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Performance analysis of Gb/s WDM FDDI network

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ABSTRACT

In this paper, we propose a time-token multi-Gb/s Wavelength Division Multiplexing Fibre Distributed Data Interface (WDM/FDDI) architecture and examine its throughput efficiency and delay under heavy load for different network configuration using discrete event simulator.

Keywords: Fibre distributed data interface, Wavelength division multiplexing, reconfigurable add-drop multiplexer, Optical ring network

1. INTRODUCTION

Recently, there has been an increasing interest in distributed communication systems for metropolitan area networks (MAN) to support real-time applications such as multimedia communications, which require a high bandwidth and guarantee time delivery with a minimum delay.

Despite their flexibility and high-speed capabilities, SONET/SDH ring architectures have inefficient asymmetric data traffic when deployed in MANs [1]. By utilising the broad bandwidth available in the backbone optical network and introducing cost-effective metro architectures and protocols, new high-speed services can be provided, thus stimulating revenue growth for network and service providers.

The Fibre Distributed Data Interface (FDDI) uses timed-token access in a ring topology to share the medium among stations as illustrated in Figure 1. Standard FDDI supports 100Mbps transmission rate using fibre optic transmission media [2]. The suitability of FDDI for real-time applications is mainly due to its high bandwidth and allocated-access-time property. A substantial increase in network capacity can be achieved through the use of Wavelength Division Multiplexing (WDM) [3], and therefore, the combination of WDM and FDDI is anticipated to enhance the performance of future MAN ring networks significantly.

During the initialization time of a conventional FDDI network, all nodes negotiate a common value for a Target Token Rotation Time (TTRT), and the chosen TTRT must be small enough to satisfy the response-time requirements of all nodes. There are two modes of transmission in FDDI networks: Synchronous and Asynchronous. Time-constrained applications such as voice and real-time traffic use the synchronous mode. Applications that do not have time constraints use the asynchronous mode. Synchronous frames are given higher priority over asynchronous frames [4]. Each node is assigned a fraction of the TTRT, known as its synchronous bandwidth H_i, which is the maximum time the node is allowed to transmit its synchronous messages every time it receives the token.

When a station receives the token, it starts transmitting its synchronous messages for a time no more than its allocated synchronous bandwidth. After that time, asynchronous messages can be transmitted for a time interval called the Token Holding Time (THT), where $THT = TTRT - TRT$, and TRT is the token rotation time, which is the time interval between two successive receptions of the token by a station. The station must release the token immediately either after the THT is expired or when it has no frames to transmit [5].

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A station can transmit synchronous traffic whenever it receives a token. A station can transmit asynchronous traffic only if the TRT is less than TTRT. For asynchronous traffic, a station on an *n*-station ring may have to wait as long as *n* times the THT interval to receive a token. This delay is unacceptable for some applications, especially if the number of stations or THT is large. Even though synchronous frames are given priority to be transmitted first, stations may still be unable to complete the transmission of a synchronous message before its deadline [6].

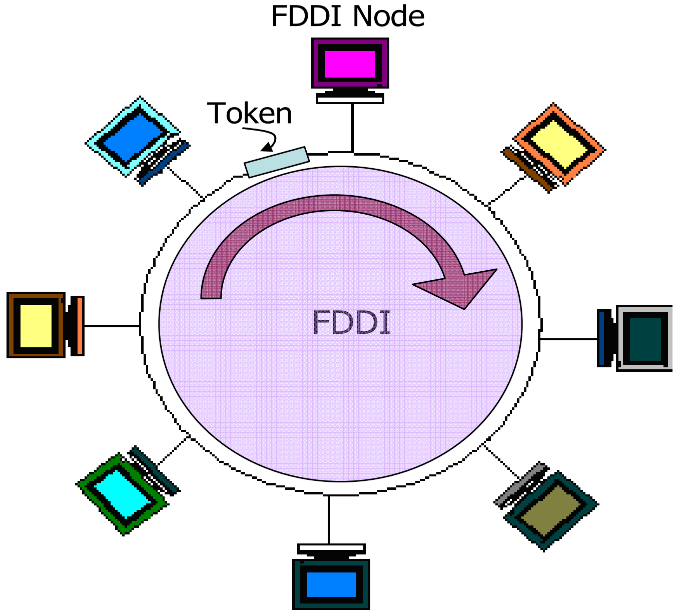

Figure 1: FDDI standard network

Wavelength-division-multiplexing (WDM) have been extensively investigated for MAN [7]. WDM is a powerful technique to access a tremendous bandwidth by simultaneously transmitting several signals at different optical wavelengths over the same optical fibre [8]. By utilizing multiple WDM channels, a very large aggregate bit rate (defined as the product of the number of wavelengths and the bit rate per wavelength) is achieved [9].

To achieve higher performance for the FDDI network, we propose the use of wavelength division multiplexing (WDM) in conjunction with FDDI. In particular, we investigate the performance of WDM/FDDI under heavy load for different ring configurations by using object-oriented modular discrete event simulator. We optimize the parameters affecting the performance of WDM/FDDI network, such as TTRT, synchronous bandwidth allocation, total number of stations, the extent of the fiber, number of active stations, and the frame size, to maximum the network performance.

This paper is organized as follows: In Section 2, we review work related to FDDI networks. The proposed WDM/FDDI network architecture is presented in Section 3, and simulation results are discussed in Section 4.

2. RELATED WORK

An extensive research has been conducted on FDDI networks, where the objectives were mainly focused on maximizing the throughput and minimizing the delay to guarantee meeting the individual message deadline.

Nord and et al. [10] proposed a distributed MAC protocol for variable length packet asynchronous optical ring networks, and compared its complexity with variable-length packet techniques that support spatial wavelength reuse. Shin and Zheng [11], a modified MAC protocol of the FDDI has been proposed to improve the network to support synchronous and asynchronous traffic. Buzluca and Harmanci [12] proposed a dynamic synchronous bandwidth allocation scheme with distributed management protocol for deadline guarantees in an FDDI network. However, these schemes and modifications do not meet the high-speed and delay time requirements for the next generation backbone networks.

Conti and et al. [13] suggested a new protocol, called RT-Ring, which is able to support transmission of both real-time and generic traffic over a slotted ring network, and showed that this protocol provides a much higher capacity than that of standard FDDI protocol. Although this protocol can attain high efficiency when the number of active nodes is small, its efficiency reduces dramatically as the number active nodes increases, and for many real-time applications, this leads to an increase in delay and missing of the packet deadline.

Kirov [14] proposed a fuzzy FDDI approach that can be implemented into each network node to control the access delay, THT and throughput, thus improving the network performance. Cobb and Lin [4] introduced a modified timed-token FDDI protocol. Both of the latter approaches can slightly improve the network performance however, they cannot achieve multi Gb/s throughput and full utilization of the bandwidth of the optical media.

Recently, the use of WDM has been proposed by several researchers to improve the performance of ring optical networks. Herzog and et al. [15] proposed the use of WDM to extend the IEEE Standard 802.17 Resilient Packet Ring (RPR) and Cheung et al. [16] reported a multi-channel FDDI where each node is permanently connected to one channel for reception while the transmission to any of the available channel is arbitrary. The main drawback of this scheme lies in the time delay that results from wavelength switching as packets are sent to different nodes. This time delay decreases the throughput and reduces the performance of the network.

3. WDM/FDDIRING NETWORK MODEL

The physical layout of the proposed WDM/FDDI consists of a number of nodes arranged in a ring topology sharing access to the transmission optical media, with packets carried by different wavelengths, as shown in Figure 2. Any node ready to transmit frames must wait for a token on any WDM channel. Upon receiving a token, the station begins transmitting frames on the same WDM channel. The node also keeps monitoring other channels to receive or relay frames from other nodes. A node transmits synchronous traffic within its synchronous bandwidth as soon as it receives a token. Once the synchronous bandwidth allocation is expired, it transmits its asynchronous frames (if any) for no more than the THT. When the THT is expired the node releases the token even if it has more frames to transmit, and the remaining frames wait until the next token arrives. It should be noted that the remaining frames might also be transmitted on a different WDM channel if available. Each WDM/FDDI nodes equipped with a reconfigurable optical add drop multiplexer (ROADM) to add or/and drop any wavelength channel. When the node captures a token, it simply drops its wavelength, tunes its laser to the same wavelength, and transmits the packets through the add port.

Due to the presence of many tokens in the network, the station might receive a token in less than the ring latency thus reducing the station access delay. Therefore, in a WDM/FDDI network, a node takes less time to receive a token than a conventional FDDI network, leading to a higher network throughput and a lower access time. A WDM/FDDI token consists of eight symbols (each symbol is 4 bits). The proposed token format includes two additional symbols in comparison to standard FDDI token, as shown is Figure 2. This defines a so-called *token identification* field for discriminating tokens, hence allowing the rotation time (TRT) to be calculated for each token.

Consider an optical wavelength division multiplexing (WDM) ring network interconnecting nodes along a unidirectional single fibre ring network, where the nodes are numbered sequentially as n = 1, 2, 3…, N. Suppose that the wavelength channels $\{ \lambda_1, \lambda_2 \dots , \lambda_M\}$ are propagating in the single fibre ring network.

Assume that the standard FDDI network has the same throughput as the WDM/FDDI, then $P_s = M \cdot P_{WDM}$ where P_s is the throughput for the standard FDDI, M is number of WDM channels and P_{WDM} is the throughput for each WDM channel. Since the ring latency, D, is much less than N×TRT for all practical designs [2], the TTRT is roughly the same for both networks. Thus the maximum access delay for the WDM/FDDI network is approximately M times less than the Standard FDDI network. On the other hand, if we fix the maximum access delay for both networks by changing their

TTRTs (where TTRT for WDM/FDDI is roughly equal to M times that of the standard FDDI), this leads to $P_{WDM} = MP_s$. In this case, the total throughput of the WDM/FDDI network becomes

$$Throughput \approx M \cdot B \frac{N(TRT - D)}{N \cdot TRT + D} \tag{1}$$

Where B is the capacity of each channel (assume all channels have the same capacity). Note that for a dual ring network, the throughput should be multiplied with a factor of 2.

The maximum access delay can be described as:

$$Max\ Access\ Delay \approx \frac{(N-1)TRT - D}{M} \tag{2}$$

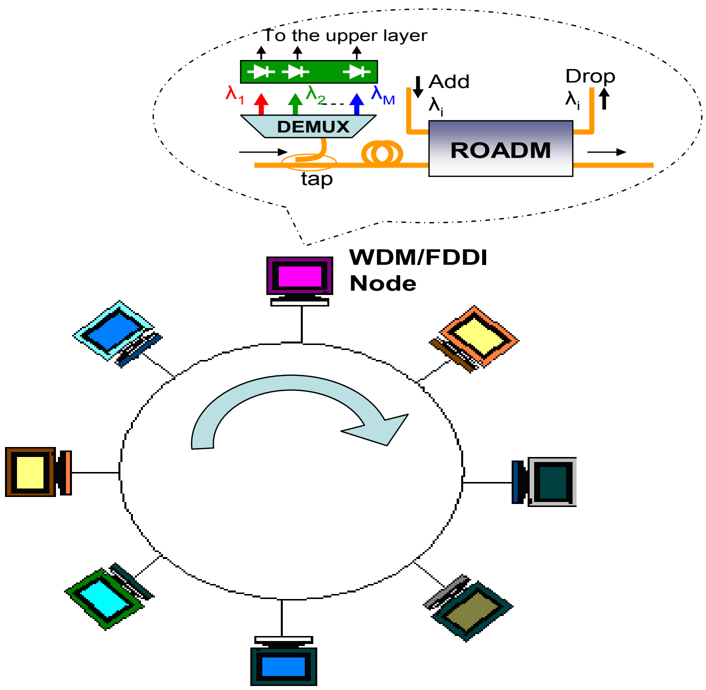

Figure 2: WDM/FDDI network architecture.

4. SIMULATION RESULTS AND DISCUSSION

Using the object-oriented modular discrete event simulator OMNET++ we evaluated the WDM/FDDI network and carried out extensive simulations on several scenarios to verify its advantages. A unidirectional ring of 250 nodes and 100 kilometre fibre length ring was considered as a case study. Assuming a node latency of 0.6 microsecond and a propagation delay of 5.085 microsecond per kilometre [11], and a uniform packet generation scheme, where all the 300 nodes generated the same amount of traffic and had always data to transmit. Figure 3 shows the simulated maximum access delay as a function of TTRT for a standard FDDI network (single channel) and a WDM/FDDI network (multiple channels). It is shown that increasing the TTRT increases the maximum access delay. However, it is noticed that the maximum access delay decreases for the multi-token WDM/FDDI network. The maximum access delay decreases as the number of wavelength channels is increased. This means, a node in a standard FDDI network requires a longer time to receive a usable token than a multi-token WDM/FDDI network. It is also noticeable that every additional channel causes a reduction in the maximum access delays. Figure 4 shows the FDDI network throughput as a function of the TTRT for the same network configuration. It is obvious that the throughput for the WDM/FDDI network is much higher than that of a standard FDDI network and that around 1 Gbps throughput can be attained with ten WDM channels.

To summarize the result presented so far, when the load of the network is saturated, WDM FDDI network gives higher throughput, and lower maximum access delay compare to the standard FDDI network without restricting the number of active stations. But TTRT value should be selected carefully because large value of TTRT will increase the throughput, as well as increase the maximum access delay. So the selection of TTRT requires a trade-off between these two requirements.

Based on the work reported by Jain [17], the optimum TTRT value of 8ms represents a reasonable trade-off between the efficiency and the maximum access delay. Accordingly, a network capacity for the optimum TTRT of 8ms was investigated by measuring the number of full size frames (4500 bytes) transmitted in the network in a given time interval. The results of this scenario are reproduced in Figure 5. It is observed that the number of frames transmitted within a three-channel network is significantly higher than that within a single token network in the same period of time. The increased network capacity allows frames to be sent in bursts, satisfying the guaranteed deadline, and provides higher network utilization and performance than the standard FDDI

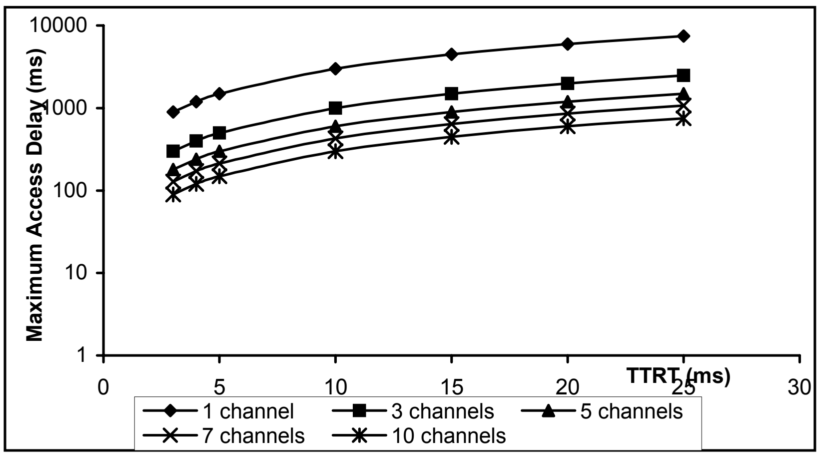

Figure 3: Maximum access delay as a function of TTRT for standard and WDM FDDI networks.

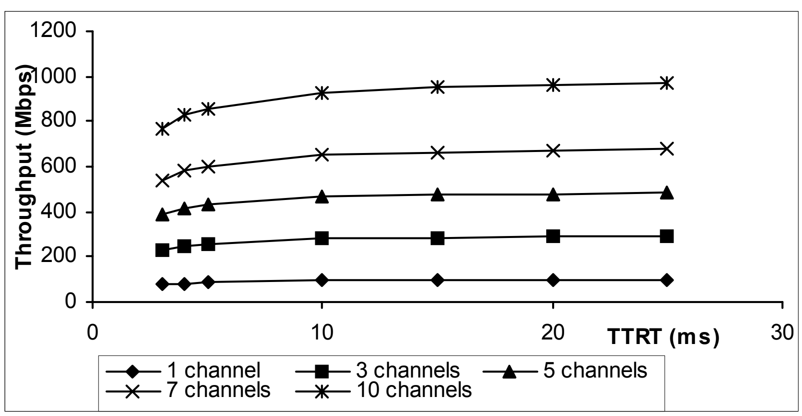

Figure 4: Throughput as a function of TTRT for standard and WDM FDDI networks.

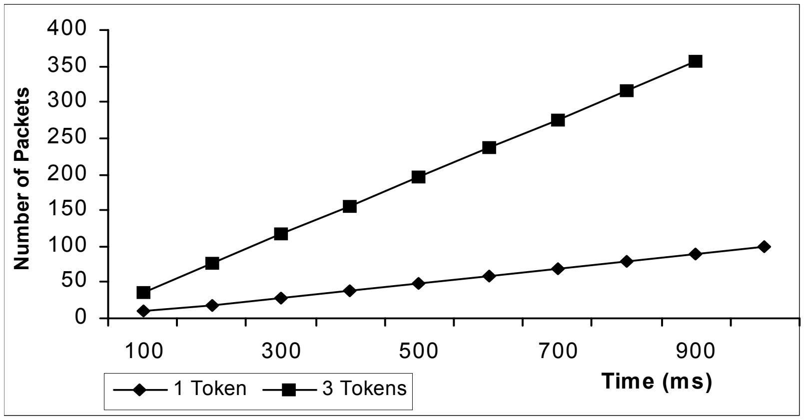

Figure 5: Number of transmitted full frames versus time

The number of active and inactive stations and the total fiber length also affect the performance of the network. In general, increasing the number of stations change the ring latency, due to additional fiber length and station delay. For a WDM/FDDI network, a 7 WDM channels has been taken as an example to study the effect of total fiber length and total number of stations, when the TTRT is 8ms. Figure 6 and 7 illustrate the maximum access delay and throughput as a function of total fiber length. As shown in Figure 6 and 7, rings with longer fiber lengths, which display a slightly lower throughput and longer maximum access delay than shorter fiber length rings. In this case, we found that while an increase in the number of active stations has only a slight effect on the throughput, it increases in the maximum access delay considerably. Even in multi-token networks, the throughput for 100 stations is higher than that of 500 stations for the same fiber length, and the maximum access delay for 100 stations is much lower than the maximum access delay of 500 stations for the same fiber length.

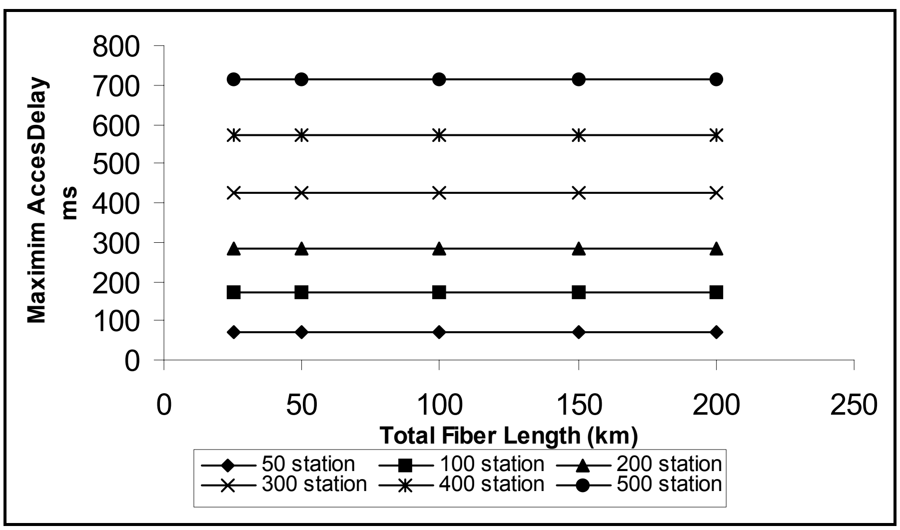

Figure 6: Total fiber length as a function of maximum access delay

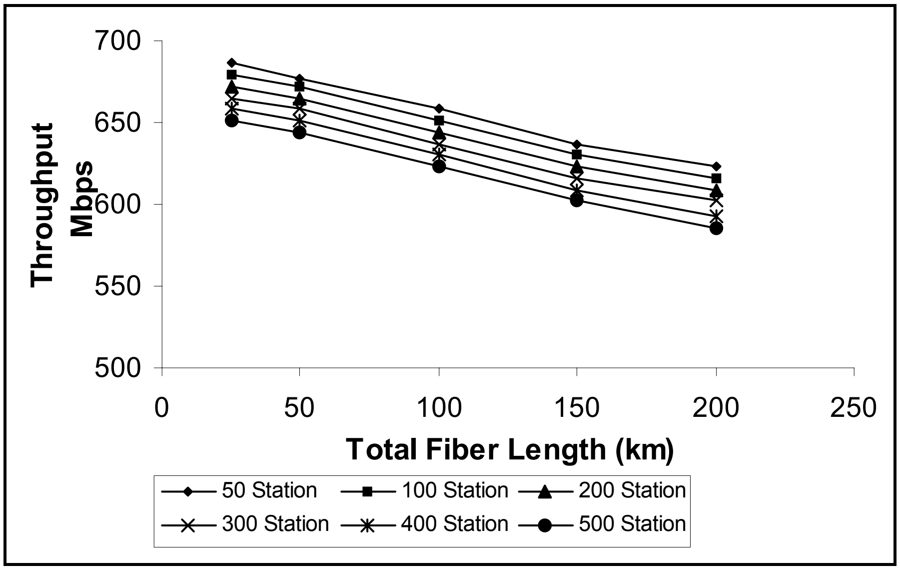

Figure 7: Total fiber length as a function of throughput.

Figure 8 shows the maximum access delay versus the number of active stations for a multi-token network consisting of 250 stations, with a TTRT of 8ms, and a total fiber length of 100km. As illustrated in Figure 8, increasing the number of active stations in the network affects the maximum access delay, so it is preferred to reduce the number of active stations to get a lower access delay. Note, however, that this delay is reduced when WDM is used, whereas the access delay in a 7-channel network is lower than the delay in a 3-channel network. To attain a higher netwrork performance, it is important to use WDM techniques and minimise the number of active stations.

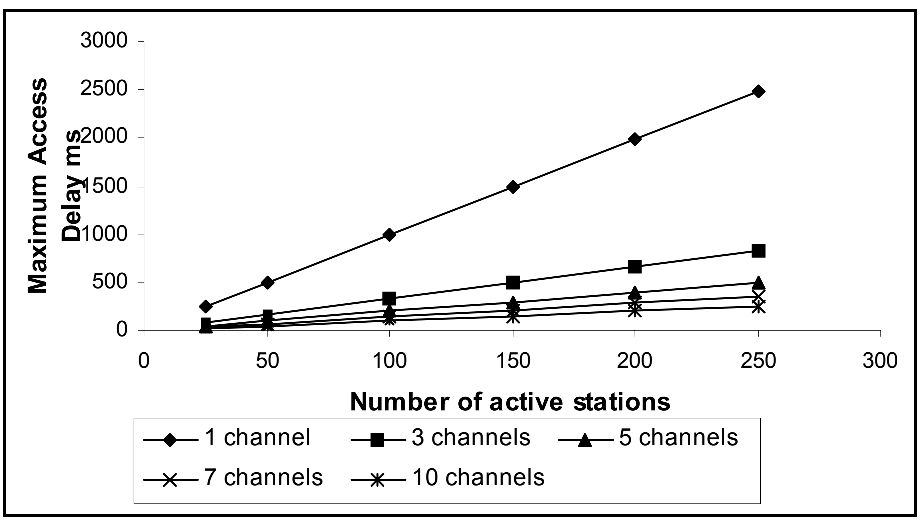

Figure 8: Number of active stations as a function of maximum access delay.

5. CONCLUSION

In this paper, we have proposed and simulated the performance of a WDM/FDDI backbone network. The simulation results have shown that WDM/FDDI can achieve higher throughput and lower access delay than standard FDDI networks. Moreover, stringent requirements for message deadline can easily be met with WDM/FDDI networks, making them very promising for next generation packet switched optical ring networks.

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