IMPLEMENTING WAVELENGTH DIVISION MULTIPLEXING FOR HIGH SPEED FDDI NETWORK

by

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ABBREVIATIONS

AMD	Advance Micro Device
ANSI	American National Standard Institute
ATM	Asynchronous Traffic Mode
AWG	Arrayed Waveguide Grating
B-ISDN	Broadband Integrated Service Digital Network
CMOS	Complementary Metal Oxide Semiconductor
CRC	Cyclic Redundancy Check
DAS	Dual Attachment Station
DNA	Downstream Neighbor Address
E/O	Electrical – Optical Converter
ECL	Emitter Coupled Logic
FBRN	FDDI-Based Re-configurable Network
FDDI	Fiber Distributed Data Interface
FDDI/WDM	FDDI network combined with WDM Technique
IP	Internet Protocol
LAN	Local Area Network
LDDI	Local Distributed Data Interface
LLC	Logical Link Control
MAC	Media Access Control
MIB	Management Information Base
NAUN	Next Available Upstream Neighbor

NED	Network Descriptive Language
NEDC	Network Descriptive Language Compiler
NIF	Neighborhood Information Frame
O/E	Optical – Electrical Converter
OMNET++	Objective Module NETwork tested bed in C++
OSI	Open System Interconnection
P.I	Primary Input
P.O	Primary Output
PHY	Physical Layer
PMD	Physical Medium Dependent
QAS	Quad Attachment Station
QoS	Quality of Service
S.I	Secondary Input
S.O	Secondary Output
SAC	Single Attachment Concentrator
SAS	Single Attachment Station
SBA	Synchronous Bandwidth Allocation
SIF	Station Information Frame
SMT	Station Management
THT	Token Holding Time
TRT	Token Rotation Time
TTRT	Target Token Rotation Time
VLSI	Very Large Scale Integration
WDM	Wavelength Division Multiplexing

PELAKSANAAN PEMULTIPLEKSAN PEMBAHAGI PANJANG GELOMBANG DI DALAM RANGKAIAN FDDI BERKELAJUAN TINGGI

ABSTRAK

Kemajuan dalam Pemultipleksan Pembahagi Panjang Gelombang (Wavelength Division Multiplexing (WDM)) telah meningkatkan lebar gentian optik tunggal. Bagi rangkaian kawasan setempat dan metropolitan (LAN dan MAN), rangkaian FDDI menyediakan satu rangkaian yang dapat memberi mutu perkhidmatan yang baik dan celusan yang tinggi. Jika digabungkan dua teknologi ini, ia mampu menyediakan satu rangkaian dengan segala kecemerlangan prestasi dan kebolehpercayaan yang lebih besar. Melaksanakan WDM dalam FDDI memberikan anggaran *N* kali lebih celusan rangkaian daripada rangkaian FDDI biasa dengan satu saluran. Nilai *N* bergantung pada bilangan saluran yang dapat disokong dalam rangkaian berkenaan. Bilangan saluran sama dengan bilangan panjang gelombang yang digunakan dalam rangkaian tersebut. Tesis ini mengemukakan dan membincangkan satu rekabentuk baru rangkaian yang menggabungkan FDDI dengan WDM bagi mengurangkan lengahan capaian maksimum dan meningkatkan celusan rangkaian pada konfigurasi rangkaian yang berbeza-beza. Rangkaian ini dipanggil FDDI/WDM dan beroperasi melalui pelbagai saluran yang beroperasi secara bebas pada satu panjang gelombang yang berlainan dan tidak bertindih. Setiap stesen akan menggunakan sebuah unit antaramuka untuk beroperasi antara saluran-saluran panjang gelombang yang berbilang ini.

Prestasi FDDI/WDM yang beroperasi melalui saluran jarak gelombang berbilang dinilai dengan menggunakan parameter rangkaian yang berlainan dengan beban penuh bagi trafik tak segerak, menggunakan penyelakuan yang dinamakan OMNET++. Parameter-parameter rangkaian yang digunakan ialah TTRT, jumlah panjang gentian optik, bilangan stesen yang aktif, dan saiz rangka data. Kajian ini menunjukkan FDDI/WDM memberikan celusan rangkaian yang besar (menghampiri 1Gbps pada 10 saluran rangkaian) dan kurang lengahan (~100ms pada 10 saluran rangkaian) berbanding dengan rangkaian FDDI biasa. Prestasi rangkaian meningkat seiring dengan penambahan bilangan saluran. Tambahan pula, bagi mencapai prestasi yang optimum, parameter rangkaian (iaitu TTRT, panjang gentian optik dan bilangan stesen) mestilah dipilih dengan berhati-hati, kerana ianya mempengaruhi celusan rangkaian dan lengahan maksimum.

ABSTRACT

The advance in Wavelength Division Multiplexing (WDM) technology has tremendously increased the bandwidth of a single fiber optic. For a local and metropolitan are network (LAN and MAN). FDDI network offers an excellent network resiliency, good Quality of Services (QoS) and high network throughput. These two technologies if combined can offer a network with all excellent performance and higher reliability. By implementing WDM in FDDI will give an approximately *N* times network throughput offered by conventional FDDI network within a single channel. The value of *N* depends on the number of channels that can be supported in the network. The number of channels is equal to the number of wavelength used in the network. This thesis presents and discusses a new network architecture, which combined conventional FDDI with WDM to decrease the maximum access delay and increase the throughput over different network configurations. This network is called FDDI/WDM operate over multiple non-overlapping channels, with each channel operating independently on a different wavelength. Each station will use an interfacing unit to operate over multiple wavelengths channel.

The performance of FDDI/WDM network operating over different number of wavelength channels is evaluated with different network parameters under heavy load for asynchronous traffic, using discrete event simulator called OMNET++. Network parameters used are TTRT, total fiber length, number of active stations, frame size. The study shows that FDDI/WDM gives a higher throughput (almost 1Gbps on 10 channels network) and less delay (~ 100ms on 10 channels network) compared to the standard

FDDI network. Network performance increasing as the number of channels is increased. Furthermore, to achieve higher performance network parameters (i.e. TTRT, total fiber length, number of stations) should be selected carefully.

CHAPTER ONE

INTRODUCTION

1.1 Introduction

Optical networks offer high-speed data bit rate, and very low bit error rate, which are needed in many applications. Today optical fibers are used for all types of communication including voice, video, and data applications. The most significant properties of an optical fiber, which make it superior to copper wires are;

- Huge bandwidth: Which is of the order of hundreds of terahertz (THz).
- Low attenuation: The low attenuation of fiber means that longer distance communication is possible without the need to regenerate the signal with repeaters. Fibers of attenuation as low as 0.2 dB/km are easy available.
- Small Size: The fiber is very thin. The outer diameter of a single strand of fiber is in the range of 100 μm.
- No Electromagnetic Interference: Light traveling through fiber does not cause EMI.
- No Radio-Frequency Interference: Optical communication is immune to radio-frequency interference (RFI).
- Security: The light traveling through the fiber does not generate electromagnetic fields and it is nearly impossible to wiretap without detection. Thus fibers are considered to provide better security (Jain, 1994).

The fiber distributed data interface (FDDI) is a token ring network that has many similarities to the IEEE 802.5 (Token Ring) standard but is specially intended for the faster speed offered by optical fiber, and is designed to run at 100 Mbit/s. The FDDI was designed to be compatible with the IEEE 802 LAN standards and shares the common logical link control (LLC) level, thus making it particularly suitable as a backbone to interconnect IEEE 802 LANs. Several new civilian and military networks have adopted FDDI as the backbone network (Naugle, 1994). FDDI can support up to 500 stations with a distance between stations of 2 km, the maximum ring circumference of 200 km, and the physical medium between stations is multimode optical fiber, supporting synchronous and asynchronous traffic simultaneously (Naugle, 1994).

When a network station wants to transmit information, it waits for the arrival of the token (token is a frame circulated in the FDDI ring and used to determine the right of the station to transmit data). Upon receiving the token, the station can transmit for a fixed time interval called token hold time (THT), the station release the token either immediately after completing transmission or when the station has no more frames to transmit.

A station on a n-station ring may have to wait as long as n times the THT interval to receive a token, this maximum access delay is unacceptable for some applications like voice traffic and real-time applications, specially if the number of stations or THT is large.

The Fiber Distributed Data Interface (FDDI) is suitable for real-time and non-real-time communication because of the high speed and the performance guarantees are provided.

However, these guarantees are achieved at the expense of non-real-time traffic because the real-time messages are given higher priority over non-real-time messages, resulting an excessive delay for non-real-time communication.

To get higher performance from the FDDI network, wavelength division multiplexing (WDM) technique has been used in FDDI network for asynchronous traffic, to reduce the maximum access delay and increase the throughput of the network. To achieve better performance we made synchronous and asynchronous traffic running apart, on different physical path. We exploit the high bandwidth offered by optical fiber to apply WDM technique. Applying WDM on asynchronous traffic will reduce the delay that might happen during token waiting, thus increasing network throughput, which increases the performance of the network in asynchronous applications. The separation between synchronous and asynchronous traffic is to obtain higher network throughput, low access delay and to provide Quality of Service (QoS) for the network.

Wavelength division multiplexing (WDM) is a promising technique to utilize the enormous bandwidth of the optical fiber. Multiple wavelength-division multiplexed channels can be operated in a single fiber simultaneously, however a fundamental requirement in fiber optic communication is that these channels are non-overlapping and operate at different wavelength. These channels can be independently modulated to accommodate dissimilar data formats (Ramamurthy, 1998). We proposed this technique is to use in FDDI network to allow multi-tokens to circulate around the network, each in different channels, therefore, more than one station can transmit and receive at the same time, thus increasing the performance of the network.

Two types of stations are provided in FDDI/WDM network, Dual-attachment station (DAS), and quad-attachment station (QAS). Optical bypass relay in QAS is provided to prevent ring disruption when the station becomes inactive. Two Standby rings supported in QAS network to enhance the fault tolerance in synchronous and asynchronous traffic.

In FDDI/WDM network, any station that wants to transmit frames must wait for token arrival. When a station captures the token, it starts transmitting frames on the same token channel, and at the same time it monitors the other channels, whether receiving or repeating frames from other stations.

Performance is an important issue in the design, implementation, and operation of networks. Networks must be able to perform well even when the load is high. The performance of any FDDI network depends on the workload as well as system network parameters (e.g. number of active stations, load per station) . Parameters can be either fixed or user settable. Fixed parameters are those that the network manager has no control over. These parameters vary from one network to another, such as cable length and number of stations. The stable parameters, which can be set by the network manager or individual station manager, include various timer values. Most of these timers affect the reliability of the ring such as Target Token Rotation Time (TTRT) and synchronous time allocation. The workload also has a significant impact on the network such as number of active stations. The study of FDDI/WDM performance has been done with respect to these parameters.

The study of FDDI using WDM (FDDI/WDM) has been done under heavy load for different ring configurations by using Objective Modular Network Tested in C++

(OMNET++), which is an object-oriented modular discrete event simulator, developed at Technical University of Budapest, Department of Telecommunications. It consists of hierarchically nested modules, the depth of module nesting is not limited, which allow the user to reflect the logical structure of the actual system in the model structure.

OMNET++ probably uses the most flexible method; it has a human-readable textual topology description format (the NED language), which is easy to create. And the output of the simulation is written into a data files, and can use external programs, like Excel, to process the results.

1.2 OBJECTIVES

Due to the soaring demand in high speed networks to support real-time applications, which require very high bit rate (e.g. compressed NTSC requires 1.5 Mbps), optical fibers are used to achieve higher bit rate of 40Gbps for STM-256, with low delay (5.085μs/km).

The objectives of this research are:

1. To design a new network architecture which can provides Quality of Services (QoS) and has high network throughput and low access delay based on wavelength division multiplexing technology.
2. To analyze the network performance in terms of the maximum access delay and throughput on the number of wavelength channel.

3. To identify and analyze the effect of the network parameters (e.g. TTRT, number of station, total fiber length) on the throughput and maximum access delay network performance.

CHAPTER TWO

LITERATURE SURVEY

2.1 Fiber Distributed Data Interface

American National Standard Institute (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 fiber was first raised in subcommittee X3T9.5 at the October 1982 meeting and subsequently the LDDI standard was abandoned and a new effort based on fiber began. This new standard was named Fiber Distributed Data Interface or FDDI (Jain, 1993). The major contribution to FDDI in its early history certainly had individual goals, which influenced the design choices. A starting concept was the use of optical fiber. This was based, in part, on the perceived direction of future technology. Mostly, it was recognition of the real advantages that optical fiber offered over copper for higher bandwidth and longer distance. Fiber seemed to offer the only hope of reducing the huge bulk of I/O cables already filling up false floors, computer centers, and buildings. Reliability was the major goal. Emerging VLSI technology providing increasing chip speed and complexity, allowing more powerful protocol to be implemented in hardware, with improved reliability and simplicity of customer installation and use. Other key goals included interoperability in multi-vendor installations, high data integrity, high performance, and extensible and scalable architecture (Ross and Hamstra, 1993).

FDDI uses a ring topology. The choice of the ring topology versus bus topology has been a topic of religious debate in the network community, but ring topology was chosen due to many advantages i.e. mostly digital components, easy fault isolation, scalable in bandwidth, and scalable in distance (Ross, 1987). Several ring designs were proposed for FDDI. IBM proposed their token ring architecture to IEEE 802 in 1982. It was determined that high-speed token ring could be built with acceptable cost and performance. The project began to be use in FDDI. The basic frame format of IEEE 802.5 was adopted to allow higher-level protocol compatibility. However, key changes were made to support operation at a much higher data rate. Physical layer changes including mapping the frame formats and rings control functions into the 4B/5B code, while IEEE 802.5 MAC protocol was redesigned to scale to higher speeds and longer rings. Key changes included a pure pipeline approach to both control and data flow with separate receive and transmit state machines, optimizing for transmitting bursts of frames on each token opportunity, stripping based upon source address, and the normal release of the token by a station immediately upon transmission of the last frame. These changes resulted in significantly improved performance, particularly for higher speeds and larger rings (Ross and Hamstra, 1993).

Moulton (1981) began to present fiber optics data link concepts to X3T9.5 in 1981; he began contacting optoelectronics and semiconductors suppliers to solicit his support for a fiber optic LAN standard. He became the major architect of the FDDI physical layer.

The nucleus of what would become FDDI was presented to X3T9.5 by Sperry in 1983 (Ross and Hamstra, 1993). The technical leaders of FDDI were looking for the best solution to the I/O and LAN interconnect problem. As a result they made two additional

FDDI changes from IEEE 802.5. The receive clock of IEEE 802.5 and FDDI is recovered from the incoming data stream. In the case of IEEE 802.5 the transmit clock is derived from the incoming clock. This means that a series of identical stations may each introduce identical data-dependent jitter into the ring clocking. This jitter is cumulative; if too much is accumulated then ring clocking is lost. The problem is exacerbated by the increased number of stations and the data rate (Ross and Hamstra, 1993).

Salwen (1983) proposed and demonstrated a distributed stable clock system. It uses a separate transmit clock that runs independently of the receive clock on each data link, with enough data buffering in each station to absorb the difference in clock between adjacent stations. This data buffering is restricted in length because of its location in a critical data path that limits the maximum overall FDDI frame length to 4500 bytes. Another advantage of the FDDI clocking system is the simplicity of specification.

The second major change was in the scheduling algorithm. IEEE802.5 uses an eight–level priority system, with round robin scheduling within each priority level. The FDDI was initially proposed with a similar scheme, but this was replaced with a Token Rotation Time (TRT) scheduling algorithm in 1983. The TRT algorithm provides two or more classes of service, each class receives assured bandwidth and controlled access delay, but there is no attempt to limit priority inversion unless the assured service of a higher class is threatened. As embodied in FDDI, the TRT algorithm supports multiple priority classes for asynchronous service, although these have little relative effects except under sustained heavy loads (Grow, 1982).

Another major contribution was the early commitment of advanced micro devices (AMD) to FDDI. AMD was already developing a chip set for LDDI, which they adapted to FDDI. This commitment was instrumental in gaining multivendor support of FDDI as a standard. AMD also provide early publicity for the FDDI standards activity with the first paper published on FDDI (Joshi and Iyer, 1984).

The original FDDI physical layer independent (PHY) had been required to preserve at least two bytes of preamble between frames, and the media access control (MAC) had been required to process any frame preceded by two bytes of preamble. These requirements were relaxed by X3T9.5 in February 1984 to make it easier for the implementers. Although the fact that the preamble could erode to a few bytes was discussed at that time, it was decided to let the implementers worry about the problem. Some of them never discovered it, some forgot about it, others ignored it, and a few deal with it. After several months of investigation and extensive simulation work, the problem was solved by adding a smoothing function downstream of the elasticity buffer to prevent the gaps between frames from eroding (Ross and Hamstra, 1993).

It was an early decision that FDDI should have separate standards for MAC and PHY functions. This offered a substantial benefit, a station could have a configurable relationship between MAC's and PHY's. This facilitated implementation of the counter-rotating ring philosophy. It also allows stations to be built with a wide range of functionality ranging from a simple workstation that would have just one MAC and one PHY up to a concentrator that might well have dozens of PHY's and several MAC's. By June of 1984, it was recognized that PHY had become too complicated to remain in one document. The decision was made to separate the optical interface and optical data link components into a separate document, designated Physical Medium Dependant (PMD). The separation of PHY and PMD allowed the work on PHY to proceed unencumbered by the ensuing issues on connectors and transceivers (in the short term), and the incorporation of alternative data links (in the long term) (Ross and Hamstra, 1993).

In October of 1985, a fixed shroud connector designed by AMP Corp. was chosen over several other contending connectors. The advantage touted for the fixed shroud, which extended beyond the tips, was that the ferrules and sensitive fiber tips were protected from accidental damage. This connector choice was repeatedly challenged over the ensuing years until June 1988 when PMD was finally forwarded by X3T9 for approval with its final technical content.

The station Management (SMT), is the most important of FDDI standard. It has been described as the most sophisticated multivedor interoperability document ever created (at least for the lower layers of the OSI model). SMT provides services such as connection managements, station insertion and removal, station initialization, configuration management, fault isolation and recovery, and communication protocol for external authority. The need for SMT was recognized in April of 1984, and a SMT project was soon formalized. Ross and Burr (1984) created a shell SMT document. Included in the document were the initial connection management state machines that had originally been in PHY. This was the era of rapid-growth SMT. With the availability of FDDI hardware components, the SMT participants came under increasing pressure from their respective managements to finish the job. In this environment, agreements were made and remade with amazing speed. Connection management was redone, with dramatically expanded capabilities. Bit signaling proposed by Ocheltree

(1988) was added to enable passing information between the PHY entities of stations without requiring MAC's. The concept of a Station Information Frame (SIF) was adopted, allowing one station to solicit key status information from another. The development of the Management Information Base (MIB) was initiated and added to SMT.

The key feature of FDDI, including the 100 Mb/s data rate, the use of optical fiber, the token ring protocol, and the configuration concept, were chosen within Sperry Corp. before formal FDDI work began in X3T9.5. In addition to that, 100Mb/s data rate was projected to represent a knee of the cost/performance curve for optical fiber components in the late of 1980. Hamstra (1988) chose 100 Mb/s data rate as a target to be used in copper wires. There were some basis for this, LDDI used coaxial cable at 50 Mb/s and advancing RF modem technology was projected to provide similar data rate over longer distance using broadband coaxial cable. The 100 Mb/s data rate was seriously challenged during the work on FDDI-II.

It was apparent that technical innovation came from a variety of contributors and that adopting their new ideas to improve the FDDI standards. Indeed, as the standards progressed, the overall capability and applicability of FDDI grew considerably. By the time FDDI matured, it had become a family of standards with much broader appeal than was imagined in the early days. It is the premier high performance LAN of today and success as a backbone standard for IEEE 802 LAN standards. FDDI and the follow-up work coming can be expected to dominate of high-speed LAN networking.

Much more studies done after that, Jain (1991) proposed the effects of FDDI network parameters on the network performance. The performance of FDDI LAN depends upon the configuration and workload parameters such as the extent of the ring, number of stations on the ring, number of stations that are waiting to transmit, and the frame size. Analytical modeling and simulation methods were used to investigate the effect of the Target Token Rotation Time (TTRT) on various performance metrics for different ring configurations. The analysis demonstrated that setting the TTRT at 8 ms provides good performance over a wide range of configurations and workloads. After that Jain (1990) analyzed the error detection capability of the FDDI, where he quantifies frame error rate, token loss rate, and undetected error rate. The analysis was limited to noise events not resulting in the change of symbol boundaries.

Interest increases in multimedia networks, ever higher speed and greater bandwidth must be made available. Moreover, the interconnection of existing local area network (LAN), especially those within a limited geographic area, will require high speed bridging. A possible solution to meet these requirements is to consider the FDDI. When FDDI is chosen as a backbone network for hierarchical interconnection of medium performance LAN's, and is part of a high speed multi-network (interconnection of heterogeneous high speed sub networks), it is essential for the multi-network manager to know the global state of the FDDI sub networks and other sub networks in real-time. Sclavos *et al.* (1994) proposed the quality of service (QoS) of FDDI in high-speed multi-networks. They focused on QoS computation, monitoring, control and management within a FDDI sub network. This application has been realized using the Eiffel object oriented language.

During the past several years, a large number of FDDI network have been installed and this number is still increasing rapidly, due to its high transmission speed. At the same time, engineers working in different directions to improve the performance of the FDDI. Hutchison *etal.* (1991), developed the FDDI physical layer hardware to improve the performance, correctness and reliability of the FDDI station. First they used CMOS (complementary metal oxide semiconductor) technology instead of ECL (emitter coupled logic) to develop high integrated and low-cost chip set. Secondly they add another phase lock loop in the transmitter component to improve the performance of the station. Then they add a new component called Smoother to prevent the loss of data packet at the media access control (MAC) in overflow or underflow. They simulate the network consisting of 200 stations for four weeks, and they found that these developments had improved the performance, correctness and maintainability of the FDDI networks. This work was improving FDDI hardware, but so much works have been done to improve the software of the FDDI like, Etherton (1993), he modified the FDDI kernel operating system to improve the synchronous transmission of the FDDI station. They added a two-tiered regulation facility, which at the lowest level would place an upper bound on the information transmission rate from the device driver buffer to the queue adapter, which is notion of standard and guaranteed performance system queues which user-level traffic could be directed into. A simulation was done to compare the modified and standard FDDI, the results show that the modified one provides the required performance guarantee for real-time traffic.

The standard FDDI architecture was enhanced in order to improve its fault-tolerance capability while a scheduling methodology, including message assignment, bandwidth allocation, and bandwidth management is developed to support real-time communication. Zhao *etal.* (1995), designed an enhanced network architecture called FDDI-Based Re-configurable Network (FBRN), this architecture uses multiple FDDI trunk rings to connect stations providing high transmission bandwidth and increasing the fault tolerance of the FDDI network. Only one of these rings is used for transmission and the others are reserved as backup. Each FDDI trunk ring can wrap up to dual loops to isolate a fault trunk link. Each station has certain reconfiguration capabilities that provide an additional level of fault-tolerance. Once an FDDI trunk ring is disabled due to faults, messages can only be transmitted on other rings before the fault ring is recovered. If all rings are fully utilized before the fault occurs, it is not possible to transfer message traffic from a fault ring to a non-fault ring. Both analytical and simulation show that FDDI-based re-configurable network can sustain a greater number of faults as compared to an ordinary FDDI network. The major concern in the design of such network is their vulnerability to faults or damages inflicted by component failures and/or enemy attacks. More work on this was done by Chen *et al.* (1995), they used on-line and off-line management components in multi-ring FDDI-Based Re-configurable network (FBRN) to maintain high network bandwidth in spite of faults, and to improve the network management in real-time applications. On-line management component deals with system run-time activities such as network initialization, fault detection, network reconfiguration, and message migration from fault rings to non-faulty ones. Off-line management component involves message assignments, bandwidth allocation and verification that the fault-tolerance real-time requirements can be met. Analytical test was done, and they observed that the performance of the network critically depends on the message grouping strategies used in off-line management component. After that, Kamat *et al.* (1994) proposed a probability analysis of the available bandwidth of FDDI-based reconfigurable networks given number of links faults. They considered three networks of varying degree of configuration, full reconfigurable, partially reconfigurable and non-reconfigurable networks. The partially reconfigurable networks were found to be an excellent compromise between high reliability and ease of the implementation.

Now it has became important to avoid message loss whenever it possible especially in real-time communication. Malcolm *etal.* (1996) provide a comprehensive study of the use of FDDI networks to support real-time communication in mission-critical system. They developed efficient test to check whether the message loss may occur, either due to missing deadlines or due to buffer overflow. They examined the probability and system performance over a wide range of network loads. These tests are extremely useful in the design and operation of mission-critical system using FDDI networks.

Now FDDI networks have been widely deployed to support real-time traffic such as voice and video communications. Shin and Zheng (1995) modified the standard FDDI protocol, and called it FDDI-M. This increased the network ability to support synchronous traffic, higher transmission efficiency, better quality of service, and fairness in transmitting asynchronous messages compared to the standard FDDI network. Their idea of modifying of FDDI protocol is to control the worst-case of token rotation time (TRT) not to exceed the TTRT. The modification was easy to implement, they only added one AND gate to the timer circuit of TRT to stop counting when the node is transmitting/forwarding a synchronous packet and resume when the node starting/ forwarding asynchronous packets. Simulation has been done to verify the advantages of the FDDI-M over FDDI and FDDI-II. The network simulated in a single ring of 50 nodes, and 92 km ring length. The results show that FDDI-M network increases the network ability to support synchronous traffic, and it has greater efficiency to support real-time multimedia applications. Chen *etal.* (1998) continued the study of the modified FDDI protocol FDDI-M to support synchronous traffic under different Synchronous Bandwidth Allocation (SBA) schemes. They simulated the network to study the performance of FDDI-M for MPEG video traffic. The simulation was done under heavy load for FDDI single ring of 50 stations and 92 km ring length. They used three classes of video streams, class I is low quality video, such as cartoon, animation, and video conference. Class II was common video applications such as TV programs. Class III was high quality video, such as HDTV. They found that FDDI-M offer significant improvement over FDDI for all SBA schemes.

It is well known now that FDDI token ring network provides guaranteed throughput for synchronous messages and a bounded medium access delay for each station. However, this fact alone cannot effectively support many real-time applications that require the timely delivery of each critical message. The reason for this is that the FDDI guarantees a medium access delay bound to nodes, but not to messages themselves. The message-delivery delays may exceed the medium-access delay bound even if a node transmits synchronous messages at a rate not greater than the guaranteed throughput. Zheng and Shin (1995) solved this problem by developing a synchronous bandwidth allocation (SBA) scheme, which calculates the synchronous bandwidth necessary for each application to satisfy its message-delivery requirement.

The studies to improve FDDI were not limited only on synchronous traffic. Hamdaoui and Ramanathan (1993) proposed a scheme for reducing response time for non-real-time messages, while still providing the same quality of service to real-time messages.

The idea is to transmit non-real-time messages ahead of real-time messages as long as the real-time messages can still meet their deadlines. Network simulation has been done, and the result shows that this technique reduced the response time of non-real-time messages, and still guaranteeing the deadlines of read-time messages.

Due to the high performance can get in FDDI networks, new studies appear to mix FDDI with another protocol system or technique to improve the performance of FDDI in digital multimedia communication. Long *et al.* (1993) they used Swift transport protocol in FDDI network to support high data rate in synchronous transmission mode. (Swift is an architecture for distributed file system to support the storage and processing multimedia. Swift provides high data rate by using a high-speed interconnection medium and using multiple storage devices operating in parallel. Swift can use any appropriates storage technology including high-performance disk arrays). They simulated the performance of the network using CSIM. The simulation was done under realistic load constraints, various combination of audio, video. The number of stations in the ring was varied from 2 to 100, and TTRT was two milliseconds. The results show that the throughput was consistently equal to the load, while the delay and jitter (the variation in transmission delay) fall within the guaranteed maximum, which is 4 ms. Also Ramamurthy *et al.* (1995) proposed WDM in FDDI node, where nodes can be partitioned to operate over multiple subnetwork, each subnetwork operating independently on a different wavelength, and inter-subnetwork traffic forwarding performed by a bridge. They examined the architecture of the nodes and the bridge, and found the average packet delay is minimized. Furthermore Andres *et al.* (1992) proposed studies of using FDDI traffic through ATM network for digital multimedia traffic as shown in Figure 2.1. After that, Yamamoto *et al.* (1993) focused on FDDI networks interconnection, and they present a new traffic control scheme for FDDI interconnection through ATM. The scheme consists of two parts, bandwidth allocation algorithm and feedback type buffer protection flow control. In addition to that, Mongiovi *et al.* (1991) proposed interconnecting FDDI networks through B-ISDN, while Bucci *et al.* (1994) proposed a study of connection FDDI with Ethernet networks.

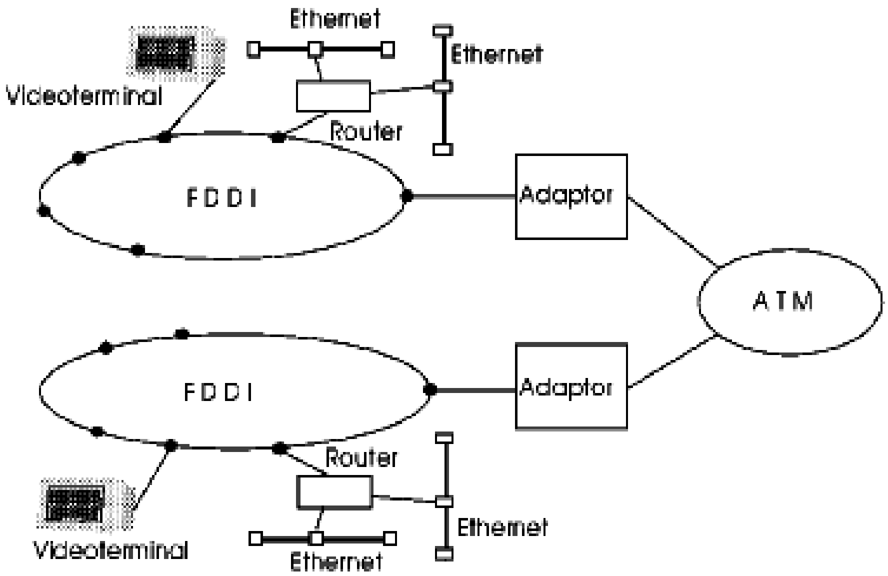

Figure 2.1 The FDDI through ATM network

Yang *et al.* (1996) proposed a new architecture for wireless FDDI networks and address the issue to providing a real-time communication service, and a dynamic bandwidth management scheme, which can be use in mobile communications.

FDDI now offers a bandwidth of 100 megabits per second (Mbps), and connected using ring topology uses a timed token access method to share the medium among stations. FDDI network can have a maximum of 500 stations and the maximum length of fiber cable between two successive stations is 2 km. This assumes a popular type of fiber called multimode fiber. Another type of fiber called single-mode fiber is also allowed, in which case the distance between stations can be as much as 60 km. The maximum allowed length of the medium in the network is 200 km. FDDI uses a special bit pattern, called token that continuously circulates the ring. Any station in the network wants to transmit information must waits for the arrival of the token. Upon receiving the token, the station can transmit for a fixed time interval called the Token Holding Time (THT). The station must release the token immediately either after THT expired or when it has no frames to transmit. All the stations on the network agree to a target token rotation time (TTRT) and limit their transmission to meet this target. There are two modes of transmission in FDDI network: Synchronous and Asynchronous. Time-constrained applications such as voice and real-time traffic use the synchronous mode (jain 1991).

2.2 Wavelength Division Multiplexing

The optical multiplexing concept is now quite old. It dates back to at least 1958 (De lang, 1970). But it waits until 1977 to obtain the first practical solution put forward by Tomlinson and Aumiller. Over the past decade, we have witnessed a rapid growth in optical communication. At first, it was used for long distance links. Nowadays, optical transmission is finding growing applications in short and medium-distance professional links as well as in local networks, and seems to be capable of taking a prominent part in telephone customer networks. The transmission bit rate becomes higher and higher, and despite the fact that single-mode fiber has a substantial bandpass, the wavelength division multiplexing that corresponds to the superimposition of optical signal at different wavelength on a single fiber often becomes, as a matter of fact, the best choice for a capacity increase at lower cost, and its applications extended further and further beyond the optical communication domain (Laude, 1993).

Significant amount of work have been done using this WDM to improve the performance of networks or communication systems. Dowd (1992) demonstrated a multiprocessor system with a large number of nodes could be built at a low cost by combining the recent advances in high capacity channels available through optical fiber communication. The system capitalizes the self-routing characteristic of WDM to improve the performance and reduce complexity of the communication subsystem. Also, Modiano and Barry (1999) designed and analyzed asynchronous WDM in Local Area Network to overcome the effects of propagation delay. The system was based on broadcast star architecture that used un-slotted access protocol.

WDM can also be used in the circuit switching of TeraNet networks, which offer user access rates up to one Gigabit per second (Gbps). The networks provide both circuit switching and ATM packet switching in a hierarchical fashion (Gidron *et al.*, 1991). In (1997) Borella proposed the basic components of WDM optical network, such as multiplexers, demultiplexers, filters, tunable transmitters, tunable receivers, optical amplifier, switches, and wavelength converter. Also, Laude (1993) exposed that most of WDM components can be used in most of the optical WDM networks.

Internet also uses WDM technique, since the bandwidth usage in the internet doubles every six to twelve months, and data network capacities are now exceeding voice network capacities (Turner, 1999). The emergence of WDM technology is unlocking more bandwidth and leading to lower cost hence fueling further demand. Turner (1999) proposed a WDM burst switch to exploit the tremendous bandwidth of optical technology. It is a new synthesis of optical and electronics technologies. In addition to that Maier *et al.* (2000) developed a novel MAC protocol using switchless wavelength division multiplexing based on arrayed-waveguide grating (AWG) to improve the performance of the network. WDM technology is now being used in ATM switches, IP routers, and most type of optical networks.

In 1993 Kovacevic & Mario proposed a novel time and wavelength division multiple access scheme for an optical metropolitan area network based on a passive star. This scheme supports circuit switched traffic in an environment with large number of users and large number of applications with relatively small bandwidth requirement (e.g. voice and compressed video). The scheme uses subframe tuning pipelining in order to compensate for the relatively slow tuning speed of optical devices available today. Furthermore Tong & David (1994) proposed a simple and effective scheme for constructing WDM network (in which each station is equipped with a set of fixed wavelength transmitters and receivers) based on a given regular graph. The scheme is flexible enough to support a much wider range of regular graphs.

Optical networks is a quickly developing area. It is a key technology in communication networks. In general WDM optical network consists of routing nodes interconnected by point-to-point fiber optics link. Ralf Klasing (1998) proposed a survey of recent theoretical results obtained for wavelength routing in all optical networks and also state several open problems connected with this line or research. Furthermore in 1995 Tong & David present an optical network based on passive star couplers. In order to reduce the hardware interface cost and exploit higher bandwidth, each station is assumed to have only one fixed wavelength transmitter and one fixed wavelength receiver to reduce the propagation delay for multi-hop optical network, and to perform dynamic bandwidth allocation. Also Alanyali & Ender (1999) present connection provisioning for optical networks employing wavelength division multiplexing. A heuristic algorithm is developed and numerically studied for routing and wavelength assignment of a set of static connection requests. The algorithm runs much faster than the optimum solution of this problem. An adaptation of the algorithm is proposed to design restorable networks, which can handle a specified set of failures. The proposed algorithm is based on taking all failures into consideration simultaneously, and performs better than developing independent designs for each failure.

Barry & Humblet (1996) introduced a traffic model for circuit switched all-optical networks which used to calculate the blocking probability along a path for networks with and without wavelength changers. They investigate the effects of path length, switch size, and interference length (the expected number of hops shared by two sessions which share at least one hop) on blocking probability and the ability of wavelength changers to improve performance. In 1998 Ramaswami & sasaki proposed optical wavelength division multiplexed (WDM) networks with limited wavelength conversion that can efficiently support lightpaths (connections) between nodes. Each lightpath follows a route in the network and must be assigned a channel along each link in its route. The load max of a set of lightpath requests is the maximum over all links of the number of lightpaths that use the link. At least max wavelengths will be needed to assign channels to the lightpaths. If the network has full wavelength conversion capabilities then max wavelengths are sufficient to perform the channel assignment.

Maier *et al.* (2000) proposed a scalable and reliable switchless wavelength division-multiplexing (WDM) network that is based on an arrayed waveguide grating (AWG). All wavelengths are used for data transmission and the signaling is done in band. Each node at the network periphery is equipped with a single tunable transceiver for data and a broadband light source for control while the network itself is completely passive. Broadcasting is realized by spectrally slicing the broadband signal. The proposed random distributed medium access protocol is reservation based and schedules variably sized data packets on a basis without resulting collisions.

Computer communication is one of the most rapidly developing technologies satisfying all kinds of applications. The interest in FDDI network increases to support multimedia communications. Research and development in optical WDM networks have matured considerably over the past few years, and they seem to have suddenly taken on an explosive form. WDM became widely used in the optical networks to utilize the enormous bandwidth of the optical fiber. Much work has been done to improve the performance of FDDI network and will continue to do, because there is no limit for the human desires.