A NETWORK ARCHITECTURE FOR ADVANCED AIRCRAFT

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ABSTRACT

Next-generation avionic systems require a fault-tolerant, high-performance data communications mechanism to support advanced avionics processing. These systems will be comprised of loosely-coupled avionics processing elements, including data processors, signal processors, and displays, that will communicate through a high-speed, message-passing avionics interconnect. Northrop has proposed the Fiber Optic Data Distribution Network as a candidate interconnect for these advanced avionics systems. In addition to providing the functionality, performance, and fault-tolerance requirements for these next-generation platforms, the FDDN achieves multi-vendor interoperability, which is essential towards meeting the system-level goal of common avionics.

INTRODUCTION

The Fiber Optic Data Distribution Network (FDDN) is a networking architecture defined to meet the interprocess communications needs posed by advanced avionic systems. Requirements for the FDDN have primarily been driven by the Joint Integrated Avionics Working Group (JIAWG). The JIAWG was formed under the Office of the Secretary of Defense (OSD) to consolidate all advanced avionics development activities across the services. Three major programs were selected to fall under the JIAWG umbrella: the Navy's Advanced Tactical Aircraft (ATA), the Air Force's Advanced Tactical Fighter (ATF), and the Army's Light Helicopter (LHX).

Among the first accomplishments of the JIAWG was the establishment of the Advanced Avionics Architecture (A³) as the framework for future avionic systems. A set of Common Modules is also being defined to provide the avionics integrator with a complement of standard avionics building blocks from which an avionics system can be developed. The primary goal of the Common Modules approach is to reduce overall avionics costs; the government cannot afford to design and maintain custom equipment for each avionics platform.

The A³ represents a significant departure from previous avionic systems. In previous systems, a single mission computer performed all avionics processing and controlled avionics sub-systems through the MIL-STD-1553 bus. MIL-STD-1553 is a 1 Mbps, command/response multiplex bus designed to be the primary interconnect for centralized avionic systems. While MIL-STD-1553 was well suited for this architecture, it does not possess the functionality or meet the performance demands of the distributed A³. Recognizing these limitations, the JIAWG defined the High Speed Data Bus (HSDB) as the primary avionics interconnect[3]. The HSDB is a 50 Mbps, token-passing, linear bus based on a variant of the IEEE 802.4 token-passing bus access protocol[4]. Unfortunately, the HSDB only provides Data Link services. Mandatory, upper-layer functionality has not yet been specified, resulting in increased demands on the already complex Host operating system[5]. This ineffective partitioning reduces overall Host performance.

The FDDN is a high-performance network architecture designed to meet the varied demands posed by the distributed A³. A variant of the JIAWG A³ proposed by Northrop is shown in Figure 1. Advanced, avionic applications residing in common data and signal processors, as well as special-purpose processing elements utilize the FDDN as an extension to the Host operating system interprocess communications facility. A distributed avionics database will be maintained by the FDDN to facilitate the exchange of mission critical data. In addition, responsive message-passing services are offered to enable critical control information to be transparently exchanged throughout the avionic system.

AVIONICS INTERPROCESS COMMUNICATION REQUIREMENTS

Distributed processing imposes significant performance and functionality demands on the avionics network. The network must guarantee that avionics data is delivered timely and reliably. Adequate concurrency and growth capacity is also essential. A distributed database must be maintained to allow data-driven
Versatile communication services are needed to support distributed, data-driven avionics processing. Reliable, message-oriented services are required to enable sequenced, arbitrary-length data transfers. Bulk data transfer services must be provided to support down-line loading and database initialization through the network. Flow control and rate control must also be enforced to alleviate receiver congestion at the data sinks. Protocol operation must be parameterized to facilitate diverse avionics system configurations and behavior. Flexible addressing modes coupled with an efficient multicast facility are also necessary to support process migration and Host-independent processing.

Fault tolerance is also essential to achieve avionics system integrity. Communications must be maintained, even when failures have occurred on the network. Effective fault mechanisms must quickly detect and isolate network faults. Extensive management services are also required to contain faults and rapidly initiate recovery. A single failure must not preclude communications among the remaining Hosts in the system.

Another key requirement is multi-vendor operability. Because attachments to the network will be developed by a variety of independent vendors, an unambiguous, standard interconnect is essential. This can only be achieved through the use of standards. Emerging commercial standards that are based on proven technologies are evolving in industry. Risks associated with the integration of these protocols have been significantly reduced by readily available VLSI implementations, test and integration tools, and documented analyses of the protocols. The avionics network must exploit these advances to reduce development, integration, and testing costs.

**FDDN OVERVIEW**

The FDDN has evolved from commercially-developed protocols in order to realize the vast benefits of standards (see Figure 2). Rigorous use of standards motivates a limited set of building blocks that reduce the risk and ultimately the cost of providing connectivity throughout the avionics system. Figure 3 depicts a functional block diagram of the FDDN delineating four functional layers. The Host Interface provides an efficient Host/Network interface as well as maintaining a distributed database for Host applications. Message-oriented services and routing are provided by the Transfer Layer, which is based on the emerging Xpress Transfer Protocol (XTP). The LAN Layer supports a responsive, high-bandwidth LAN based on the ANSI Fiber Distributed Data Interface (FDDI). Network media, attachment, and bypass functions are provided by the fiber optic FDDN Cable Plant, which has been designed to endure the stringent military aircraft environment. In addition, distributed management services are provided to ensure a high degree of availability and network integrity.

![FDDN Evolution](image-url)

**HOST INTERFACE**

The Host Interface provides the physical and logical interface between the FDDN and the Host. This interface has been designed to decouple the Host from the network, minimizing the interaction necessary to support Host/FDDN data transfers. The JAWS standard Protocol Interconnect (PI-Bus) [6] serves as an intermediary between the Host and the FDDN for all information exchange. Host autonomy is achieved by maintaining Host buffers, including the database, resident within the FDDN. These buffers eliminate the need for speed-matching mechanisms when interfacing different types of Hosts to a common FDDN module.

Distributed database management capability is provided by the FDDN to maintain the Global Dynamic Database. This platform-dependent database is comprised of the blackboards and data required for advanced avionics processing. The Global Dynamic Database is a logical abstraction that is partitioned...
Figure 3.
FDDN Functional Block Diagram.

Figure 4.
FDDN Global Dynamic Database.
FDDN module will maintain a partition of the entire logical database determined by the applications processes that it must service. Application processes poll the database to read a particular entry. The Host Interface responds by returning the current value associated with the functional address.

Each time an entry is polled, an access tag is updated. This access tag indicates whether or not the entry has been updated. Polling is used to eliminate the need for the FDDN to interrupt the Host when data is received. When database updates are received (from the Host or the network), the Host Interface will clear the access tag and overwrite the appropriate location with the updated value. Both time tags and transaction IDs are used to qualify Database updates for time and order synchronization.

FDDN also provides an efficient message-passing capability. Message Buffers consist of a pair of read/write First-In-First-Out (FIFO) queues are maintained to enact message transfers. Host messages with real-time response requirements are placed in the Immediate Message Queue. Upon receipt of an Immediate Message, the Host Interface will interrupt the Host and deliver the message as rapidly as possible. Messages that do not have such stringent latency ceilings are stored in the Non-Immediate Message Queue. This queue can be configured to deliver messages to the Host in a variety of ways, including:

- Host polls for message(s)
- Only when the Queue is filled
- When n messages are received

This Host data transfer scheme improves overall system performance. Processing intensive context switching and interrupt handling, which are required for FDDN/Host data exchange, can be greatly reduced. Backplane bus loading is also relaxed, as fewer bus operations are required to deliver messages to the Host.

TRANSFER LAYER

The FDDN Transfer Layer includes the functionality of the ISO/OSI Network and Transport Layers (Layers 3 and 4 of the ISO/OSI reference model). The Network Layer provides internetwork routing and path determination. The Transport Layer maintains reliable, process-to-process, message-oriented communications. These two layers have been consolidated into a single Transfer Layer entity to enhance communications performance.

The Xpress Transfer Protocol [7] has been incorporated into the FDDN protocol suite. The XTP was developed by Protocol Engines Incorporated (PEI) of Santa Barbara, California, and is intended for use in those real-time networks that support distributed systems, e.g., avionic systems. PEI was formed to promote the protocol and to develop the Protocol Engine™, a VLSI implementation of the XTP. This protocol was recently selected by the U.S. Navy LAN committee for the Survivable Adaptable Fiber Optic Embedded Network (SAFENET) [8] LightWeight Protocol (LWP) [9]. PEI also intends to pursue ANSI and ultimately ISO standardization for the XTP.

The XTP supports connection-oriented data transfers with implicit connection setup. A connection, which defines the state of a communications link, is a virtual circuit established between two Transfer Layer entities. XTP connections (referred to as Contexts) require minimal overhead and can be rapidly established on a demand basis, utilized, and terminated to support many concurrent applications data flows. This greatly decreases connection management complexity and resources necessary for enhanced concurrency.

Internetworking support is provided to achieve processor-independent communications. Each application process is assigned a virtual address. To initiate a message transfer, a process presents the Host Interface with a process name for the destination of the transfer. The Transfer Layer must map these process names into physical network and station addresses that correspond to the current location of the destination process. An address map, maintained by Management, supports this procedure. This allows processes to be reallocated among common processing elements with no impact on the Host software.

Message sequencing and packetization services ensure that packets are delivered in the proper order. The XTP utilizes a sequence number space that readily maps into the Host interface buffer space to simplify processor-intensive address translations, which increases performance. Duplicate packet detection is also provided to prevent the XTP from delivering multiple copies of the same packet to the Host.

Error control ensures that data is not lost or corrupted. The XTP utilizes a checksum to detect errors in the packet stream. Lost packets, as well as duplicates, are detected by the sequence number mechanism. Recovery from packet errors is supported through either Go-Back-N or selective retransmission schemes. Selective retransmission allows a receiver to request only those packets that were not properly received.

Rate-based flow control prevents against receiver processing and buffer congestion. Flow control allows receivers to throttle fast senders as buffers begin to fill. When a sender reaches its flow control limit, it is blocked until the receiver returns an updated allocation. XTP specifies the allocation, on a per-context basis, in terms of a maximum burst size per transmission interval. Flow control allocations can be dynamically adjusted to respond to traffic variations on the network.

The XTP also offers a versatile Multicast capability to support distributed processing. Multicast allows one sender to access multiple receivers with a single message operation. Two types of multicast functions are available: Data Sharing and Address Independent Query. Data Sharing allows a sender to transfer a Host message to multiple receivers. This is extremely useful in managing a distributed database i.e. the Global Dynamic Database. Address Independent Query allows a sender to access a server through a well-known functional address. This query allows users access to various network and system servers that may reside in various physical processors in the system. By using an efficient recovery scheme, XTP multicast services can provide for error recovery in the case of non-received packets.

LAN LAYER

The FDDN LAN Layer provides the Data Link and Physical Layers of the ISO/OSI reference model, and consists of two standard protocols: the ISO 8802/2 Logical Link Control (LLC) and the ANSI Fiber Distributed Data Interface (FDDI). The LLC offers protocol stack multiplexing that accommodates future integration of enhanced upper-layer protocols. The FDDI is a 100 Mbps token passing ring LAN that was designed for fault-tolerant operation and high-bandwidth transmission.

Logical Link Control

The FDDN employs the ISO DIS 8802/2 Type 2 LLC [10] protocol. This protocol was was derived from the IEEE 802.2 LLC, which was is currently being standardized by ISO. The LLC offers a simple, connectionless service that multiplexes upper-layer protocol stacks onto the Data Link channel. Stack multiplexing is necessary to allow upper-layer management
applications access to the FDDI to enact real-time management operations, e.g. fault recovery, and allow for future grow and expandability without affecting the LAN Layer. The LLC also supports a set of management services that are used to achieve DataLink layer integrity. While the LLC functionality has been partitioned to the FDDN LAN layer, these functions will be implemented in the Protocol Engine™ chipset.

The FDDI defines a 100 Mbps, dual, counter-rotating ring topology that utilizes the Timed Token Rotation (TTR) protocol. A dual, counter-rotating ring was selected for the FDDI to overcome the limitations of the basic ring topology as shown in Figure 5[11]. This topology provides full duplex links (physical paths) between adjacent stations in the network, which are essential for initialization and fault recovery. Four elements make up the FDDI standard: the Media Access Control (MAC) [12] protocol, the Physical Layer (PHY) protocol [13], the Physical Medium Dependent (PMD) protocol [14], and the Station Management (SMT) protocol [15]. The MAC, PHY, and SMT protocols are included in the FDDN LAN Layer. The FDDI PMD has been replaced with a militarized, fiber optic transmission system and the FDDN Cable Plant.

**FDDI Media Access Control**

The FDDI MAC provides the processing necessary to allow packets (frames) to be transferred on the ring. Major functions of the MAC include: Frame formulation, Frame error checking (a 32-bit Frame Check Sequence (FCS) and Frame Status field is used to detect frame errors on the ring), address recognition, and shared media access in accordance with the TTR protocol. The FDDI supports both individual and multicast addressing with a 48-bit address space.

The FDDI TTR protocol is a bandwidth sharing protocol that uses time to arbitrate access to the network. Its suitability for avionic application has been previously investigated [16]. The FDDI supports two types of bandwidth: synchronous and asynchronous. Synchronous bandwidth allows a station access to the media during each token arrival (limited by its synchronous bandwidth allocation). A station is allocated synchronous bandwidth in proportion to its expected transmission requirements. The remaining bandwidth is asynchronous, which varies with the synchronous traffic on the ring. If the token arrives and a station does not have synchronous data to transmit or does not utilize the entire synchronous bandwidth allocation, the amount of the asynchronous bandwidth pool increases by the amount of the station’s unused synchronous bandwidth. This results in an efficient use of bandwidth that guarantees frame latency.

**FDDI Physical Layer Protocol**

The FDDI PHY protocol provides clock synchronization and an encode/decode function for the FDDI data stream. Clock synchronization is distributed throughout the entire FDDI ring. Each FDDI station maintains a local transmit clock and derives its receive clock from the inbound bit stream. An elasticity buffer resolves the frequency and phase difference between the local (transmit) and derived (receive) clocks. The elasticity buffer shrinks when the receive clock is faster than the local transmit clock. Conversely, the elasticity buffer grows when the receive clock is slower than the transmit clock. This allows the network to operate without a highly accurate oscillator. The FDDI PHY standard specifies a clock stability of 125 MHz ± 0.005%.

The clock frequency of 125 MHz is necessary to support the 4B/5B code. Outbound data from the MAC is encoded into 5-bit code groups, each of which represents a 4-bit data symbol. The inbound FDDI data stream is decoded into 4-bit data symbols and passed to the MAC receiver. If an invalid symbol is received, the MAC is notified that a fault was detected. This 4-bit for 5-bit (4B/5B) encoding/decoding results in a code that is 80% efficient; the 100 Mbps data rate requires a signalling rate of 125 Mbaud. Manchester encoding, by contrast, is only 50% efficient. In addition to the data symbols, there are eight non-data symbols defined in the 4B/5B code that allow the PHY to convey various control information at the Physical Layer. This line state capability supports low-level management, which is extremely valuable when upper-layer failures occur on the network.

**CABLE PLANT**

The Cable Plant defines the fiber optic network medium needed to support the 125 Mbaud FDDI bit stream. In addition, interface characteristics for the FDDN militarized fiber optic transmission system have also been considered. Cable Plant functions
are identical of those specified in the FDDI PMD (see Figure 6). Optical requirements, however, were adapted for the militarized, airborne environment. The Cable Plant requirements are under evaluation by the SAE-AS13 Fiber Optics Committee (Advanced Architecture Task Group). Final component selection depends on the findings of the committee, which consists of prime contractors, subsystem developers, and component manufacturers. Cable Plant design requirements under examination include the airborne environment, including radiation effects, avionics installation, and maintenance procedures. System-level parameters, such as bit error rate and margin, will also be specified as the FDDN matures.

The FDDN media consists of passive elements that comprise the FDDN transmission media: fiber, cables, connectors, splices, couplers, and the optical bypass device. FDDN module connections to the cable plant are independent; the primary ring is physically isolated from the secondary ring to enhance network survivability. The FDDN Module is attached to the FDDN media through the bypass device. The optical bypass is a passive, fail-safe, optical switch that couples a fiber optic transceiver to the medium. This network-critical device isolates failed FDDN modules from the network. A militarized bypass is under development to meet the FDDN requirements.

**MANAGEMENT**

Management is required for the FDDN to maintain overall communications availability. The FDDN management structure consists of both Local Management entities and Network Management entities, which are distributed among each FDDN Module. Local Management provides the capability to configure, control, and monitor individual FDDN Module resources. Network Management provides the coordination between the FDDN Modules in the network to maintain communications integrity and to administrate network-wide policy throughout the entire FDDN. The FDDN management framework, which supports management information flow throughout the network is based on the ANSI/ISO [17,18] and IEEE 802.1 [19] management baseline.

**CONFIGURATION MANAGEMENT**

The configuration of the network must be carefully administered to efficiently allocate and maintain FDDN resources. Provisions have been made to update network performance and configuration characteristics in order to adapt to changing demands. Network Management controls the network initialization procedure to systematically establish the avionic communications capability. Station insertion and removal is also facilitated by distributed network control algorithms. Network performance capacities have been parameterized to allow dynamic adaptation to rapidly changing traffic demands. FDDI bandwidth and response time behavior, as well as the Transfer Layer address map, flow control limits, and buffer allocations must be updated to accommodate varied avionic processing scenarios. The ISO Common Management Information Services (CMIS) [20] and Common Management Information Protocol (CMIP) [21] provide for a standard approach for parameter adaptation. FDDN statistics can also be gathered to enable further performance evaluation.

**FAULT DETECTION, ISOLATION, AND RECOVERY**

Network Management must ensure that overall communications are provided even when failures occur on the network.
Fault detection is hierarchical in the FDDN management approach; the Transfer Layer detects packet ordering and message errors, the FDDI Layer checks for frame and symbol errors and the MFOTS constantly monitors the fiber optic signal on the medium. Management coordinates these fault detection mechanisms and rapidly initiates recovery to sustain system communications.

SUMMARY

Advanced aircraft require a high-performance, fault-tolerant interconnect that facilitates distributed avionics processing. While a versatile, interprocess communications network is needed, the HSDB only offers a high-speed packet service. Northrop has proposed the FDDN architecture as an alternative to the HSDB for the A'. The FDDN offers a comprehensive suite of services which have been designed to support data-driven avionics processing. FDDN protocols have been derived from emerging commercial standards, which are implemented in VLSI to achieve performance and interoperability. Comprehensive functionality, rigorous adherence to standards, and VLSI minimize the risk of the FDDN for next-generation aircraft.

REFERENCES