type of variation may not suit many constant bit rate (CBR) telecommunication applications that require a strict periodic access. For example, on an integrated services digital network (ISDN) B-channel, which supports one 64-kb/s voice conversation, one byte is received every 125 μs. Such circuit-switched traffic cannot be supported on FDDI. If an application needs guaranteed transmission of n bytes every T μs, or some integral multiples of T μs, the application is said to require isochronous service.

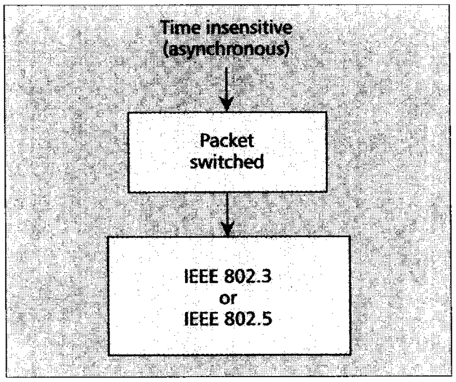
FDDI-II provides support for isochronous service in addition to the asynchronous and synchronous service provided by FDDI (Fig. 3).

Like FDDI, FDDI-II runs at 100 Mb/s. FDDI-II nodes can run in the FDDI mode (also called basic mode). If all stations on the ring are FDDI-II nodes then the ring can switch to the hybrid mode, which provides isochronous service in addition to basic mode services; but if even one station is not an FDDI-II node then the ring cannot switch to the hybrid mode and continues in the basic mode. In the basic mode on FDDI-II, synchronous and asynchronous traffic is transmitted in a manner identical to that on FDDI. Isochronous service is not available in the basic mode.

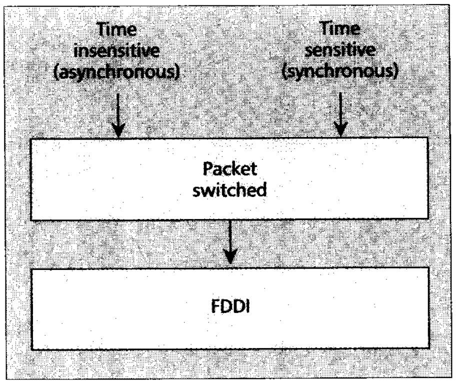
Most multimedia applications such as video conferencing, real-time video, and entertainment video can be supported on FDDI. The required time guarantee of a few tens of milliseconds can be easily guaranteed with the synchronous service and a small TTRT. Since the TTRT cannot be less than the ring latency, applications requiring time bounds less than twice the ring latency cannot be supported by FDDI. Similarly, applications requiring strict periodic access require FDDI-II. The main problem is that the hardware for all stations on the ring has to be upgraded to FDDI-II even if only one or two stations require isochronous service.

To service periodic isochronous requests, FDDI-II uses a periodic transmission policy with transmission opportunities repeated every 125 μs. This interval matches the basic system reference frequency clock used in public telecommunications networks in North America and Europe. At this interval, a special frame called a "cycle" is generated. At

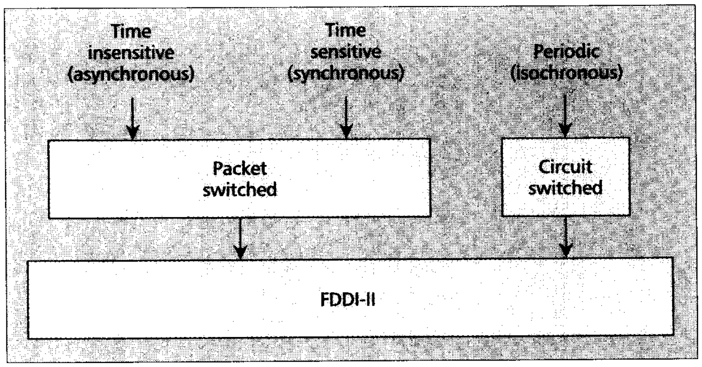
Raj Jain is now at
Washington University in Saint Louis
Jain@cse.wustl.edu
http://www.cse.wustl.edu/~jain/



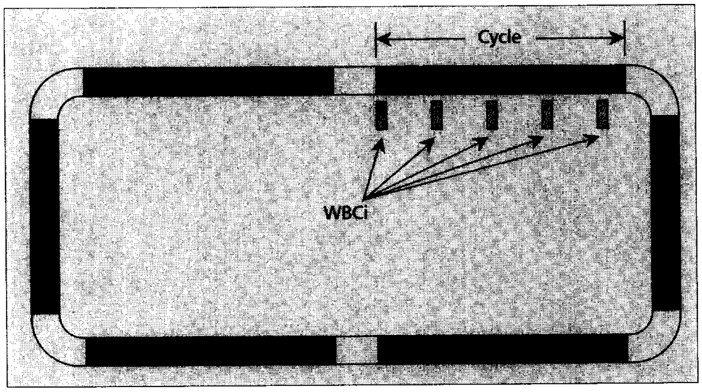
■ **Figure 1.** *Service provided by IEEE 802.3 and IEEE 802.5 networks.*



■ **Figure 2.** *Services provided by FDDI.*



■ **Figure 3.** *Services provided by FDDI-II.*



■ **Figure 4.** *Cycles.*

100 Mb/s, $1562\frac{1}{2}$ bytes can be transmitted in 125 µs. Of these, 1560 bytes are used for the cycle and $2\frac{1}{2}$ bytes are used as the intercycle gap or cycle preamble. At any instant, the ring may contain several cycles (Fig. 4).

The bytes of the cycles are preallocated to various channels for communication between two or more stations on the ring. For example, a channel may have the right to use the 26th and 122nd bytes of every cycle. These bytes are reserved for the channel: if the stations owning that channel do not use it then other stations cannot use it, and the bytes will be left unused.

The 1560 bytes of the cycle are divided into 16 wideband channels (WBCs) of 96 bytes each. Each WBC provides a bandwidth of 96 bytes per 125 µs or 6.144 Mb/s, sufficient to support one television broadcast, four high-quality stereo programs, or 96 telephone conversations.

Some of the 16 WBCs may be allocated for packet mode transmissions and the others for isochronous mode transmissions. Channels 1, 5, and 7, for example, may be used for packet mode transmissions or packet switching, while Channels 2, 3, 4, 6, and 8 through 15 are used for isochronous mode transmissions or circuit switching. All WBCs could be allocated for circuit switching alone, or packet switching alone. Allocation is made using station management protocols now being defined.

Low-Cost Fiber

After the initial FDDI specifications were completed in 1990, it was realized that the high cost of optical components was one of the impediments to rapid deployment of FDDI. To switch from the lower speed technology of Ethernet or token ring, it was necessary to rewire the building, install FDDI concentrators, install FDDI adapters in systems, install new software, and so on. Although the cost of all components was continuously decreasing, it was still high. Therefore, a standard effort was begun to find a low-cost alternative.

This effort resulted in a new media-dependent physical layer (PMD) standard called low-cost fiber PMD (LCF-PMD). As the name suggests, the committee originally intended to find a fiber cheaper than the 62.5/125 µm multimode fiber (MMF) used in the standard FDDI. Several alternatives such as plastic fiber and 200/230 µm fiber were considered but quickly rejected when it was realized that the real expense was in the devices (transmitters and receivers) and not in the fiber. A search for lower powered devices then began.

LCF-PMD allows low-cost transmitter and receiver devices to be used on any FDDI link. These devices are cheaper because they have more relaxed noise margins and are either lower powered or less sensitive than the devices specified in the original PMD, which we prefer to call the MMF-PMD. The specification has been designed for links up to 500 m long (compared to 2 km in MMF-PMD). This distance is sufficient for most intrabuilding applications.

Only interbuilding links longer than 500 m need to pay the higher cost of MMF-PMD devices. Any combination of LCF, MMF, single-mode fiber (SMF), synchronous optical network (SONET), and

Issue	MMF	LCF
Wavelength	1300 nm	1300 nm
Fiber	62.5/125 multimode*	62.5/125 multimode*
Transmitted power	Max –20 dBm	Max –22 dBm
Received power	Min –31 dBm	Min –29 dBm
Rise time at transmit	Max 4 ns	0.6 to 3.5 ns
Rise time at receive	Max 4.5 ns	0.6 to 5 ns
Connector	Duplex-FDDI	Duplex-SC or duplex-ST
Connector keying	Port and polarity	No port. Polarity only.

*See text for other sizes.

■ **Table 1.** *Low-cost fiber vs. multimode fiber PMD.*

copper links can be intermixed in a single FDDI network as long as the distance limitations of each are carefully followed.

Table 1 provides a comparison of the key design decisions for LCF and MMF PMDs. These issues are explained further below.

Wavelength — LCF uses the 1300-nm wavelength, i.e., the same wavelength used in multimode and single-mode PMDs. Initially, an 850-nm wavelength was suggested because 850-nm devices are used in fiber optic Ethernet (IEEE 802.3 10BASE-F) and token ring (IEEE 802.5J) networks. These devices are sold in large volume and are slightly cheaper than 1300-nm devices. However, the 850-nm wavelength would have introduced a problem of incompatibility. Users would have to remember (and label) the source wavelength and use the same wavelength device at the receiving end, and the receiver would have to be replaced every time the transmitter was replaced. On the other hand, with 1300 nm at both ends, the user need only worry about the distance; as long as the distance is less than 500 m, the two ends can use any combination of LCF and MMF devices.

Fiber — LCF specifies 62.5/125-µm graded-index multimode fiber, the same fiber specified in MMF-PMD. Initially, plastic fibers and 200/230-µm step-index fibers were considered. Although inexpensive, plastic fibers have a high attenuation so their use would have severely limited the distance. Larger core 200-µm fibers allow more power to be coupled in the fiber. The connectors and splices for these fibers are also cheaper since no active alignment is required. However, the large diameter of the core implies more dispersion and therefore lower bandwidth. For 200-µm fiber, a bandwidth-distance product of 30 MHz-km was predicted while 80 MHz-km (800 MHz over 100 m) has been measured. Since the 200-µm fiber has an attenuation of 16 dB/km compared to 2 dB/km for 62.5/125-µm fiber, transmitters for 200-µm fiber would have been required to produce more power.

The main problem with 200/230-µm fibers is that intermixing them with 62.5/125 fibers on the same link causes a significant power loss. When it was realized that a 50 percent cost reduction goal could be achieved by simply changing the transmitting and receiving power levels by 2 dBm, all efforts to change the fiber came to a halt.

In addition to the 62.5/125 fiber, MMF-PMD allows 50/125, 85/125, and 100/140 fibers. LCF-PMD allows 200/230 in addition to these fibers. When these alternative fibers are used, the link loss budget must be carefully analyzed and allowance must be made for differing cross-sections and apertures of fibers and transceivers.

Connector — The duplex connector specified in MMF-PMD was designed specifically for FDDI. Due to its low-volume production, its cost is high. Significant savings can be obtained by using other simplex connectors. In fact, many FDDI installations already use the simplex-ST connector. The LCF committee wanted to use a duplex connector to avoid the problem of misconnections resulting in two transmitters being connected to each other.

A duplex subscriber connector (SC) was proposed (Fig. 5). The SC connector is a Japanese standard; it is an augmentation of the fiber connector (FC). It was developed in 1984 to provide a push-pull interface, which reduces the space required between the connectors (compared to connectors rotated by fingers). As a result, a large number of connectors can be placed side by side. Considerable savings in packaging cost result as more ports are put on a given size board in a concentrator. SC has a connector loss of 0.3 dB and a return loss (reflection) of 43 dB.

In the United States, straight tip (ST) connectors are more popular than SC or FC connectors. A number of companies have proposed duplex-ST connector designs with specifications matching those of the duplex-SC. After much heated debate, termed "Connector War II," duplex-SC was voted the main selection, with duplex-ST being the recommended alternate.

Transmitter/Receivers — Even slightly reducing the transmitted power and dynamic range reduces the cost significantly. LCF-PMD reduces the required transmit power by 2 dBm and the receiver dynamic range by 2 dBm. The transmitted power range is (–22, –14) dBm while the received power range is (–29, –14) dBm. This means that the maximum loss allowed in the fiber is only 7 dB (=29–22) instead of 11 dB. This is sufficient for a 500 m link.

Chromatic Dispersion Parameters — The 2-km length limit on MMF links is primarily due to chromatic dispersion, thus chromatic dispersion parameters in MMF-PMD were very carefully specified, including the slope of the dispersion curve. The effect of dispersion on bandwidth is inversely proportional to the length of the link. For 500 m or shorter links, the bandwidth is sufficient to carry FDDI signal and chromatic dispersion is not a problem. Dispersion parameters are therefore not specified for LCF links. Even the spectral width specification has been removed. Hence, sources do not have to be tested for spectral width. This results in lower cost transceivers.

Rise and Fall Times — Since LCF-PMD uses the same fiber as MMF-PMD with the link length decreased from 2 km to 500 m, the pulse broadening caused by fiber dispersion is less. The change in pulse rise and fall times due to the fiber is not as much. The time thus saved has been allocated to transmitters and receivers to reduce their cost. LCF transmitters can have a rise/fall time of 4.0 ns compared to 3.5 ns for MMF transmitters, so lower quality (hence, cheaper) transmitters can be used.

Similarly, LCF receivers are required to receive pulses with a rise/fall time below 4.5 ns compared to 5 ns for MMF receivers. This again means less work and hence lower cost for the receivers.

Twisted-Pair PMD

As soon as the initial FDDI products appeared on the market, it was realized that requiring users to rewire their buildings with fibers was an impediment to FDDI acceptance. Even if you only need to connect two nearby pieces of equipment on the same floor, you need to install fibers. Rewiring a building is a major expense and is not easy to justify unless the technology is absolutely necessary.

In addition to the wiring expense, the optical components used in FDDI equipment are also very expensive compared to the electronic components used in other existing LANs. This led several manufacturers to look into the possibility of providing 100-Mb/s communication on existing copper wiring. It was determined that 100 Mb/s transmission using high-quality (shielded or coax) copper cables is feasible at a much lower cost compared to fiber, particularly if the distance between nodes is limited to 100 m. The transceivers for copper wires are much cheaper than those for optical fibers.

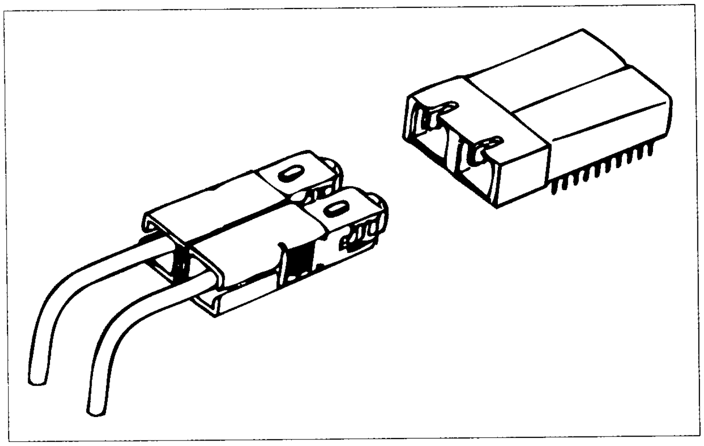
An FDDI ring can have a mixture of copper and fiber links. Therefore, short links in office areas can use existing copper wiring installed for telephones or other LAN applications. The result is considerable cost savings and quicker migration from lower speed LANs to FDDI. Proprietary coaxial cable and shielded twisted-pair (STP) products, which support FDDI links of up to 100 m, are already available. More than 98 percent of the data cable running in offices is less than 100 m and 95 percent is less than 50 m. These can be easily upgraded to run at 100 Mb/s.

FDDI twisted-pair PMD (TP-PMD) is still under development. The major design issues are as follows.

Categories of Cables — Sending a 125-Mb/s signal over a coaxial cable or STP is not as challenging as on an unshielded twisted pair (UTP). Given the preponderance of UTP cabling to the desktop in most offices, allowing FDDI on UTP, however difficult, would be a major win for FDDI. The first issue was whether we should have different coding methods for UTP and STP or one standard covering both. The decision was made to have one standard for both. The next issue was which categories of UTP should be covered. Data-grade twisted pair (EIA Category 5) is easier to handle while Category 3 cable introduces more complexity, so it was decided that the TP-PMD standard will not support Category 3 cables. A long-term TP-PMD working group has been formed to look at the issues surrounding Category 3 cables.

Power Level — The attenuation (loss) of signal over copper wires increases at high frequency. To maintain a high signal-to-noise ratio, one must either increase the signal level (more power) or use special coding methods to produce lower frequency signals. Increased power results in increased interference and therefore special coding methods are required.

Electromagnetic Interference — The main problem caused by high-frequency signals over copper wires is electromagnetic interference (EMI). After 4b/5b encoding, the FDDI signal has a bit rate of 125 Mb/s. With nonreturn to zero inverted (NRZI) encoding, this results in a signal frequency of 62.5 MHz. At this frequency range, the copper wire acts as a broadcasting antenna. Electromagnetic radiation from the wire interferes with radio and television transmissions. EMI increases with the signal level. The Federal Communications Commission (FCC) places strict limits on such EMI hence the power that FDDI transmitters can use is severely limited; in turn, the distance at which the signal becomes unintelligible is also limited.

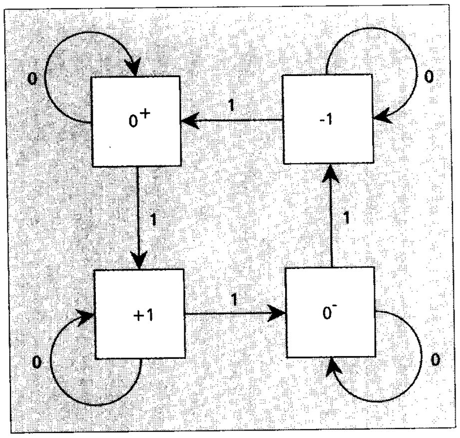


■ **Figure 5.** *Duplex-SC connector.*

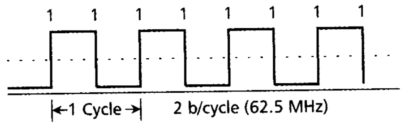
One solution to the EMI problem is to use STP wires. The special metallic shield surrounding the wires prevents interference. Another solution is to use special coding techniques that result in a lower frequency signal. This second approach has the advantage that the UTP wires (which reach all desks) can be used for FDDI. The issue of coding has now been resolved and a three-level coding called multilevel transmission 3 (MLT-3) has been selected. This reduces the signal frequency by a factor of 2.

MLT-3 is basically an extension of NRZI to three levels, so it is often called NRZI-3. The three levels are denoted by +1, 0, and −1. Like NRZI, a "zero" bit is coded as the absence of a transition and a "one" bit is coded as a transition. The successive transitions are all in the same direction (ascending or descending) except when the signal reaches a level of +1 or −1, at which point the direction is reversed. The complete transition diagram consists of four states labeled +1, 0^+, 0^-, and −1 (Fig. 6). The labels indicate the level of the signal when the system is in that state. The input bits are represented by arcs. Thus, if the signal level is +1 and a zero is to be sent, the signal level remains +1 in the next bit period. On the other hand if a one is to be sent, the signal level is changed to 0 (state 0^-). Another one in this state will cause the signal level to change to −1.

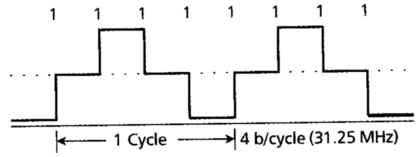
To understand the effect of multilevel encoding on the signal frequency, consider the NRZI and MLT-3 encodings of a stream of 1s (Fig. 7). With NRZI, each cycle of the signal consists of 2-bit times. Assuming an FDDI bit rate of 125 Mb/s, the signal has a frequency of 62.5 MHz. With MLT-3, the cycle length is 4 bits and the signal frequency is 31.25 MHz.



■ **Figure 6.** *MLT-3 transition state diagram.*

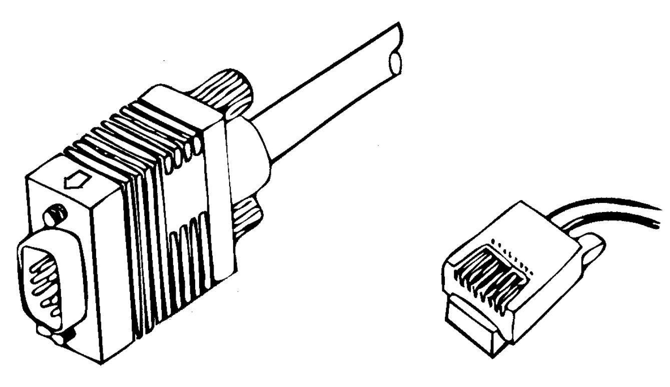


(a) Two-level code



(b) Three-level code

■ **Figure 7.** *NRZI and MLT-3 coding of a stream of 1s.*



(a) DB-9 (STP)

(b) RJ-45 (UTP)

■ **Figure 8.** *Connectors for TP-PMD.*

Scrambling — Even though MLT-3 and other encoding schemes reduce the signal frequency, they are not sufficient to meet the FCC EMI requirements for UTP. Another way to reduce interference is to scramble the signal so the energy is distributed uniformly over a range of frequencies rather than concentrated at one frequency.

Connectors — Figure 8 shows the RJ-45 and DB-9 connectors proposed for TP-PMD. Both are popular connectors available at a very low price due to their widespread use in the computer and communication industries.

FDDI on SONET

Synchronous optical network (SONET) is a standard developed by ANSI and Exchange Carriers Standards Association (ECSA) for digital optical transmission. If you want to lease a fiber-optic line from your telephone company, it is likely to offer you a "SONET link" instead of a dark fiber link. A SONET link allows the telephone company to divide the enormous bandwidth of a dark fiber among many of its customers. The SONET standard has also been adopted by the International Consultive Committee on Telegraphy and Telephonics (CCITT). There are slight differences between the CCITT and ANSI versions. The CCITT version is called synchronous digital hierarchy (SDH).

A SONET system can run at a number of predesignated data rates, specified as synchronous transport signal level N (STS-N) rates in the ANSI standard. The lowest rate STS-1 is 51.84 Mb/s. Other rates of STS-N are simply N times this rate. For example, STS-3 is 155.52 Mb/s and STS-12 is 622.08 Mb/s (Table 2). The corresponding rate at the optical level is called optical carrier level N (OC-N). Since each bit results in one optical pulse in SONET (no 4b/5b type of coding is used), the OC-N rates are identical to STS-N rates.

For the CCITT/SDH standard, the data rates are designated synchronous transport module level N (STM-N). The lowest rate STM-1 is 155.52 Mb/s. Other rates are simply multiples of STM-1.

In both cases, some bandwidth is used for network overhead. Table 2 also shows the data rate available to the user, i.e., the payload rate.

Is FDDI a Misnomer?

ANSI Task Group X3T9.5 was formed in 1979 to provide a high-performance I/O channel called local distributed data interface (LDDI). The idea of using optical fibers was first raised in subcommittee X3T9.5 at the October 1982 meeting. Subsequently the LDDI standard was abandoned and a new effort based on fiber was begun. This new standard was named the "Fiber Distributed Data Interface," or FDDI.

Initially the standard was expected to be used only on a fiber medium in a fully distributed manner for data transmission; it was expected to only specify an interface similar to small computer system interface (SCSI). The features of FDDI have slowly been extended to meet diverse needs and now the name FDDI has actually become a misnomer. A more appropriate name for the current FDDI standards would be **** (four asterisks), where each asterisk stands for a wildcard in that position. FDDI is now an any media, centralized or distributed, any traffic (voice, video, or data) LAN, MAN, or interface.

FDDI standards now cover non-fiber media including copper wires. Since FDDI-II uses a centralized ring master station, it is not fully distributed peer-to-peer protocol. Data was never considered to be the only traffic on FDDI. Even initial versions have features for voice, video, and other telephony applications. Finally, FDDI is a full-featured network and not just another bus interface.

SONET physical-layer mapping (SPM) takes the output of the current FDDI physical layer, which is a 4b/5b encoded bit stream, and places it in appropriate bits of an STS-3c synchronous payload envelope (SPE). An STS-3c SPE consists of 2349 bytes arranged as 9 rows of 261 bytes each. Of these, 9 bytes are used for path overhead. Since one SPE is transmitted every 125 µs, the available bandwidth is (2349 x 8)/125 or 139.264 Mb/s, which is more than the 125 Mb/s required for FDDI. The extra bits are used for network control purposes and as stuff bits for overcoming clock jitter.

SONET uses a simple nonreturn to zero (NRZ) encoding of bits. In this coding, a 1 is represented as high level (light on) and a 0 is represented as low level (light off). One problem with this coding is that if too many 1s (or 0s) are transmitted, the signal remains at on (or off) for a long time, resulting in a loss of bit clocking information. To solve this problem, the SONET standard requires the scrambling of all bytes in a SONET signal by a frame synchronous scrambler sequence of length 127 generated by the polynomial $1 + x^6 + x^7$. Certain overhead bytes are exempt from this requirement.

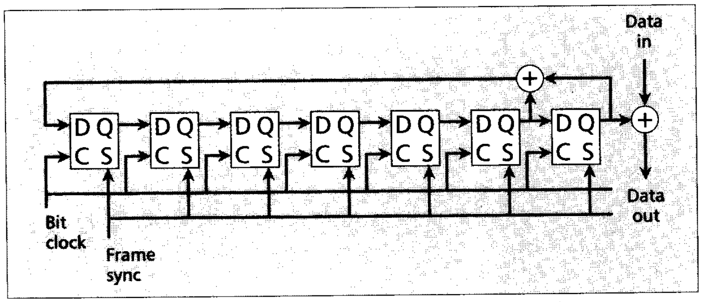
The scrambler consists of a sequence of seven shift registers (Fig. 9). At the beginning of a frame, a seed value of 1111111 (binary) is loaded in the register. As successive bits arrive, the contents of shift registers are shifted and the sixth and seventh registers' contents (corresponding to the x^6 and x^7 terms, respectively) are exclusive-or'ed and fed back to the first register (corresponding to the first term in the polynomial). The output of the final shift register is a random binary pattern, which is exclusive-or'ed to the incoming information bits.

The scrambling operation is equivalent to exclusive-oring of the bits with a particular 127-bit sequence, which is highly random and does not contain long sequences of 1s or 0s. The frequency of transitions in the resulting stream should increase; however, if the user data pattern is identical to any subset of this sequence, the resulting stream will have all 1s in the corresponding bit positions; similarly, if the user data pattern is an exact complement of any subset of this sequence, the resulting stream will have all 0s in the corresponding bit positions.

In the design of the FDDI-to-SONET mapping, a key issue was ensuring that the FDDI signal pattern does not result in long series of 1s or 0s after scrambling. For this purpose, two steps have been taken. First, several fixed stuff bits are used throughout the SPE to break up the FDDI stream. As a result, FDDI data cannot affect more than 17 contiguous bytes. Even the 17-byte string has one bit that is a stuff control bit and therefore not under user control. Second, the scrambler sequence was analyzed, to find the longest possible valid 4b/5b pattern that could match (or complement) a portion of the scrambler sequence. The longest possible match for random sequences of FDDI data or control symbols and the SONET scrambler sequence is 58 bits (7.25 bytes) of valid symbols. Thus, it is not possible for an FDDI user to cause serious errors in the SONET network by simply sending a data pattern.

ANSI designation	Optical signal	CCITT designation	Data rate (Mb/s)	Payload rate (Mbps)
STS-1	OC-1		51.84	50.112
STS-3	OC-3	STM-1	155.52	150.336
STS-9	OC-9	STM-3	466.56	451.008
STS-12	OC-12	STM-4	622.08	601.344
STS-18	OC-18	STM-6	933.12	902.016
STS-24	OC-24	STM-8	1244.16	1202.688
STS-36	OC-36	STM-12	1866.24	1804.032
STS-48	OC-48	STM-16	2488.32	2405.376
STS-96	OC-96	STM-32	4976.64	4810.176
STS-192	OC-192	STM-64	9953.28	9620.928

■ **Table 2.** *SONET/SDH signal hierarchy.*



■ **Figure 9.** *Shift-register implementation of a SONET scrambler.*

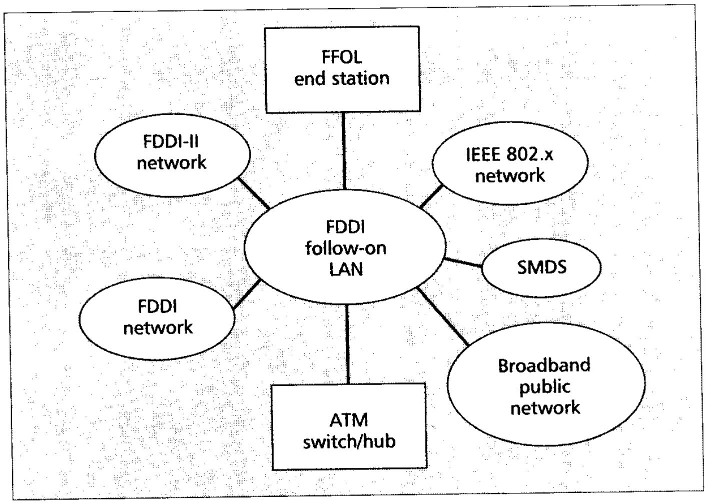
FDDI Follow-On LAN

Both FDDI and FDDI-II run at 100 Mb/s. A higher speed backbone network is needed to connect multiple FDDI networks. The FDDI standards committee realized this need and has started work on next generation of high-speed networks. The FDDI follow-on LAN (FFOL) project is currently in its infancy and not much has been decided. The information presented here is preliminary and subject to rapid change.

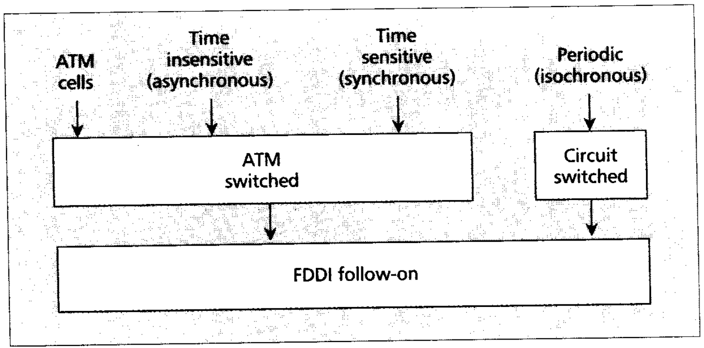
A key goal of FFOL is to serve as a backbone network for multiple FDDI and FDDI-II networks, where it should at least provide the packet switching and circuit switching services of FDDI-II. For a backbone network to be successful, it should be able to carry the traffic on a wide variety of networks. Broadband integrated services digital networks (B-ISDN), which use asynchronous transfer mode (ATM), run at speeds close to FDDI speeds and are expected to use FFOL. ATM networks use small fixed-size cells. FFOL is expected to provide an ATM service allowing cells to be switched among ATM networks. Then IEEE 802.6 dual queue dual bus (DQDB) networks could also use FFOL as the backbone (Fig. 10). Easy connection to B-ISDN networks is one of the key goals of FFOL.

Some of the issues in the design of a high-speed network are as follows.

Data Rate — By the time FFOL is ready, MMFs are expected to be in common use because of FDDI, and users will want to use the installed fiber in FFOL. It is well known that MMFs in FDDI design have a capacity to run 100 Mb/s (125 Mb/s signaling



■ **Figure 10.** *FDDI follow-on LAN as a backbone.*



■ **Figure 11.** *Services provided by the FDDI follow-on LAN.*

rate) up to 2 km; therefore they can carry a 1.25 Gb/s signal up to 200 m, or a 2.5 Gb/s signal up to 100 m. The 100 m distance covers the length of the horizontal wiring supported by ANSI/EIA/TIA 568 for commercial building wiring standards. Limiting FFOL to below 2.5 Gb/s allows much of the installed MMF in the buildings to be switched from FDDI to FFOL.

To carry telecommunication network traffic, FFOL should support data rates that are compatible with SONET. FFOL will be designed to be able to efficiently exchange traffic at STS-3 (155.52 Mb/s), STS-12 (622.08 Mb/s), STS-24 (1.24416 Gb/s), and STS-48 (2.48832 Gb/s).

Media Access Modes — The term media access modes refers to the traffic switching modes supported by a network. FDDI supports three different modes of packet-switching: synchronous, asynchronous, and restricted asynchronous. Depending on delay and throughput requirements, an application can choose any one of these three media access modes. FDDI-II adds support for periodic (isochronous) traffic that normally requires circuit switching, and FFOL is expected to support these modes. In addition, FFOL is expected to explicitly support ATM switching (Fig. 11). ATM switching is slightly different from packet switching. All ATM cells are the same size, the switching instants are fixed, and a slotted network design is generally used.

Topology — FFOL is expected to allow the dual-ring-of-trees physical topology supported by FDDI. Additional topologies may be allowed. Segments of public networks may be included in the FFOL networks. In current FDDI, only SONET links are allowed.

All LANs are designed so that responsibility for ensuring that the packet is delivered to the correct destination is shared by all nodes. In this case, switching is distributed and the medium is shared (Fig. 12). An alternative is to distribute the medium and share switches (Fig. 13).

The latter approach has an advantage: not all end stations need to pay the cost of a high-speed connection. Links can be upgraded to higher speeds only when necessary. The end systems are simple; most of the design complexity is in the switches. Since several parallel transmissions can occur at all times, the total throughput of the network is several times the bandwidth of any one link. For example, a total network throughput of several Gb/s is possible with all links having a bandwidth of only 100 Mb/s. Most telecommunication networks and wide-area computer networks use the switch-based approach and there is a trend towards a switch-based mesh topology even in high-speed LANs; but it is not clear whether FFOL will consider a mesh topology.

Recently, FFOL activities have slowed down as the participants are questioning the need for FFOL in view of the other competing gigabit standards such as fiber channel, high-performance parallel interface (HIPPI), and ATM based networks.

Summary

FDDI is the next generation of high-speed networks. It is an ANSI standard being adopted by ISO and implemented all over the world. It allows communication at 100 Mb/s among 500 stations distributed over a total cable distance of 100 km.

FDDI will satisfy the needs of organizations that require a higher bandwidth, a larger distance between stations, or a network spanning a greater distance than the Ethernet or IEEE 802.5 token-ring networks. It provides high reliability, high security, and noise immunity. It supports data as well as voice and video traffic. FDDI-II provides all the services provided by FDDI but adds support for isochronous traffic.

Low-cost fiber PMD allows cheaper links using low cost fiber as well as low-powered transceivers. The net link budget has been reduced from 11 dB to 7 dB, allowing links only for lengths less than 500 m. Most intrabuilding links are within this distance range. The cost of the connector has also been reduced by selecting duplex versions of popular simplex connectors. These connectors are required to only have polarity keying so that an untrained user cannot misconnect a transmitter to another transmitter. No port type keying is required.

Standardization of FDDI on copper will reduce its cost considerably and help bring FDDI to the desktop.

The next higher speed version of FDDI, called FDDI follow-on LAN and running at 622 Mb/s to 1.2 Gb/s speed, is currently being discussed.

Further Reading

The FDDI protocols are described in a number of ANSI standards and working documents. These standards are also being adopted as ISO standards [1-10].

Much of this article has been excerpted from Jain [11]. See Burr and Ross [12], Ross and Moulton [13], Ross [14-16], and Hawe, Graham, and Hayden [17] for an overview of FDDI.

Caves and Flatman [18], Teener and Gvozdanovic [19], and Ross [20] provide an overview of FDDI-II.

Ginzburg, Mallard, and Newman [21] discuss some of the problems in transmitting high bandwidth signal over copper.

Stallings [22] has a chapter devoted to the SONET standard. The analysis of the SONET scrambler for FDDI mapping is presented in Rigsbee [23]. The FDDI-SONET mapping has been published as ANSI T1.105a-1991 [24], which is a supplement to and is now included in the ANSI T1.105-1991 standard [25].

FFOL requirements and design considerations are summarized in Ocheltree, Horvath, and Mityko [26] and in Ross and Fink [27].

Acknowledgement

Thanks to Bill Cronin and Paul Koning for useful feedback on an earlier version of this paper.

References

[1] ANSI X3.184-199x, "Information Processing Systems — Fiber Distributed Data Interface (FDDI) Part 4: Single-Mode Fiber PMD (SMF-PMD)," ASC X3T9/89-080, Rev 4.2, December 7, 1992, ISO/IEC CD 9314-4:199x.

[2] ANSI dpANS X3.186-199x, "Information Processing Systems — Fiber Distributed Data Interface (FDDI) Part 5: Hybrid Ring Control (HRC)," ASC X3T9.5/87-10, Rev. 6.3, ISO/IEC DIS 9314-5:199x, May 28, 1992.

[3] ANSI dpANS X3.229-199x, "Information Processing Systems — Fiber Distributed Data Interface (FDDI) Part 6: Token Ring Station Management (SMT), ASC X3T9.5/84-49, Rev. 7.2, ISO/IEC WD 9314-6:199x, June 25, 1992.

[4] ANSI X3.231-199x, "Information Processing Systems — Fiber Distributed Data Interface (FDDI) Part 7: Token Ring Physical Layer Protocol (PHY-2)," Rev. 5, June 17, 1992, ISO/IEC WD 9314-7.

[5] ANSI X3.237-199x, "FDDI Low-Cost Fibre Physical Layer Medium Dependent (LCF-PMD)," ASC X3T9.5/92-155, Rev. 1.3, September 1, 1992, ISO/IEC WD 9314-9:199x, 50 pp.

[6] ANSI X3.239-199x, "Enhanced Media Access Control (MAC-2)," Rev. 4.1, September 3, 1992.

[7] ASC X3T9/92-201, "FDDI Twisted Pair Physical Layer Medium Dependent (TP-PMD)," Rev. 0.3, February 17, 1993.

[8] ISO 9314-1:1989, "Information Processing Systems — Fiber Distributed Data Interface (FDDI) Part 1: Token Ring Physical Layer Protocol (PHY), 31 pp.

[9] ISO 9314-2:1989, "Information Processing Systems — Fiber Distributed Data Interface (FDDI) Part 2: Token Ring Media Access Control (MAC)," 67 pp.

[10] ISO/IEC 9314-3:1990, "Information Processing Systems — Fiber Distributed Data Interface (FDDI) Part 3: Token Ring Physical Layer Medium Dependent (PMD)," 47 pp.

[11] R. Jain, *"FDDI Handbook: High-Speed Networking Using Fiber and Other Media,"* (Addison-Wesley, Reading, MA, available Dec. 1993).

[12] W. Burr and F. Ross, "The Fiber Distributed Data Interface: A Proposal for a Standard 100 Mbit/s, Fiber Optic Token Ring Network," *Proc. FOC/LAN '84*, Las Vegas, NV, Information Gatekeepers, Boston, MA, pp. 254-257, 1984.

[13] F. Ross and R. Moulton, "FDDI Overview — A 100 Megabit Per Second Solution," *Proc. Wescon '84*, Electron. Conventions Manage., Los Angeles, CA, 2/1/1-2/1/9, 1984.

[14] F. Ross, "FDDI — A Tutorial (Fibre Distributed Data Interface)," *IEEE Commun. Mag.*, vol. 24, no. 5, pp. 10-17, 1986.

[15] F. Ross, "Overview of FDDI: the Fiber Distributed Data Interface," *IEEE J. Sel. Areas Commun.*, vol. 7, no. 7, pp. 1043-1051, 1989b.

[16] F. Ross, "Fiber Distributed Data Interface: A n Overview and Update," *Fiber Optics Magazine*, July-Aug., pp. 12-16, 1991.

[17] W. Hawe, R. Graham, and P. Hayden, "Fiber Distributed Data Interface Overview," *Digital Technical J.*, vol. 3, no. 2, pp. 10-18, 1991.

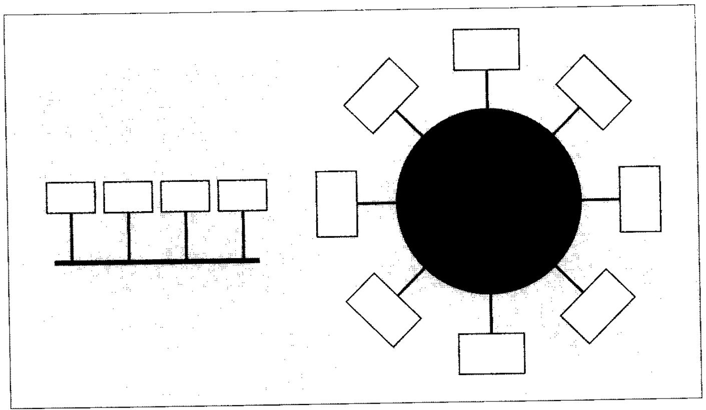


Figure 12. *Shared-media distributed-switching approach.*

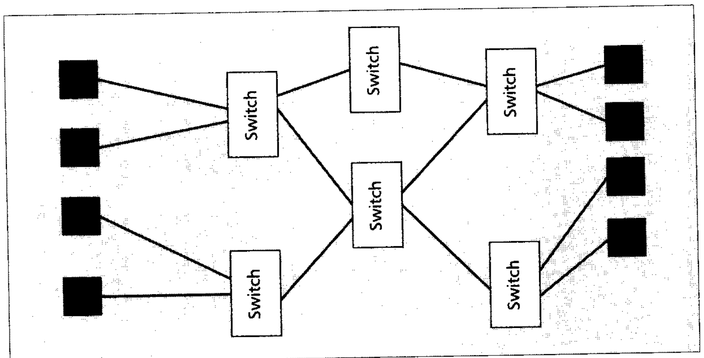


Figure 13. *Shared-switch distributed-media approach.*

[18] K. Caves and A. Flatman, "FDDI-II: A New Standard for Integrated Services High Speed LANs," *Proc. International Conference on Wideband Communications*, Online Publications, Pinner, Middlesex, England, pp. 81-91, 1986.

[19] M. Teener and R. Gvozdanovic, "FDDI-II Operation and Architectures," *Proc. IEEE LCN '89*, Minneapolis, MN, pp. 49-61, 1989.

[20] F. Ross, "Get Ready for FDDI-II," *Networking Management*, vol. 9, no. 8, pp. 54-56, p. 58, 1991.

[21] S. Ginzburg, W. Mallard, and D. Newman, "FDDI Over Unshielded Twisted Pairs," *Proc. IEEE LCN '90*, Minneapolis, MN, 395-398., 1990.

[22] W. Stallings, "ISDN and Broadband ISDN," (MacMillan, New York, 633 pp., 1992).

[23] E. Rigsbee, "SONET Scrambler Interference Analysis of ASC X3T9.5 (FDDI) Mapping Data," Presentation to ASC X3T9.5 Working Group on FDDI/SONET PHY-layer Mapping, SPM/90-011, 1990.

[24] ANSI T1.105-1991, "Digital Hierarchy — Optical Interface Rates and Formats Specifications (SONET) (FDDI and STS path signal level)," Supplement to ANSI T1.105a-1991, 20 November 1991, 5 pp.

[25] ANSI T1.105-1991, "Digital Hierarchy — Optical Interface Rates and Formats Specifications (SONET)," 2 July 1991. ANSI T1.105-1991 includes supplement ANSI T1.105a-1991.

[26] K. Ocheltree, S. Horvath, and G. Mityko, "Requirements and Design Considerations for the FDDI Follow-On LAN (FDDI-FO), Version 2.0," Presentation to ASC X3T9.5 ad hoc working meeting on FDDI Follow-On LAN, FFOL-007, X3T9.5/90-068, 17 May 1990, 5 pp., 1990.

[27] F. Ross and R. Fink, "Overview of FFOL — FDDI Follow-On LAN," *Computer Commun.*, vol. 15, no. 1, 5-10, 1992.

Biography

RAJ JAIN [F '93] is a senior consulting engineer at Digital Equipment Corporation, Littleton, Massachusetts. He received a Ph.D. degree from Harvard University in 1978 and has taught graduate courses in performance analysis at M.I.T. He serves on the editorial boards of *IEEE/ACM Transactions on Networking, Computer Networks and ISDN Systems, Computer Communications* (UK), and the *Journal of High Speed Networks*. A frequent speaker at conferences, he has been an ACM Lecturer since 1992 and is also the Vice-Chair of ACM SIGCOMM. He received a Computer Press Award for his book, "The Art of Computer Systems Performance Analysis" (Wiley, New York, 1991). He is listed in "Who's Who in the Computer Industry, 1989," "Who's Who in Writers, Editors, & Poets 1991-92," and "Contemporary Authors 1991."