FDDI-II Operation and Architectures

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ABSTRACT

FDDI will likely become the preferred local area network for systems of the 1990's. It provides both the high bandwidth and low latency needed to match the increased capacity of future personal computers, at least for "traditional" LAN applications. The improved latency, however, is not low enough for a true multimedia LAN. What is needed is an access method that simplifies the interface to video and sound networks as well. FDDI-II is an extension of FDDI that provides this additional service. Implementing this extension, while not trivial, is relatively straightforward and does not necessarily add much to the complexity of an FDDI station. This paper discusses the FDDI-II architectural models and operations as defined in the FDDI Hybrid Ring Controller (HRC) specification and additionally presents example implementation architectures for FDDI-II systems.

1. INTRODUCTION

As is well known by now, FDDI is a 100 Mbps local area network and interconnect based on a ring topology using a timed-token protocol. The FDDI network is defined by a set of four documents:

1. the Physical Media Dependent (PMD) standard defining the fiber connection and transceiver,
2. the Physical Layer (PHY) standard defining data encoding and decoding as well as clock requirements, jitter removal, and frequency mismatch compensation,
3. the Media Access Control (MAC) standard describing the access protocol, station addressing and data formats and protection; and
4. the Station Management (SMT) standard which specifies how a station behaves in the dynamics of a real network - initialization, configuration, and error control.

FDDI-II is primarily defined by one additional document: the Hybrid Ring Controller (HRC) standard which describes an upwardly compatible "hybrid" mode of operation. Hybrid Mode provides the standard packet transport used by FDDI and other normal local area networks as well as an "isochronous" transport similar to that provided by the public switched networks.

At the MAC layer, FDDI-II is almost completely the same as FDDI. The only difference is that data may be presented to the P-MAC (packet MAC) at less than the full 100 Mbps rate. At the PMD layer, there are no differences: the transceiver, cable, and connector systems are identical. Even at the PHY layer, the changes are relatively small: more sophisticated smoothing and repeat filters and one additional symbol to decode. Almost all of the extensions to FDDI are localized in the HRC which is architecturally placed between the PHY and the P-MAC as shown in figure 1.

The rest of this paper has three major parts: (1) a description of the FDDI-II environment and integration advantages, (2) a summary of the operation of an FDDI-II network and the architecture of an FDDI-II station as described by the HRC draft standard, and (3) a description of a possible implementation for various FDDI-II stations.

1.1. FDDI-II Environment

Not too long ago, the only standard interactive communications tool used by an individual was a telephone with slower backup provided by mail and TELEX. Now, the
desktop computer has joined the telephone by providing electronic mail and document sharing capabilities. Video teleconferencing is also available for those with the resources. FDDI-II makes the most sense when placed in this complex communications environment, one that is rich in interfaces but is currently prohibitively expensive to bring to each individual.

1.1. Customer Equipment

The primary interfaces for an individual are the systems on the desk: a computer's display, keyboard, and pointing device, and a telephone (with minimal integration between the two). It is very desirable for these systems to be much more tightly integrated, with interactive video and improved-quality sound as likely additions.

There are other important peripherals that are frequently located away from the individual user: printers and data servers for computer-based functions, voice mail systems for telecom functions, modem pools for non-ISDN networks, and (in a rich enterprise) video switching systems for teleconferences. Once again, these it would be best if these two functions could be integrated...so the electronic mail was voice and text and video and graphic, and the printers could produce hard copies of still video, text, and graphic data.

This personal and remote equipment is frequently connected by customer-owned networks ranging from twisted-pair RS 232 data connections to wide-band video coax networks, but with very little integration between any of them. For example, even with elaborate voice/data PBX or Centrex offerings, it is difficult to have a personal computer interact with the telephone features—arrange a conference call based on a personal data base, or display a list of outstanding voice mail messages and select one for playback. Integration functions are usually limited to gateway functions (data PBX, modem pools, LAN-packet network gateways).

1.1.2. Public Network Interfaces

There are three primary public network types that were anticipated in the design of FDDI-II:

1) Analog telephone public switched network. This is currently the most common, although larger enterprises are starting to switch to digital. Nonetheless, this will probably remain extremely important for smaller organizations for the rest of this century.

2) Digital public switched network. This might be called "traditional ISDN" and usually is primary rate (1.544 Mbps T1 in North America is an example) with a few higher rates just recently being offered (35 Mbps DS3 in North America). Since this is a switched service, all packet-oriented transport must be provided by customer equipment.

3) Packet-oriented networks. In the long term, this will likely be provided by the public utilities, but right now the packet networks are mostly layered on top of the utilities' switched services by value-added providers. This has led to a proliferation of protocols with nothing like the uniformity of the analog switched network. Hopefully, broadband ISDN, the 802.6 MAN, and/or the ATM proposals will bring this under control.

1.2. FDDI-II Integration

Currently, if an individual had to have instant access to all these communications systems, then that person would have: a telephone, a FAX machine with its own telephone line, a personal computer with both modem and LAN ports (plus the LAN access cable and another telephone line), and a camera and second video display with wide-band cabling and control system.

FDDI-II brings all these services to the desktop with one basic interface using one media and one access method. The specialized interfaces (analog or ISDN telecom, external packet network, or wideband video) can be located wherever convenient, with FDDI-II providing individual access as shown in figure 3.
1.3. Definitions

The following terms are used in this paper (these definitions are extracted from the HRC draft standard):

**Basic Mode**: An FDDI-II network operating in Basic Mode supports FDDI token ring operation only, that is, only the packet switching service is provided. The data unit transmitted on the medium in Basic Mode is the FDDI frame.

**Circuit**: A circuit is a bidirectional communications capability provided over a continuous isochronous channel(s) between two or more CS-MUX level entities.

**Circuit Switching**: Circuit switching is the service that provides and manages a set of circuits.

**Circuit Switching Multiplexer (CS-MUX)**: A CS-MUX multiplexes and demultiplexes circuits onto Transmission Channels for transmission.

**Cycle**: The cycle is the HRC frame. It has a duration of 125 microseconds and nominally carries 3,120 symbols at 100 Mbps.

**Cycle Master**: One ranked monitor in an FDDI-II ring assumes the role of the Cycle Master. The ring has only one Cycle Master at a time. The Cycle Master is responsible for generating and maintaining the Cycle Structure and the timing of the ring. The Cycle Master inserts a Latency Adjustment Buffer to adjust the ring size to be an integer multiple of 125 microseconds. The Cycle Master is selected by bidding among ranked Monitor Stations - the monitor with the highest rank becomes the Cycle Master.

**Cyclic Groups**: The Cycle Structure contains 16 Wideband Channels (WBCs), which are byte interleaved with each other. The interleaving scheme physically organizes the WBCs into 96 Cyclic Groups per cycle, at 100 Mbps. Each Cyclic Group contains one byte from each WBC. The bytes from each WBC occur in the same position in each Cyclic Group.

**Dedicated Packet Group**: The Dedicated Packet Group is the part of the Cycle Structure which provides a minimum packet channel bandwidth of 0.768 Mbps (at 100 Mbps).

**Hybrid Mode**: An FDDI-II network operating in Hybrid Mode imposes a cycle structure with a length of 125 microseconds. The cycle supports a variable rate packet switching service using the FDDI token ring protocol plus a time-division multiplexed circuit switching service. The bandwidth is partitioned as a dedicated packet data channel plus sixteen Wideband Channels which are dynamically allocated for packet data or isochronous use.

**Hybrid Multiplexer (H-MUX)**: The Hybrid Multiplexer is the component that directs the data flow between the Packet and Isochronous Media Access Control sublayer and the Physical Layer.

**Hybrid Ring Control (HRC)**: Hybrid Ring Control is the protocol that exists in an FDDI-II station to provide integrated packet and isochronous switching. It consists of the Hybrid Multiplexer and the Isochronous Media Access Control.

**Isochronous**: The term "isochronous" indicates the essential characteristic of a time-scale or a signal such that the time intervals between consecutive significant instants either have the same duration or durations that are integral multiples of the shortest duration.

**Isochronous Media Access Control (I-MAC)**: The I-MAC is the data link sublayer entity which provides isochronous data access to a shared medium local area network.

**Latency Adjustment Buffer (LAB)**: The LAB is a component that is required at the Cycle Master to insure that the ring isochronous channel latency is a multiple of 125 microseconds.

**Media Access Control (MAC)**: The MAC is the Data Link Layer sublayer responsible for scheduling and routing data transmissions on a shared medium Local Area Network (e.g. an FDDI ring).

**Monitor Station**: Monitor Stations in an FDDI-II network are those stations capable of becoming the Cycle Master. A Monitor Station is permitted to participate in the Monitor Contention procedure to become the Cycle Master only if it has a rank that is greater than zero.

**Non-Monitor Station**: A Non-Monitor Station in an FDDI-II network does not have the capability of becoming the Cycle Master. It does not enter into the Monitor Contention procedure to select the Cycle Master.

**Packet Media Access Control (P-MAC)**: The data link sublayer entity responsible for scheduling and routing data transmissions via a packet data channel on a shared medium local area network.

**Packet Switching**: The service that transfers packetized data. It is provided in FDDI and FDDI-II by the FDDI Packet-Media Access Control entity (P-MAC).

**Physical (PHY) Layer**: The Physical Layer is responsible for transmitting and receiving a symbol stream on the physical transmission medium.

**Slave Station**: A slave station in an FDDI-II network is any station which is not the Cycle Master. A Slave Station may be either a Monitor Station or a Non-Monitor Station.

**Station**: A station is an addressable entity physically attached to the ring medium, capable of transmitting, re-
ceiving, and repeating information. An FDDI station has one or two PHY entities, one or more MAC entities, and one SMT entity.

Station Management (SMT): The supervisory entity within an FDDI station which monitors and controls the various FDDI entities including PMD, MAC and PHY.

Transmission Channel: A transmission channel is a portion of a Wideband Channel. It is used to transfer isochronous data. Transmission channels may be of different sizes. The ISDN basic rate channel, of 64 kbps, is one of the transmission channels supported by this standard.

Wideband Channel (WBC): The WBC is a single unit of bandwidth in the HRC that is assigned to either isochronous or packet data use. WBCs may be subdivided into transmission channels.

2. FDDI-II STATION ARCHITECTURE

Stations composed of FDDI and HRC entities are referred to as FDDI-II stations. The FDDI Packet MAC (P-MAC) and the HRC components, and their architectural relationship to LLC and a Circuit Switching Multiplexer (CS-MUX) are illustrated in figure 1. This figure does not imply an implementation configuration.

A Monitor Station, illustrated in figure 4, incorporates the Physical Layer (PHY), Packet Media Access Control (P-MAC) and Logical Link Control (LLC) required by FDDI. Additionally, the Hybrid Multiplexer (H-MUX), Isochronous Media Access Control (I-MAC), and Latency Adjustment Buffer (LAB) are required by Monitor Stations. The LAB is operational in the Cycle Master and may be operational in the other Monitor Stations.

A Non-Monitor Station, illustrated in figure 5, also incorporates the PHY, P-MAC and LLC required by FDDI and the HRC H-MUX and I-MAC. Non-Monitor Stations, however, do not have the LAB, nor do they have the capability to initiate cycles.

3. FDDI-II OPERATION

FDDI-II is defined as an extension to FDDI which integrates isochronous and packet data on the same FDDI medium by use of the HRC protocol. The 'dual ring of trees' network topology, specified for use with FDDI, is equally applicable to FDDI-II. Similarly, the other major parameters defined for FDDI, including the media type, total media path length, bit rate and number of stations supported on a network, also apply to FDDI-II.

An FDDI-II station may operate in one of two modes: Basic Mode, which is identical in operation to the original FDDI token ring, and Hybrid Mode, which is the FDDI-II mode of operation. Hybrid Mode operation requires the existence of a Hybrid Ring Control (HRC) entity between the FDDI MAC and the FDDI PHY and differs from Basic Mode in that both FDDI token ring operation and isochronous data transfer are multiplexed onto the same medium with ring bandwidth being dynamically allocated between packet and isochronous traffic in units of 6.144 Mbps. This paper will concentrate on the characteristics of Hybrid Mode operation.

The Hybrid Mode of operation is controlled by a station called the Cycle Master. The Cycle Master is responsible for generating special FDDI-II frames known as cycles onto the ring and also for inserting a Latency Adjustment Buffer to adjust the ring size so that it contains an integral number of these cycles. Stations capable of assuming the Cycle Master role are known as Monitor Stations. All other stations on the hybrid ring are referred to as Non-Monitor Stations.
Stations. There may be any number of Monitor stations on the ring but there may only be one Cycle Master at any one time. The Cycle Master may be assigned before Hybrid Mode initialization, or it may be selected dynamically through the Monitor Contention process from a set of ranked Monitor Stations. This would happen either during hybrid initialization, or during the recovery process after cycle synchronization has been lost or after out of sequence cycles have been detected. The value of a station's rank for use during Monitor Contention is derived from a combination of an optional assigned logical rank and a station's ID in such a way as to guarantee unique Monitor ranks. A logical rank may be assigned to any Monitor station by a Network Manager.

The Hybrid Ring is initialized in Basic Mode via the MAC Claim process. After initialization FDDI-II remains in the Basic Mode of operation until a user application has a requirement to transmit isochronous data, such as voice. The application then makes the appropriate request to Station Management, which responds by attempting to take the ring into Hybrid Mode. The exact process followed may vary according to circumstances, typically, however, this would involve allocating synchronous bandwidth to isochronous traffic, assigning Monitor ranks, and ensuring that all stations on the ring are FDDI-II compatible. (Every station on the ring must have FDDI-II capability in order for the transition to Hybrid mode to succeed.) The transition to hybrid mode is initiated by a Monitor station transmitting a cycle onto the ring. The rotation of the first cycle round the ring effectively takes the ring to hybrid mode. Once hybrid mode operation had been established a ring would normally stay in Hybrid Mode. It could, however, be taken back to Basic mode if required by use of the MAC Claim or Beacon process.

During Hybrid Mode ring operation the Cycle Master transmits cycles consisting of preamble, cycle header, dedicated packet group, and cyclic data groups every 125 microseconds. The cycle timing used may be derived from the Cycle Master's local timing or alternatively may be derived from some external frequency reference such as ISDN. In the absence of errors "slave stations" (all stations except the Cycle Master) monitor and repeat the Cycle Header unchanged. Both the Cycle Master and the slave stations monitor the various fields of the Cycle Header to ensure that correct ring synchronization is being maintained. Within the dedicated packet group and cyclic data groups, normal FDDI token ring operation takes place on the bandwidth assigned to the packet data channel, while circuit switched connections may be established within the bandwidth assigned to isochronous traffic. The signalling required for setting up circuit switched connections would normally be carried out over the packet channel.

### 3.1. Cycle Structure

The HRC protocol is based on special HRC frames called cycles that carry packet and isochronous data. A new cycle, consisting of control and data octets, is generated by the Cycle Master every 125 μs. The 125 μs cycle was chosen to facilitate interconnection with public switched networks. This Cycle is partitioned into 4 parts: the Preamble, the Cycle Header, the Dedicated Packet Group, and the WBC Cyclic Groups as shown in figure 6.

![Figure 6. The HRC Cycle](image)

- **Cycle:** 125 μs (nominally 3125 symbols)
- **PA:** Preamble (nominally 5 symbols) The Preamble is nominally 5 symbols long. The cycle clocking algorithm will normally produce preamble lengths between 4 and 6 symbols.
- **CH:** Cycle Header (24 symbols)
- **DPG-11:** Dedicated Packet Data Group (24 data symbols). The DPG is byte interleaved among the Cyclic groups
- **CG0-95:** Cyclic Group 0 to 95 (32 symbols, 2 symbols per WBC). The nth symbol pair in each Cyclic Group belongs to the nth WBC, where n ranges from 0 to 15.

The Cycle Header establishes the 125 microsecond boundary and conveys the cycle control information and the Programming Template.

The rest of a cycle's bandwidth is partitioned into a Dedicated Packet Group and 16 Wideband Channels (WBC) each corresponding to 6.144 Mbps of the ring's bandwidth. Each Wideband Channel can be dynamically allocated for either packet data or isochronous use by the Cycle Master via a programming template transmitted in each cycle. The Dedicated Packet Group (DPG) guarantees a minimum packet channel bandwidth of 768 kbps (12 bytes of the cycle). It is concatenated with any Wideband Channels allocated to packet traffic to form the Packet Data Channel. The Packet Data Channel provides a virtual FDDI ring (with the data rate depending on the number of WBCs allocated to it) over which the Packet MACs may run the normal FDDI timed token protocol.

Each WIBC allocated for isochronous use can be subdivided into lower speed transmission channels by the
Isochronous Media Access Control (I-MAC) component of the HRC. Each data octet of a transmission channel provides 64 kbps of isochronous bandwidth, which corresponds exactly with one ISDN B channel. FDDI-II therefore provides very efficient support for 64 kbps circuit switched voice calls, as well as other ISDN B channel data. Furthermore the Wideband Channel bandwidth of 6.144 Mbps may conveniently be subdivided into either 4 units of 1.536 Mbps or 3 units of 2.048 Mbps and thus provides efficient support for both the American and European primary rate ISDN channels. In order to further increase flexibility and provide support for different types of service, FDDI-II allows separate allocator stations for isochronous WBCs with different allocation policies to coexist on the same ring.

The WBCs are byte-interleaved across 96 Cyclic Groups of 32 symbols each. Each row in figure 7 represents a cyclic group, and contains one byte from each WBC. Since WBCs are numbered from 0 to 15, the byte belonging to WBC "n" is composed of the 2n and 2n+1 symbol in each cyclic group. Figure 8 illustrates the interleaving of WBC 3 across the cyclic groups. The octets of the DPG are interleaved with the Cyclic Groups; the first octet preceding the first Cyclic Group and succeeding octets occurring after every subsequent eighth Cyclic Group.

### 3.2. Cycle Control

Cycle Control is the responsibility of the Hybrid Multiplexor (H-MUX) entity within HRC. Cycle synchronization is effected by H-MUX through use of the elements of the cycle header: the start delimiter (SD), the synchronization control symbol (C1), the sequence control symbol (C2), and the cycle sequence field (CS). The position of these fields in the cycle header is shown in figure 9.

The **Start Delimiter** (SD) consists of the two symbols JK which form a unique ten bit sequence. This is used by the FDDI-II PHY entity to identify the start of a cycle.

The **Synchronization Control symbol** (C1) may take the values R or S. A value of R indicates that synchronization has not been established and any cycle may be legitimately interrupted by a new cycle.

A value of S indicates that full synchronization has been established and the current cycle may not be legitimately interrupted by a new cycle. On receiving a cycle header with C1 set to S the FDDI-II PHY may lock into cycle holding mode. In this mode the PHY assumes that the first JK start delimiter received within a cycle is an error, it therefore does not recenter its elasticity buffer and reports it to H-MUX as a pair of violation symbols. This virtually eliminates the probability of locking on to false JKs caused by transmission errors.

A Cycle Master sets this symbol to S once full synchronization has been achieved. Slave
stations detecting a cycle synchronization error reset C1 to R.
Slave stations may never set C1 so synchronization errors on the ring are always indicated to the Cycle Master by the receipt of C1 = R.

The Sequence Control symbol (C2) may take the values R or S.
A value of R indicates that either the cycle sequence has not yet been established or that a cycle sequence error has been detected.
A value of S indicates that the correct cycle sequence has been established.
Since a Cycle Master originates the sequence it assumes it to be correct and always sets this symbol to S. Slave stations detecting a sequence error reset C2 to R. Slave stations never set C2 so any sequence errors on the ring are always indicated to the Cycle Master by the receipt of C2 = R.

A combination of R and S symbols in the C1 and C2 fields identify the cycle header to be the start of a cycle rather than a normal FDDI frame. Once hybrid mode is established, non R,S values are treated as errors and would not normally cause a return to Basic mode. However the receipt of MAC frames (eg. Claim or Beacon) does causes HRC to revert to back to Basic mode to allow normal FDDI recovery procedures to take place.

The Cycle Sequence (CS) field takes the form (NN) where N is a data symbol. Depending on its value it either represents the cycle sequence or a monitor rank.
A value between 64 and 255 indicates the cyclic sequence in the form: 64 + (n mod 192).
A value between 1 and 63 indicates a station's monitor rank. The rank is only valid if C1 = C2 = R, otherwise it is treated as an error and ignored.
A value of 0 indicates a NULL monitor rank. A station with this rank can not win the monitor contention process, however it may initiate it.

During Monitor Contention a Monitor station transmits cycles with C1 = C2 = R and CS set to their monitor rank. A Monitor receiving a contention cycle with a higher rank, yields to this cycle and enters the Slave mode of operation where it simply repeats contention cycles. Eventually the highest ranked Monitor will receive its own contention cycles, it may then assume the role of Cycle Master.
Monitor Contention would normally occur during initialization or recovery from a serious error condition such as Cycle Master failure.

The 16 Programming Template symbols (P0-P15) represent the type of data in each of the corresponding 16 WBCs. The symbols P0-P15 may each take the value R, S or T to indicate whether each corresponding WBC is carrying packet data (R symbol), or isochronous data (S symbol). The symbol T is substituted for a corrupted R or S by the station detecting the error.

The Programming Template is maintained by SMT in the Cycle Master and may be changed by the Cycle Master as necessary. In the absence of errors no other station may change the Programming Template. The received Programming Template is used by each station to identify the data for each WBC which it has open as being either packet or isochronous. For open WBCs, packet data is delivered to the P-MAC, and isochronous data to the I-MAC. The I-MAC divides each isochronous WBC into individual Transmission Channels and delivers the data from the Transmission Channels it has open to a higher layer function, the CS-MUX. (The CS-MUX is not part of the FDDI-II standard, but is expected to provide the final level of multiplexing necessary for normal octet-level circuit switching).

Figure 10 illustrates the relationship between the programming template and the WBCs' assignment to packet or isochronous mode.
The Isochronous Maintenance Channel (IMC) is dedicated to carry isochronous traffic for maintenance purposes. The recommended use for this channel is to carry voice traffic encoded to the applicable national standard.

3.3. Clocking and Synchronization
FDDI-II employs the same independent point to point clocking at the bit level that is currently specified in the FDDI standard. In addition, when an FDDI-II ring is operating in Hybrid Mode there is an independent 8 kHz clock imposed on the ring by the Cycle Master which
groups the data into the 125 microsecond cycle data structures described previously.

All slave stations synchronize to the received 8 kHz cycle rate, thus ensuring that 8 kHz synchronization is maintained round the ring. Each station, however, uses its own autonomous bit clock for transmission. Clock tolerances at ring stations are compensated for by variation in preamble length. Cycles nominally contain 15,625 bits but clock tolerances at ring stations may cause cycles to become shortened to 15,620 bits or lengthened to 15,630 bits, resulting in preamble lengths of either 4, 5, or 6 symbols. The variation in preamble is largely absorbed by a smoothing filter present in each FDDI-II PHY.

3.4. H-MUX Structure

The H-MUX is the HRC entity responsible for the management of transitions between Basic and Hybrid Modes, and for the control and maintenance of Hybrid Mode cycle synchronization. The H-MUX also controls the flow of data between the P-MAC, I-MAC and PHY entities in both modes. In Basic Mode data is passed directly between the P-MAC and the physical layer. In Hybrid mode, the H-MUX multiplexes and demultiplexes the I-MAC's isochronous data and the P-MAC's packet data onto or out of the physical layer. The functional architecture of H-MUX is illustrated in figure 11. The shaded blocks (CGEN and LAB) are only required in a Monitor Station.

The H-MUX in a Non-Monitor Station includes only the Cycle Acquisition and Cycle Exchange functional blocks.

3.4.1. Cycle Acquisition

The Cycle Acquisition process is best thought of as two co-operating sub-processes: Receive Control and Cycle Control.

The Receive sub-process continually monitors data received at the PHY interface; it is responsible for identifying the start of received cycles, cycle errors, and the receipt of MAC frames. The occurrence of these events is communicated to the Cycle Control sub-process. In addition, the Receive sub-process breaks the incoming cycles down into cycle header and data fields. The cycle header field is used by the Cycle Control sub-process, while the data field is sent to the LAB in a Monitor or Cycle Exchange in a Slave.

The Cycle Control sub-process works in conjunction with the Receive sub-process to continually monitor received data for valid cycles and MAC frames. The C1, C2, and CS fields following received start delimiters are checked, processed and the appropriate actions taken.

The Programming Template, from each received cycle, is copied by the Cycle Acquisition block and used for identifying the contents of each WBC to be either packet or isochronous data.

3.4.2. Channel Exchange

The primary function of the Channel Exchange process (CXC) is to route any WBCs which are open at this station out of the stream of cycle data to the P-MAC and I-MAC entities, insert data from the P-MAC and I-MAC back into these WBCs and combine the new cycle data with the header information from the Cycle Acquisition or Cycle Generation process to...
form the cycle to be transmitted to PHY.

3.4.3. Cycle Master Capability
In order to provide Cycle Master capability, the H-MUX in a Monitor Station must include the Cycle Generation (CGEN) and Latency Adjustment Buffer (LAB) functions in addition to the functional blocks required by a Non-Monitor station.

The LAB provides the buffering required by a Cycle Master to ensure that the ring contains an integral number of cycles. Received data is written into the LAB by the Cycle Acquisition process and read out by the Cycle Exchange process.

The Cycle Generator provides the extra control functionality required by a Monitor for it to have the capability to source cycles. The tasks which need to be performed by the Cycle Generator therefore include: deciding when to source and when to repeat cycles, controlling the LAB, providing the facility for SMT to assign WBCs, and synchronization of transmit 8 kHz timing to an external reference.

3.5. I-MAC Structure
The I-MAC performs an analogous function for isochronous data to that performed by the Packet MAC for packet data. This essentially involves controlling access to channels within open WBCs. This is done under the control of SMT which may open and close isochronous channels by updating a Steering Map within the I-MAC which identifies the current open channels within the open isochronous WBCs. The I-MAC receives all symbols within open isochronous WBCs from the H-MUX, and separates the channels based on this Steering Map. Channels in use at this station are delivered by I-MAC to the CS-MUX where they are routed to the appropriate application. Channels not open at this station are passed by I-MAC back to H-MUX so that they may be repeated. In the opposite direction, I-MAC receives data from the CS-MUX for transmission in isochronous channels. It is possible for I-MAC to open channels in a broadcast receive mode whereby a broadcast channel is both received and repeated. This is useful, among other things, for the distribution of dial and DTMF tones used in telephony.

4. FDDI-II MANAGEMENT
FDDI-II station management is a superset of FDDI station management and as a consequence FDDI-II uses all the standard FDDI connection management and fault recovery techniques. In general if recovery is not possible in Hybrid Mode an FDDI-II ring reverts to Basic Mode and executes all the standard, currently defined, FDDI recovery procedures, such as Claim, Beacon, PC Trace, etc. Similarly the procedures for inserting a station into the ring are the same for FDDI-II as for FDDI.

However the SMT services defined for FDDI token ring operation are not in themselves sufficient for FDDI-II operation. FDDI-II therefore defines extensions to FDDI SMT which are required for management of functions associated with Hybrid mode operation. These extensions can broadly be divided into three categories of SMT functions:

1) Hybrid Mode initialization and recovery procedures.
2) Management of the HRC objects: H-MUX and I-MAC.
3) Resource allocation, such as isochronous bandwidth management.

FDDI-II SMT provides such services as are required to maintain hybrid mode operation. This includes such functions as provision of reference 8 kHz timing, monitoring the H-MUX for possible error conditions, initiating H-MUX recovery, and monitoring the use of Purge frames for token recovery in Hybrid Mode.

SMT provides a full set of services to management applications to facilitate management of the set of FDDI-II objects. FDDI-II SMT therefore includes functions associated with setting HRC parameters and policy options, reporting the state of HRC variables, initiating HRC actions, re-

Figure 12. Architectural block diagram of the I-MAC
porting HRC events, opening and closing Wideband Channels at the H-MUX, opening and closing Isochronous Channels at the I-MAC, and the collection of HRC statistics. The architectural model for Management of an FDDI-II station, shown in figure 13, is similar to that already defined for FDDI, with the addition of the appropriate extensions for the HRC entities.

Possibly the most significant addition to SMT defined by FDDI-II is concerned with resource allocation and in particular bandwidth management. A hierarchy of procedures has been defined for bandwidth management as shown in figure 14 below. These fall into two broad categories. The first is concerned with the allocation of bandwidth between packet and isochronous traffic and is known as WBC Management, while the second is concerned with the allocation of isochronous bandwidth within isochronous WBCs and is known as Channel Management.

Wideband Channel Management is composed of two levels of hierarchy: the System Management procedure and Cycle Master procedures. The System Management procedure is concerned with WBC Policy Setting and provides a service to management which allows it convey to the FDDI-II Cycle Master the maximum number of WBCs that may be allocated for isochronous use.

Once policy has been set the Cycle Master SMT has the responsibility for allocating isochronous bandwidth in units of one WBC, to any stations designated as Channel Allocators, according to the policy currently in force. When the Cycle Master receives a request for isochronous bandwidth from a Channel Allocator it will, providing current policy setting allows, allocate a WBC to isochronous traffic, change the appropriate symbol in the Programming Template and assign responsibility for isochronous bandwidth allocation within that WBC to the requesting Channel Allocator.

Once a WBC has been allocated to isochronous traffic the management of the individual channels within that WBC is carried out by a station which has been designated as a Channel Allocator for that WBC. A number of Channel Allocators may exit concurrently (by default the Cycle Master is a Channel Allocator) each with responsibility for one or more isochronous WBCs. Channel Allocators are responsible for allocation of isochronous bandwidth to user stations.
When a user station wishes to set up an isochronous connection with another station across the FDDI-I network, it must first request a channel with the appropriate characteristics from a Channel Allocator. The Channel Allocator may either confirm the request or reject it giving a reason. Once a channel has been allocated, an appropriate call control protocol is used to establish the call. When the call has been terminated, the originating station informs the Channel Allocator which releases the bandwidth for future use.

Channel Allocators maintain a record of which stations are using which isochronous channels within the WBCs under its control and how much bandwidth these stations need and are allowed. Both the Cycle Master and all the Channel Allocators undertake regular garbage collection procedures to ensure that isochronous bandwidth is not "lost" due to user station or Channel Allocator malfunction.

5. IMPLEMENTATION ARCHITECTURES

Implementation of FDDI-II stations can be simple extensions of standard FDDI designs. As was mentioned in the introduction, an FDDI-II station is little more than an FDDI station with the addition of an HRC and associated hardware to handle isochronous data. The complexity of this extra hardware varies with the required functionality as shown in the following two examples.

5.1. Basic Voice/Data System

A basic FDDI-II system might just provide a sensible integration of the voice and data networks. This would distribute some of the feature processing of an advanced switching system out to the user, but mostly it would provide a much more pleasant interface for many of the more complex capabilities of such a system. In a small organization or workgroup it is conceivable that a network of FDDI-II workstations could completely replace all local switching hardware.

For this example we shall assume such a small workgroup with few data servers and standard telecom interfaces as shown in figure 15. Note that in this model the FDDI-II concentrators would be identical to their FDDI equivalents with the PHYs updated to FDDI-II specifications.

5.1.1. Basic Voice/Data Station

A basic voice/data FDDI-II station is shown in figure 16. Note that it does not have to include the monitor functions of the HRC (the grayed area), but our estimate is that this would only add $10 to $20 to the cost of the implementation and the extra redundancy for the network makes it worth while.

For this simple station, there only needs to be a single transmission channel (unless local conferencing is desired). The implementation of a single channel I-MAC and CS-MUX consists only of a single counter-comparator combination: the counter to keep track of WBC and CG numbers, the comparator to select the correct byte(s), and a latch to hold the selected data. It would be hard to get much simpler.

5.1.2. Voice/Data Interface Station

The interface station is simply the location for the interfaces to the public switched network. This would have to be somewhat more complex than a basic station because the I-MAC and CS-MUX would have to handle multiple channels. Fortunately, this is not difficult since a multi-channel I-MAC/CS-MUX is just an adaptation of the time slot interchange circuit for a simple digital PBX.
If the interface to the PSN was digital, then the station would also have to include a clock synchronization circuit to prevent data under- or overrun. This is nothing more than a long time constant PLL to keep the local cycle clock in constant phase with the PSN clock.

5.2. Wide-Band Access

If we want to take FDDI-II into a more complex environment, we might imagine a system with all the interfaces included in figure 2. This would be a true multimedia network providing video conferencing and servers.

The standard workstation implementation would be almost identical to the implementation outlined above: the only difference would be the much larger bandwidth additional channel in the I-MAC/CS-MUX for the video data. The concentrator for such a large system will likely be different, however.

5.2.1. Hybrid Concentrator

Carrying a significant number of video channels is beyond even the capabilities of FDDI. A single channel of mildly compressed full motion broadcast quality video would use almost half the capacity of the network. Only when compressed down to T1 rates can we support as many as 64 video channels, which is still not sufficient for a large network.

To address this problem, we propose a true hybrid concentrator (see figure 18) that separates the isochronous data for each slave station and uses standard space and time switching technology to interconnect video channels within the concentrator. This is also the natural place to provide interfaces to external broadband networks (SONET or analog). Combined with T1-rate video compression, these high performance concentrators would only have to be used at the root of an FDDI tree as shown in figure 19.
6. CONCLUSION
FDDI-II is a powerful extension to FDDI, providing the highly desirable isochronous transport while making minimal changes to the hard-won standards in the FDDI PMD, PHY, and MAC documents. Furthermore, this was accomplished without requiring packetizing the isochronous data, guaranteeing an easy interface to both the public switched network and customer premises equipment. Although there are other proposals for providing both standard packet and isochronous transports (such as the 802.6 Dual Queue Distributed Bus or several other broadband ISDN proposals), they all require packetizing the isochronous data. Since a packet is not the normal form of the data at the point of generation (an A/D) or consumption (a D/A), this complicates the interface.

FDDI-II implementations can be quite simple, with the extensions to an FDDI implementation only requiring variations on the time-division multiplexing circuitry that has been well-developed by modern telecom designers.

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