ABSTRACT

The Fiber Distributed Data Interface (FDDI) is a 100 megabit per second (Mbps) Local Area Network (LAN) that uses optical fiber as the medium. The FDDI protocol is based on a token ring access method. FDDI is being developed as an American National Standard (ANS) in Accredited Standards Committee (ASC) X3T9. FDDI is also being developed as an International Standard (IS) in ISO/IEC JTC1/SC 25. This paper is intended to provide an introduction to FDDI and the development of the FDDI standards.

BACKGROUND

In the late 1970's, ASC X3T9 recognized the need for a new I/O channel standard as an alternative to FIPS 60-63, which had resulted from their earlier efforts. Task group X3T9.5 was formed to work on serial interface standards, and in late 1982 work was started on FDDI. Initial proposals for FDDI were submitted by Sperry in 1983.

Meanwhile, the Institute of Electronic and Electrical Engineers (IEEE) P802 standards project was developing Local Area Network (LAN) standards for lower data rates. FDDI followed the packet data architectural concepts of IEEE P802 and chose the emerging 4 Mbps token ring protocol of IEEE P802.5 as the starting point for the protocol. These choices made FDDI ideal as both the backbone network and the higher-speed follow-on network for the IEEE P802 LANs.

In another standards arena, the Open Systems Interconnection (OSI) model was being developed. This model layered the design of computer interconnections, allowing the development of separate peer-to-peer standards for the different layers. It provided an ideal framework for developing the FDDI standards.

The 1980's saw a number of changes in the market place. An increased use of high-performance video workstations for a variety of applications brought an increased emphasis on both higher-performance and lower-cost implementations. The cost of optical fiber, which offers many advantages over copper, decreased dramatically, as did the cost of high density integrated circuit chips, so essential for low cost implementations of the complex logic of a ring.

Also in the 1980's, a new generation of digital PBXs with needs quite similar to those of many real-time applications, e.g., digital voice, video, and sensor and control data streams, established the need to integrate circuit-switched data traffic capabilities. This provided the impetus behind the development of FDDI-II.

Under these pressures, FDDI grew from the original proposals, basically aimed at the I/O Channel (back-end) application, to satisfy many other applications, including LAN backbone, front-end high-performance LAN, and circuit-switched data applications. Indeed, the set of services offered by FDDI became broad enough to allow individualized optimization of FDDI networks to satisfy the needs of quite diverse environments.

FDDI STANDARDS

The FDDI STANDARDS are being developed in conformance with the OSI reference model and the OSI management framework and layer management guidelines. There are six standards in all as shown in Figure 1. The basic FDDI, when completed, will consist of the following set of four standards:

PMD - A Physical Layer Medium Dependent standard which specifies the optical fiber link and related optical components.

PHY - A Physical Layer Protocol standard which specifies the encode, decode, clocking, and data framing.

MAC - A Media Access Control standard which specifies station configurations, ring configurations, and the control required for proper operation of stations in an FDDI ring as well as the interface to OSI Management Services.

The following two standards are being developed as extensions to the basic FDDI:

SMF-PMD - A Single Mode Fiber (SMF) version of PMD which provides an alternative to the basic PMD, increasing the permissible fiber links from 2 to 60 kilometers in length.
HRC - A Hybrid Ring Control standard which specifies an upwards-compatible version of FDDI, commonly known as FDDI-II, which adds the capability for circuit-switched services to the packet services of the basic FDDI, creating an integrated services LAN.

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**Figure 1 - Structure of FDDI Standards**

**FUNCTIONAL OVERVIEW**

The basic FDDI uses optical fiber with Light Emitting Diodes (LEDs) transmitting at a nominal wavelength of 1325 nanometers over multimode fiber. Connections between stations are made with a dual fiber cable employing a polarized duplex connector. Optical fiber links of up to 2 kilometers are provided for. A Single Mode Fiber (SMF) version of Physical Layer Medium Dependent (PMD) uses laser diode transmitters to extend individual links to 60 kilometers or greater.

The data transmission rate is 100 Mbps. The token ring protocol allows an effective sustained data rate at the data link layer well over 95 percent of this peak rate. The four-out-of-five code used on the optical fiber medium allows the use of a 125 megabaud transmission rate. The nature of the clocking, which adjusts for accumulated jitter between frames, limits frames to 4500 octets maximum. Multiple frames may, however, be transmitted on the same access opportunity.

Frames use the 48-bit address structure defined by IEEE 802. The assignment of addresses to stations is administered by the IEEE standards office with IEEE 802 stations and FDDI stations sharing a common address space.

A total of 1000 physical connections and a fiber path of 200 kilometers has been used as the basis for calculation of the default values of the recovery timers. Considering reconfiguration requirements, these choices allow for a ring of 500 stations (each station represents two physical connections) linked by 100 kilometers of duplex cable. The choice of larger values than the default values for the recovery timers allows larger networks to be configured.

**NETWORK AND STATION CONFIGURATIONS**

FDDI uses a counter-rotating trunk ring allowing reconfiguration of the ring in the event of failures. This played an important part in satisfying the high reliability objectives established for FDDI.

Each FDDI station is composed of logical entities that form to the above FDDI standards. The functionality of a given station is dependent on the number of each of the different entities of which it is composed. Networks with different physical topologies may be constructed depending on the types of stations used.

Two main classes of stations are specified. A dual attachment station (DAS) has two pairs of PHY and PMD entities and may attach directly to the counter-rotating trunk ring. A DAS station has one or more MAC entities. In the case of two MAC entities, one may be in each of the counter rotating rings, or both may be in the same ring. A DAS station may have an optical bypass switch to remove it from both rings and heal both of the rings should the station be powered down or disabled. A single attachment station (SAS) has but one PHY and one MAC and therefore cannot be attached directly into the main FDDI ring. Instead, it must be attached to the ring via a concentrator.

A concentrator, which may be either a SAS or a DAS, has additional pairs of PHY and PMD entities beyond those required for its attachment to the FDDI ring. These additional PHY/PMD pairs provide for the attachment of additional stations. These additional stations, while logically part of the ring, are physically isolated from the trunk ring by the concentrator. Varying levels of functionality, including multiple MACs, are permitted in concentrators.

The permitted FDDI topology is a ring of trees. This corresponds to one, and only one, counter-rotating trunk ring with trees of cascaded concentrators. All subsets of this topology are also legal.

**RING OPERATION**

PHY provides the protocols and PMD the optical fiber hardware components that support a link from one FDDI station to another. PHY simultaneously receives and transmits. The transmitter accepts symbols from MAC, converts these to five-bit code groups and transmits the encoded serial data stream on the medium. The reverse process is provided by the receiver.

The basic concept of a ring is that each station repeats the frame that it has received from its upstream neighbor to its downstream neighbor. If the destination address (DA) of a frame matches that MAC's address and no error is indicated, then the frame is also copied into a local buffer with MAC notifying LLC (or SMT) of the frame's arrival. MAC modifies indicator symbols in the frame as it repeats it to indicate the detection of an error in the frame, the recognition of its address, and the copying of the frame.
The frame propagates around the ring to the station that originally placed it on the ring. The transmitting station may examine the indicator symbols in the frame to determine the success of the transmission. The MAC of this transmitting station is responsible for removing from the ring all frames that it has placed on the ring, a process termed stripping. MAC recognizes these frames for stripping by the fact that the Source Address (SA) contained in them is its own address.

Each MAC must ensure that frames accepted by it are indeed intended for it, and that they are valid frames and not the result of some noise event.

If MAC has frames to transmit, it must first capture a token, a special frame that indicates that the medium is available for use. Priority requirements are implemented in the rules of token capture. If a station is not allowed to capture the token, then it must be repeated on the ring. Only after capturing a token and stripping it from the ring, is MAC allowed to transmit frames. When finished, MAC issues a new token to signify that the medium is available for use by another station.

During ring operation, SMT monitors ring activity and exercises overall control over station activity. SMT uses primitive signaling sequences to establish the point-to-point physical links between each of the PHY/PMD pairs and sets the internal configuration of the station consistent with the links established. In the event failures are detected, SMT causes the ring to reconfigure to use the counter-rotating ring, a process termed wrapping, to allow continued operation.

**FDDI-II OVERVIEW**

FDDI-II is an upward-compatible enhancement of the basic FDDI that adds a circuit-switched service to the packet service of the basic FDDI.

Figure 1 shows how FDDI-II requires one additional standard, the Hybrid Ring Control (HRC). HRC, inserted between MAC and PHY, becomes the new lowest sublayer of the data link layer. HRC multiplexes data between the (packet) MAC and the isochronous MACs (I-MACs) which are used for FDDI-II.

An FDDI-II ring has 100 Mbps of bandwidth available. This may be used for operation as a packet network as is the basic FDDI. Alternatively, portions of this bandwidth, in units of Wideband Channels (WBCs), may be dynamically partitioned for circuit-switched data. Up to 16 WBCs may be assigned. Each WBC is 6.144 Mbps, which is four times the North American, and three times the European, basic access rate to the telephone network. WBCs are full duplex and are independently allocatable and de-allocatable.

The WBCs provide a bandwidth division mechanism between the packet and isochronous traffic with a granularity of 6.144 Mbps. The allocation of virtual services within the isochronous traffic is allowed with an 8 Kbps granularity. Once a station has been assigned a WBC, or a number of WBCs, that station may suballocate the combined bandwidth of these WBCs as required. This suballocation may be in terms of any multiples of 8 Kbps subchannels, including the commonly used 16, 32, 64 (B-channel), 384, 1536, 1920, and 2048 Kbps subchannels. Mixtures of data rates in the same WBC are allowed. If preferred, the aggregate of any or all of the allocated WBCs may be used as one virtual service, satisfying the needs of such applications as high-resolution video. Thus a multiplicity of virtual circuits may be provided within the same FDDI-II ring.

**FDDI APPLICATIONS**

The basic FDDI may be used in systems as the back end interface to high performance processors, mass storage systems, and other system elements. It may act as a front end connection for high performance work stations. It may also perform the backbone function to lower performance LANs, for example, the various IEEE 802 media access methods.

FDDI-II provides additional capabilities. An FDDI-II ring may have some of its bandwidth allocated to isochronous services provided by the WBCs. This isochronous bandwidth may in turn be suballocated into a variety of virtual circuit services such as video, voice, and control or sensor data streams. Connections to high performance workstations may be provided in a circuit-switched mode. It may also provide a backbone for gateways to the public data networks. The division of bandwidth between these two kinds of services may be adjusted based on the time of day or other requirements.

ASC X3T9.5 has specified the rules of coexistence of FDDI implementations to ensure interconnectability and interoperability of FDDI-II operating in basic mode with the basic FDDI. This also allows the use of FDDI-II chips for all applications when they become available.

**PROGRESS OF STANDARDS**

The FDDI standardization effort is taking place in the ASC X3T9.5 committee which meets bimonthly with an attendance of well over 100 and a voting membership of approximately 80. Ad hoc working meetings, scheduled between the regular meetings as required, focus on specific issues as appropriate.

MAC is an American National Standard (ANSI X3.139-1987) and was published in July 1987. PHY is also an American National Standard (ANSI X3.148-1988) and was published in December of 1988. Activities in 1989 are focusing on potential enhancements to MAC and PHY, including the incorporation of the FDDI-II requirements.

PMD (X3.166-198x), having passed the letter ballots, is now in the final approval process as an American National Standard and should be published in the near future. Agreement on PMD proved particularly difficult to reach because of competition between vendors in the choice of connectors and fiber.
Work has progressed smoothly on the SMF-PMD project which was started in mid-1987. SMF-PMD (Rev. 4.1) was forwarded to X3 for processing for final approval as a standard in 1989.

The technical definition of FDDI-II, long maintained in a working paper, has been completed and is contained in the Hybrid Ring Control (HRC) document. HRC (Rev 5) was forwarded to X3 for processing for approval as a standard in 1989.

SMT has been in the definition phase in ASC X3T9.5 with heavy participation in working meetings from 1987 through 1989. Representing the meeting ground between widely differing FDDI implementation and usage philosophies, SMT has raised many contentious issues. Fortunately, the committee's determination to produce an SMT standard assuring interoperability has prevailed and SMT progressed toward a technical letter ballot in the latter part of 1989.

In a similar process, designed to produce equivalent ISO standards for FDDI, the FDDI documents are being processed by ISO/IEC JTC1/SC 25. MAC (IS 9314-2) and PHY (IS 9314-1) were published as ISO standards in the spring of 1989. PMD (DIS 9314-3) passed the ISO letter ballot for approval as an International Standard by early 1989 with publishing anticipated in early 1990. SMF-PMD and HRC are also under consideration as ISO standards.

Led by ASC X3T9.5, this FDDI standards effort reflects the FDDI product implementations of its many supporters. These include many system manufacturers as well as a number of semiconductor manufacturers working towards FDDI chip sets. FDDI chip sets available in 1989 from several chip vendors promised cost-effective implementations of these FDDI standards.

CONCLUSION

FDDI has developed as the high-speed LAN of choice. Its success has been the result of a high degree of cooperation between the many factions to complete the standard in a manner best satisfying the common goals of all. Where goals were radically different, flexibility was incorporated into the standards to allow local optimization of the FDDI ring to satisfy the different sets of goals. As a consequence, FDDI and its progeny will dominate high-speed LANs on into the next century.