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# A performance model for differentiated service over single-hop passive star coupled WDM optical networks

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ABSTRACT

One of the important issues in the design of future generation high-speed networks is to provide differentiated services to different types of traffic with/without various time constraints and priorities. In this paper, we study the problem of providing differentiated services in passive star coupled wavelength division multiplexing (WDM) optical networks. We present a medium access control (MAC) protocol based on a simple static priority based scheduling algorithm combined with channel assignment. We propose an analytical model to evaluate the performance of the differentiated services provided by the MAC protocol which prioritizes message transmissions in single-hop WDM passive star networks. We formulate the analytical model and conducted numerical study to validate the model. The study proves that the proposed analytical model is accurate enough to describe the behaviors of the differentiated service provided by the networks with the MAC protocol.

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## 1. Introduction

Wavelength division multiplexing (WDM) is an effective technique for utilizing the large bandwidth of an optical fiber. By allowing multiple messages to be simultaneously transmitted over a number of optical channels, WDM has the potential to significantly improve the performance of optical networks. A passive star coupler, equipped with tunable transmitters and tunable receivers, can be used to construct a multi-access LAN/MAN using WDM channels. It has the potential of sharing the enormous bandwidth of the optical medium among all the network users. In order to fully exploit the enormous available bandwidth of the optical fiber, efficient medium access control (MAC) protocols are needed to efficiently allocate and coordinate the system resources. Generally, the key requirements and features of MAC protocols for LANs/MANs comprise flexibility in terms of bandwidth allocation and configuration, low cost and compatibility with existing network architectures and protocols.

A major challenge in the design of future generation high-speed networks is the provision of real-time service to time-constraint applications such as video or audio information. It is also demanded that different types of traffic could coexist in one system and share the bandwidth of a few communication channels and other network resources. The networks would have the capacity to provide flexibility and efficiency to allow the coexistence of different types of traffic, such as real-time and multimedia traffic. An integrated traffic stream is composed of real-time traffic streams, in which messages have time constraints, and non-real-time traffic streams without time constraints. The most important aspect of the time-constrained applications is that a message generated at a source station must be received at its destination station within a given period of time. If the delay of a message in the network exceeds its time constraint, the message is considered as late. A scheduling algorithm for a MAC protocol that serves real-time messages is to schedule the transmission of the messages to meet their time constraints as much as possible.

There are many research results published on the real-time scheduling algorithms to provide real-time service in WDM optical networks as well as in some other networks. The proposal in Yan et al. (1996) tries to combine the pre-allocation-based technique with the reservation-based protocol to provide real-time service to the time-constrained messages by using a centralized controller for the message scheduling in optical networks. The scheduling algorithm proposed in Ma et al. (1999) is the first solution to provide real-time services in the single-hop passive star coupled WDM optical networks. The scheduling algorithm is to provide real-time service to the variable-length, burst messages with time constraints. The solution proposed in Huang and Ma (2005) explores the features at the physical layer of the same networks to improve the performance of the real-time service. There are also some research results published on the performance model of the optical networks with single server priority queuing systems. Such models can be found in Mitrani and King (1981), Gail et al. (1988, 1992), Kao and Narayanan (1990), Kao and Wilson (1999),

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Kella and Yechiali (1985), Wagner (1994, 1997), Davis (1966), and Kapadia et al. (1984). However, the network performance modeled by multi-server priority queuing systems has received less attention. In this paper, we suggest a MAC layer protocol to support differentiated service to integrated traffic, consisting of real-time and non-real-time traffic streams with different priorities, in the same type of optical networks as those in Ma et al. (1999) and Huang and Ma (2005). The performance will be mainly studied by an analytical model, which is proposed to model the network as a multi-server priority queuing system with impatient customers. The performance model of the network can also be used to evaluate the differentiated service in the networks. The major contribution in this paper is the proposal of the mathematical model to describe the operations of the system and to evaluate the performance of the differentiated service in the specified optical networks. The proposed model in this paper has been evolved from the model in Wagner (1997) with consideration of time constraints of the real-time messages as addressed in Movaghar (1998) and the channel assignment scheme (Jia et al., 1995) adopted in the passive star coupled WDM optical networks.

The organization of the paper is as follows. Section 2 describes the system background and our MAC protocol. Section 3 is to derive the proposed performance models to describe the differentiated service in the networks. Section 4 presents the comparison between the simulation and the analysis. Section 5 concludes the paper.

## 2. System background and MAC protocol

### 2.1. System background

The network architecture being considered in this paper is a single hop WDM optical network with a passive star coupler (PSC). It assumes that there are $N$ nodes. Each node is connected to the PSC via two-way fibers, in which one way is used for transmission and the other for reception. Each direction of fiber supports $C+1$ wavelengths ($\lambda_0$, $\lambda_1,\ldots,\lambda_C$) with the same bandwidth. Each of the wavelengths is considered as a logical channel. The $C$ channels ($\lambda_1,\ldots,\lambda_C$) are data channels for message transmission. The remaining channel ($\lambda_0$) is a control channel for exchange global information among nodes about the messages to be transmitted. In the network, each node is equipped with two pairs of transceiver. One pair is fixed and tuned to the control channel ($\lambda_0$). The other pair of transceiver is tunable to any data channels to access messages. Based on the current status of a WDM technology, $C$ could be much smaller than $N$.

The network operates in a slotted mode with a slot time equal to the transmission time of one fixed-length packet. The nodes are assumed to generate variable-length messages, which can be divided into several fixed-length packets. In the network, the nodes are divided into two non-disjoint sets of source nodes $S_i$ and destination nodes $D_j$. A queue of messages to be transmitted is assumed to exist at each source node $S_i$, as shown in Fig. 1. On the control channel, time is divided into control frames. A control frame consists of $N$ control slots, each of which equals to the transmission time of a control packet. A time division multiplexing access (TDMA) protocol is used on the control channel to avoid channel collision. Each node has a corresponding control slot in a control frame, during which that node can transmit its control packet.

When a source node has a message at the head of its queue to be transmitted, the source node first sends a control packet during its assigned time slot on the control channel to all other nodes. After a round-trip propagation delay, all of the nodes receive the control packet. Then the distributed scheduling algorithm is invoked at each node, which assigns the messages represented in the control frame to the appropriate data channels to be transmitted in certain time slots. Once a message is scheduled, the transmitter of the source node will be tuned to the selected data channel and the message will be transmitted at the scheduled transmission time. After another round-trip propagation delay, when the message arrives at its destination, the receiver at the destination should have been tuned to the same channel to receive the message.

### 2.2. Proposed MAC protocol

In this paper, it is assumed that the traffic at each node consists of variable length messages with or without time constraints, and they have different static priorities. Each message can be modeled to the one with possible ten classes, of which five are real-time classes and another five are non-real-time classes. The average arrival rate of each message in each type of traffic flows is the same with others. Moreover, the real-time messages have strict laxities before the beginning of their service.

Message scheduling and channel assignment are two important issues to be addressed for the design of the MAC protocols for

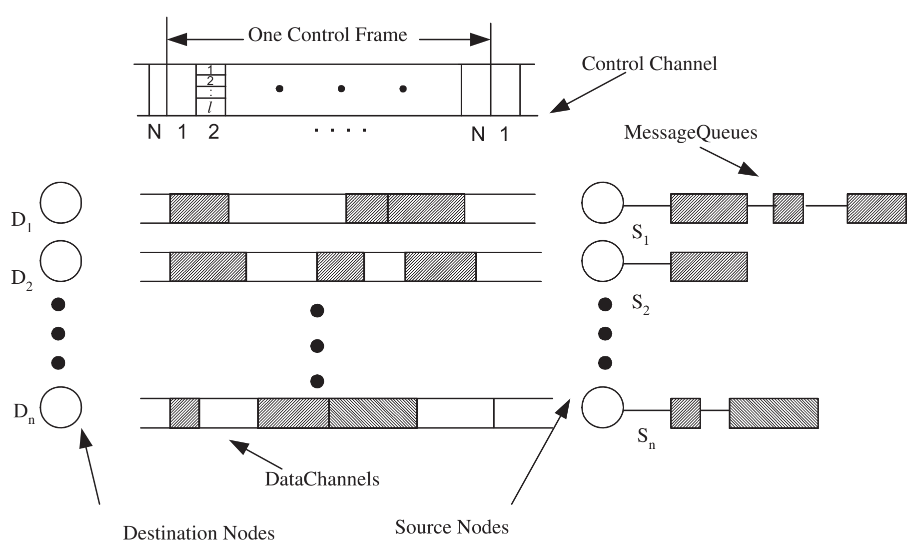


**Fig. 1.** Data and control channel configuration.

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