KMITL Sci. J. Vol. 4 No. 2 Jul-Dec. 2004

DELAY ANALYSIS AND BUFFER OCCUPANCY ANALYSIS OF SWITCHED FTTH ACCESS NETWORK

W.T. P'ng, S.B. Ahmad Anas, C.L. Cheah, H.Z. Mustaffa and M.K. Abdullah

Photonics and Fiber Optics System Laboratory,
Department of Computer and Communication Systems Engineering,
Universiti Putra Malaysia, 43400 Serdang, Selangor, Malaysia

ABSTRACT

Fiber-To-The-Home (FTTH) is one of the technologies proposed to provide huge bandwidth to the home users. In previously proposed access networks, FTTH are mostly protected from failure by having redundant network equipment or introducing a backup optical fiber cable. These are not economical approaches, as the redundant systems are not fully utilized by the network. In this paper, we introduce a novel scheme in providing protection to the FTTH access network. An intra-network switch is employed so that each and every network can be used to automatically support other networks in case of failure. Advantages of this technique compared to other schemes are addressed in this paper and the packet delays and buffer occupancy issues on the switch are reported, based on simulation analysis. The study was carried out by measuring the performance based on these parameters when the supporting optical line termination (OLT) is terminated one after another. Results show that the number of supportable Optical Network Units (ONU) can exceed the standard Full Service Access Network (FSAN) value, which is 32 units per OLT. For example, for a two OLT network, the maximum recommended ONU units are 64 whereas in the proposed system, up to an average of 80 ONUs can be supported with less than 20μs delay experienced with the high delay priority traffic.

KEYWORDS: average packet delay, buffer occupancy, optical network unit (ONU), optical line termination (OLT), Fiber-To-The-Home (FTTH).

1. INTRODUCTION

Massive telecommunications backbone network build outs in the last 4-5 years failed to improve service provider revenues and profitability [1]. Despite billions of dollars invested by service providers in long haul capacity and other new technologies, the main hurdle that limits full utilization is the bottleneck in the access portion of the networks. This bottleneck severely hinders the ability of service providers to offer new high-speed data services to their customers.

In addressing this access network bottleneck problem, Fiber-To-The-Home (FTTH) technology has been introduced in the local loop, taking advantage of optical fibers, huge bandwidth. However, there is still one obstacle, which has been generally overlooked, which is, providing protection to the access line [2]. The existing fiber optics access mainly consists of a single fiber running upstream and a single fiber running downstream. Hence, the access network is subjected to absolute failure when fiber breaks occur. Some access networks make usage of spare fiber lines and equipment but this increases the cost. The spare fiber lines and

*Corresponding author. Tel: 603-89466454, Fax: 603-86567127,
E-mail: khazani@eng.upm.edu.my

equipment are not utilized in normal conditions. A new way of providing fault tolerance to the system has to be introduced, by taking into consideration the packet transfer. In this paper, we introduce a switched FTTH access network that provides protection for the FTTH network. The viability of the approach is verified by the result for the packet delay and buffer occupancy.

2. RELATED WORKS

There have been approaches by the ITU-T to provide protection against cable or equipment failures in the access network. In the ITU-T Recommendation G.983.1, four types of protection network architectures are introduced [3, 4]. The first protection network architecture (Fig. 1a) introduces another fiber cable and a fiber switch. In this architecture, when the fiber breaks, the spare fiber could be utilized as a backup link. However, if the OLT was to fail, all ONUs would be useless.

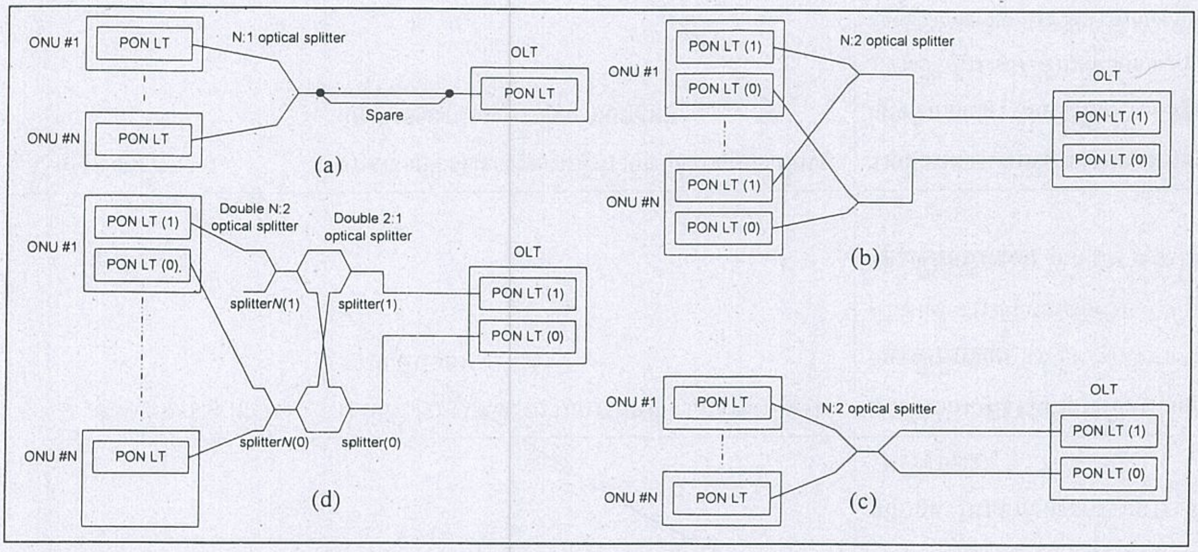


Figure 1 Four types of protected PON networks

The second architecture (Fig. 1b) specifies the full duplication of the PON architecture. This architecture provides full protection to the network. However, full duplication also doubles the cost and makes the system less economical. The third ITU-T architecture (Fig. 1c) is with redundant OLT systems. The primary OLT is normally working and the secondary is used as a cold standby. The backup equipment is not utilized when there are no failures, thus again this is not economical. The fourth architecture (Fig. 1d) proposes independent duplication of branch line and common lines. This scheme utilizes a lot of redundant equipment, thus is not considered attractive.

3. THE SWITCHED FTTH ACCESS NETWORK

The protection scheme proposed in this paper utilizes a FTTH switch, placed in the central office to interconnect four different FTTH access networks as shown in Figure 2. This ensures no powering problem, and the installation is just a matter of patching as the OLTs are very close to each other, typically in a central office. Although extra fibers are required, the cost of an extra fiber core is relatively small. This approach would protect the network in the events of both fiber breaks and OLT failures.

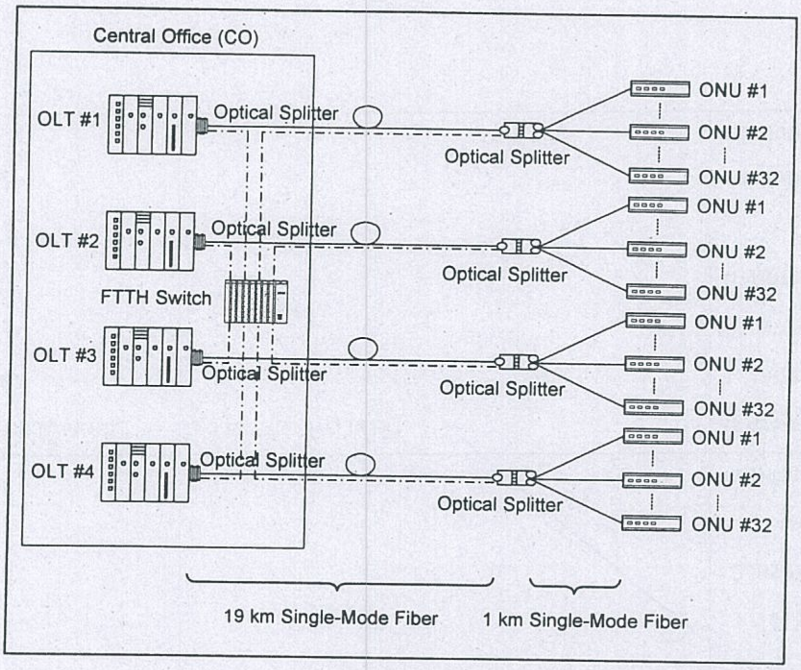


Figure 2 The switched FTTH access network

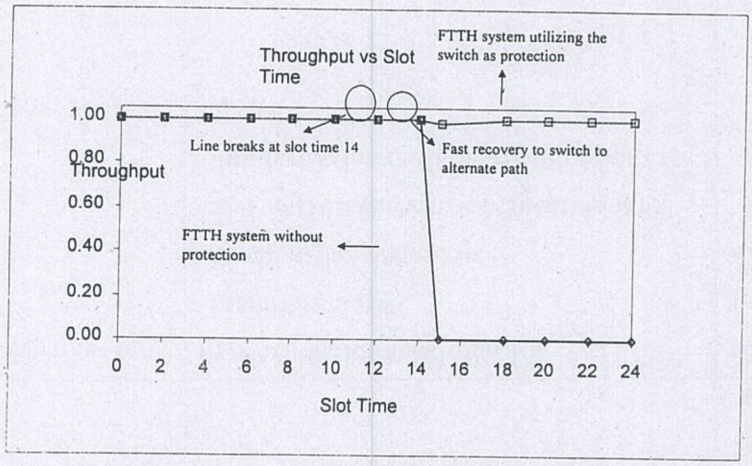


Figure 3 Comparison between an unprotected FTTH network and the switched FTTH network in the case of fiber breaks

The significant advantage of utilizing the FTTH switch is shown in Figure 3, which compares a switched FTTH network with an unprotected FTTH network in a graph of throughput versus slot time to show the service continuity of the switched FTTH network.

4. SIMULATION MODEL

A. Traffic Classification

Traffic is classified into 4 different classes as in Table 1. Time constrained services are assigned higher delay priorities in order to have a lower packet delay. Loss sensitive services are assigned higher loss priorities in order to have a smaller packet loss rate. This classification enables network nodes to support various QoS requirements.

Table 1 Traffic Classification

Traffic Class	Description
Class I	High Loss Priority and High Delay Priority
Class II	Low Loss Priority and High Delay Priority
Class III	High Loss Priority and Low Delay Priority
Class IV	Low Loss Priority and Low Delay Priority

B. Simulation Assumptions

The simulation is designed and developed using Java. The following assumptions are made for simplicity purposes:

- Variable length packets are used with a Maximum Transmission Unit (MTU) of 1500 bytes.
- Interface rate at 622.08Mbps.
- A maximum splitting ratio of 32 is used for each of the FTTH systems.
- Input buffering is assumed at 200kB.
- Switch is running on Spanning Tree Protocol (STP).
- The simulation is limited to a maximum of 128 ONU units.
- Each user can transmit all four different classes of traffic.
- Proportion of traffic distribution: 25% Class I, 25% Class II, 25% Class III, 25% Class IV.

C. Self-Calibrating Pushout (SCP)

The self-calibrating pushout (SCP) method is adapted to the switch's design [5]. The main objective of the SCP scheme is to balance the packet loss ratio by measuring, in real time, the numbers of discarded low and high loss priority (LP) packets. The primary advantage of the SCP scheme is its capability of automatically calibrating in real time each service class's packet loss ratio so as to meet each class's QoS requirements. The SCP algorithm is shown in Figure 4 whereas the queuing model is summarized in Figure 5. The buffer is logically segregated into 4 different buffers, each occupying one specific traffic class defined by the traffic priority matrix. In this simulation study, traffic is assumed to be bursty and alternates between the active (packets arrived in consecutive slots) and idle (no packets arrived).

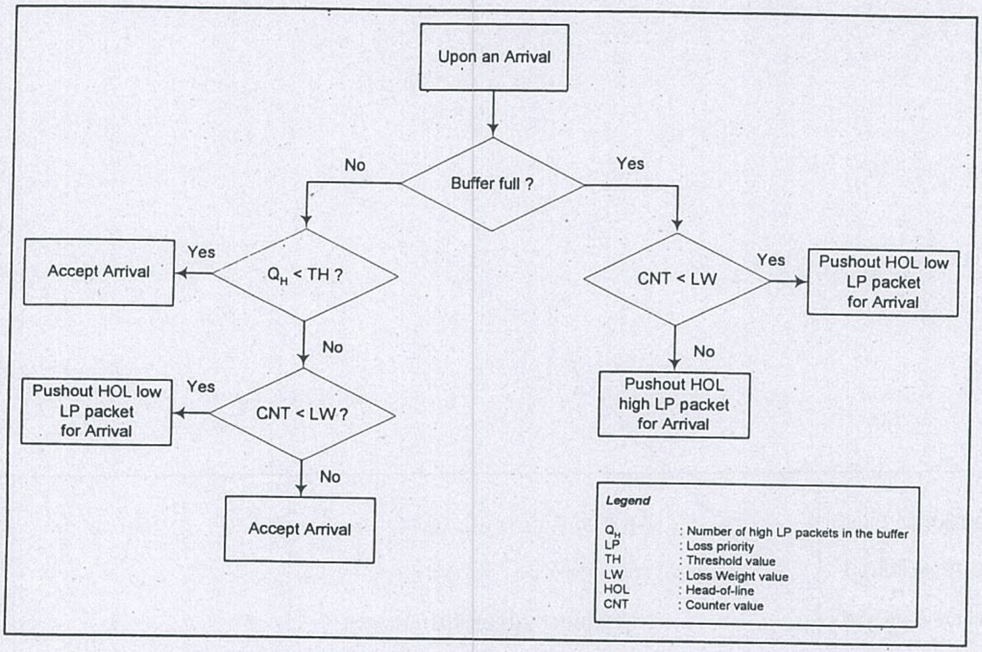


Figure 4 SCP basic working principle's algorithm

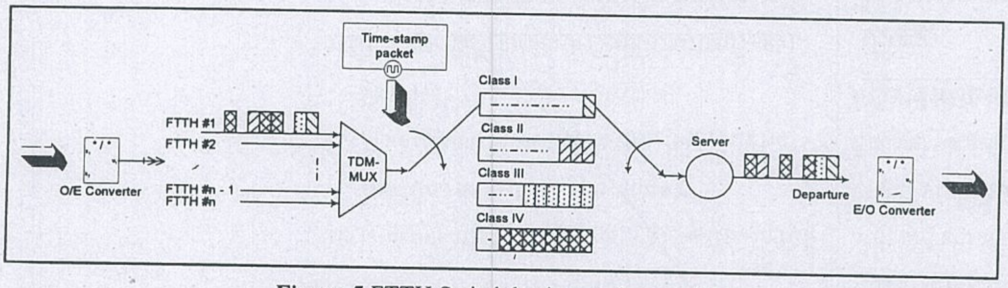


Figure 5 FTTH Switch basic queuing model

D. Performance Measurement

In this paper, packet loss ratio and average packet loss performance are evaluated. Packet Loss Ratio is defined as the number of packets discarded over the number of packets generated, as given in the equations below for the four different traffic classes.

$$PLR_{Class\_M} = \left(\sum_{i=1}^{n} \frac{Class\_M\_Packets\_Discarded\_at\_input\_line\_i}{Class\_M\_Packets\_Generated\_at\_input\_line\_i} \right)_{Class\_M}$$

The average delay, D, is the average time taken from the instant the packet arrives at the ingress port to the time taken for it to depart from the specific egress port. This is governed by the equation,

$$D_{Class\_M} = \left(\sum_{i=1}^{n} \frac{Class\_M\_Queueing\_Time\_at\_input\_line\_i + T_{service}}{Class\_M\_Packets\_Transmitted\_at\_input\_line\_i} \right)_{Class\_M}$$

where for both equations, M is the traffic class with $1 \le M \le 4$ and i is the number of input lines with $1 \le i \le n$ and the service time, Tservice, is given as:

$$T_{service} = \frac{L}{C}$$

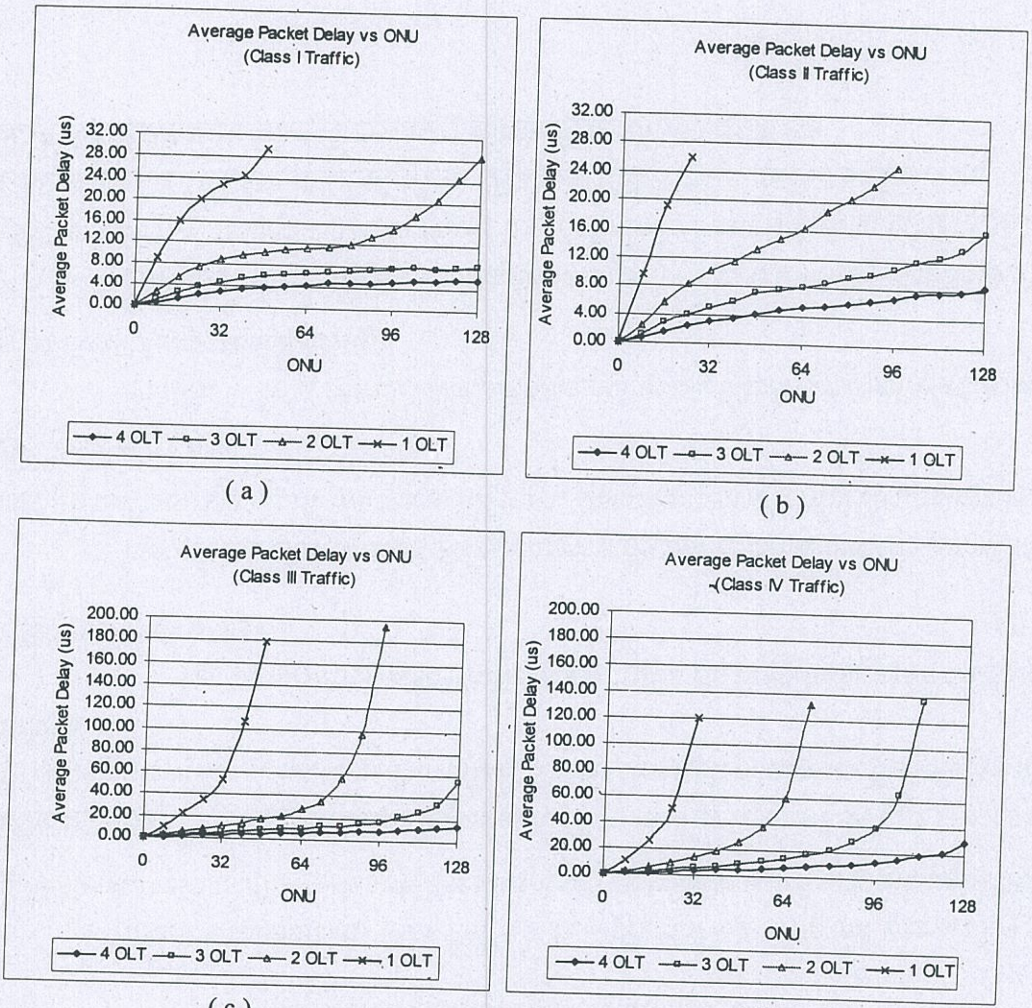
where L is the packet length specified in bits and C is the link bandwidth in bits per second.

5. RESULTS AND ANALYSIS

Figure 6 shows the average packet delay for various traffic classes against the number of ONU units. In Figure 6a, with four working OLTs in the network, a maximum of 128 ONUs of class I traffic can be supported with the average packet delay remaining below 5.72μs. Average packet delay is less than 8.49μs when 1 OLT fails. The maximum average delay sustained by the OLT units, when four or three units are used, does not exceed 10μs. When 2 OLTs fail, average packet delay does not exceed 12μs when the number of ONU does not exceed 80 units. A drastic increase in average packet delay occurs when more than 80 ONUs are used and the maximum delay is around 28μs. When 3 OLTs fail, average packet delay is below 24μs when around 40 ONUs are used. However, increasing the number of ONU further would effect a drastic increase of packet losses. This is because the switch is already experiencing congestion as explained above.

Again, similar behavior is obtained for the other traffic classes, only now lower priority traffics experience greater packet delay and are also degrading faster. Taking 120ms as the maximum allowed delay with users noticing only a slight delay [9], the proposed system is shown here capable of supporting the least priority traffics (Class IV) for up to 32 ONUs with only 1 OLT left. This is similar to that for FSAN proposed standard. This shows that, in the worst case, our system provides equivalent performance to that of FSAN standard.

Figure 7 shows the average buffer occupancy for various traffic classes against the number of ONU units. In Figure 7a, the average buffer occupancy for class 1 traffic is below 0.005 for all working conditions except for 1 OLT working condition. In 1 OLT working condition, rapid increment of average buffer occupancy is seen when ONU unit exceeds 96. This rapid increment indicates the traffic bandwidth is occupied and packets start to be stored in buffer to await their turn to be sent. Class 2 traffic (Figure 7b) shows a similar behavior to class 1 traffic where the system's buffer occupancy remains below 0.025 before ONU units exceed 64 for 1 OLT working condition. The same characteristics are again shown by class 3 and 4 traffics with the rapid increment happening in 2 and 3 working OLTs condition. Higher buffer occupancy is seen in low delay priority traffic classes as the packets of these classes are stored in buffer to give way to high delay priority classes. In the worst case (Class IV), the proposed system can support an extra 25% unit of ONUs compared to FSAN standard with less than 20kB of buffer usage.



(c) (d)

Figure 6 Average Packet Delays versus ONU for Various Traffic Classes

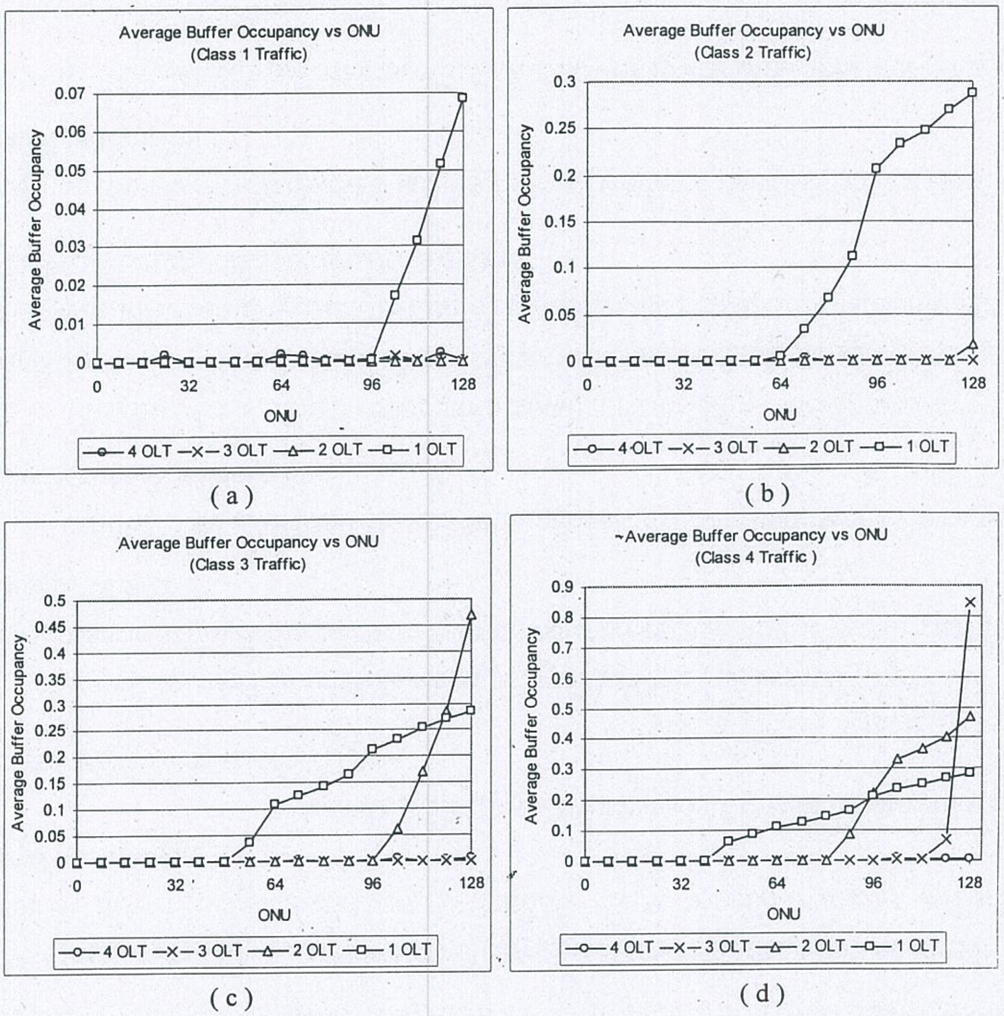


Figure 7 Average Buffer Occupancy versus ONU for Various Traffic Classes

6. CONCLUSION

We have proposed a switched FTTH network, which could be an alternative for providing protection to the FTTH system. Our results clearly show that as far as the average packet delay is concerned, the other surviving OLTs can be used to successfully support the extra ONUs in the event of failure to one or more OLTs. If there is only 1 surviving OLT, for each traffic class concerned, the number of supportable ONUs is 25% more than the FSAN value for each surviving OLTs with less than 25kB of buffering. This clearly shows the capability of this approach to provide fault tolerance to the FTTH system, whereby more ONUs can be supported by the OLTs than the FSAN proposed FTTH system.

REFERENCES

[1] "Free-Space Optics: Improving Service Velocity" http://www.freespaceoptics.org/index.cfm/fuseaction/content. WhitePapers, accessed on 21st July, 2003.

[2] G. Kramer, B. Mukherjee, and G. Pesavento. "Ethernet PON (ePON): Design and Analysis of an Optical Access Network", *Photonic Network Communications*, *3*(3), July **2001**.

[3] B.F. Effenberg, H. Ichibangase, and H. Yamashita, Advances in Broadband Passive Optical Networking Technologies, IEEE *Communications Magazine*, December **2001**.

[4] ITU-T, Study Group 15. "G.983: High Speed Optical Access Systems based on Passive Optical Network (PON) Techniques", 2001.

[5] H. Chao, H. Cheng, Y. Jenq, and D. Jeong. Design of a Generalized Priority Queue Manager for ATM Switches, *IEEE Journal on Selected Areas in Communications*, *15*(5), June **1997**.