SUPPORTING TEMPORAL QUALITY OF SERVICE IN WDMA-BASED STAR COUPLED OPTICAL NETWORK

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CERTIFICATE

This is to certify that that the dissertation entitled *"Supporting Temporal Quality of Service In WDMA-Based Star Coupled Optical Networks"* which is being submitted by Mr. Praveen Kumar Tripathi to the School of Computer & Systems Sciences, JAWAHARLAL NEHRU UNIVERSITY, NEW DELHI for the award of Master of Technology in Computer Science & Technology is a bonafide work carried out by him under my supervision.

This is an authentic work and has not been submitted in part or full to any university or institution for award of any Degree.

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CONTENTS

ABSTRACT

In this work, we are devising a preallocation-based single-hop wavelength division multiple access (WDMA) schemes to support temporal quality of service (QoS) in star-coupled optical networks. We are considering a star-coupled broadcast-and-select network architecture in which *N* stations are connected to a star coupler with *W* different wavelength channels. Each of the *W* wavelength channels is slotted and shared by the *N* station by the means of the time division multiplexing. Depending on the tunability characteristics (tunable or the fixed tuned) of the transmitter/receivers, we classify the network architecture as tunable transmitter/fixed tuned receiver (TT-FR), fixed tuned transmitter/tunable receiver (FT-TR), and tunable transmitter/tunable receiver (TT-TR). We first characterize each real time message stream *Mi,* with two parameters, the relative message deadline *Di* and the maximum (total) message size *Ci* that can arrive within any time interval of length *Di*. We then have a restricted case in a TT-FR system in which the streams from a source station are assumed to be all destined for the same destination station. Under this assumption, no source/destination conflict may occur. Then we propose a preallocation-based slot assignment scheme to preallocate slots to a set of isochronous message streams, $\{Mi =(Ci, Di) \mid 1 <= i =< n\}$ in such a way that, in any time window of size *Di* slots, at least *Ci* slots on a wavelength channel are allocated to *Mi*. With the solution derived in the restricted case as the basis, we then consider slot assignment in a (general) TT-TR system and propose a *binary splitting* scheme to assign each message stream sufficient and well-spaced slots to fulfill its temporal requirement, subject to the source/destination conflict constraints.

CHAPTER 1

INTRODUCTION

We can identify three generations of networks based on the underlying physical-level technology employed. Network build before the emergence of fibre optic technology (i.e., those based on copper wire or microwave-radio technology) is referred to as first-generation networks. Their examples include Ethernet, IEEE 802.4 token bus, IEEE token ring etc.

Second generation networks employ fibre in traditional architecture. An excellent example of this generation is the upgrade of long haul trunks in the WAN from copper or the microwave-radio to fibre connections. Other examples include new designs as the Fibre Distributed Data Interface (FDDI) ring network and IEEE 802.6 distributed queue dual bus (DQDB) for LAN/MAN environment and Broadband Integrated Service Digital Network (BISDN) for WANs. Although some improved performance can be achieved by employing fibre (i.e., higher data rates, lower error rates, and reduced electromagnetic emissions from the cable), the limitation of this generation is due to the electronic front ends employed at the network nodes.

In the third generation networks, fibre is used because of its unique properties (like information-carrying facility is nearly four orders of magnitude greater than peak electronic speeds) in order to meet the needs of the emerging high bandwidth applications. These networks are "all optical" in nature, in the sense that once the information enters the network, it may remain in the optical domain (and not face any electronic bottlenecks) until it is delivered to its destination.

The realising that the maximum rate at which each end user can access the network is limited by the electronic speed (to few gigabits per seconds), the key in designing lightwave networks in order to exploit the huge bandwidth is to introduce concurrency among multiple-user transmission into the architecture and protocols. In an all-optical networks concurrency may be provided according to either wavelength or frequency (wavelength division multiple access-WDMA), time slots (time division multiple access-TDMA).

Before coming to the real problem, first considering the optical network fundamentals. In the optical networks the transmission media is a flexible glass fibre. This fibre is known by the name *optical fibre*, and the media uses the light to transport data. To understand optical fibre, we first need to explore several aspects of the nature of light.

Light is a form of electromagnetic energy. It travels at its fastest speed in the vacuum: 300,000 km/seconds. This speed of the light depends on the density of the medium through which it is travelling.

Light travels in the straight line as long as it is moving in single uniform substance. If a ray of light travelling through one substance suddenly enters another (more or less dense) substance, its speed changes abruptly, causing the ray to change the direction, this change in the direction of light due to the difference in the density of the material is known as *refraction*.

The direction in which the ray bents depend on the change in the density encountered. A beam of light moving from a less dense into a more dense medium is bent towards the vertical. The angles made by the beam of light in relation to the vertical are called I, for incident. and R for, refracted. In the fig the beam travels from a less dense medium to a denser medium, so angle R is smaller than angle I. however if the scene is reversed and the beam travels from dense to the rarer medium then the value of I will be less than R

Now examining the case given in the Fig 1.2. here again the light is travelling from the denser medium to the rarer, however if we gradually increase the angle of incidence, so does the angle of refraction. It moves away from the vertical and closer and closer to the horizontal. At some point in the process, the change in the incident angle results in a refracted angle of 90 degrees, with the refracted beam lying along the horizontal. The incident angle now is called as the *critical angle*.

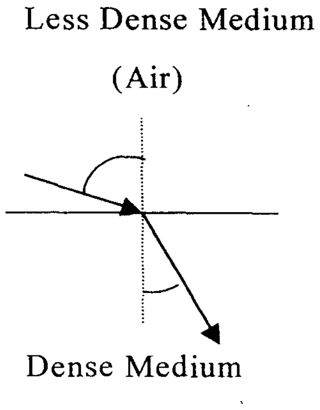


Fig 1.1

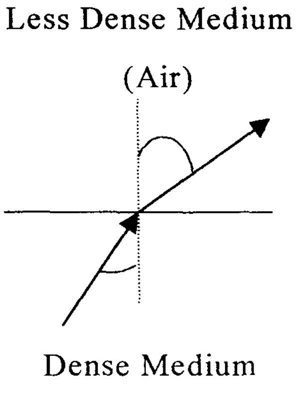


Fig 1.2

Fig 1.3 CRITICAL ANGLE

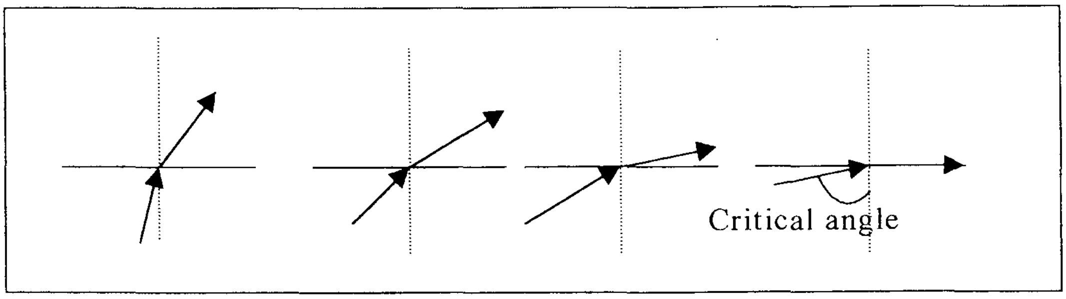
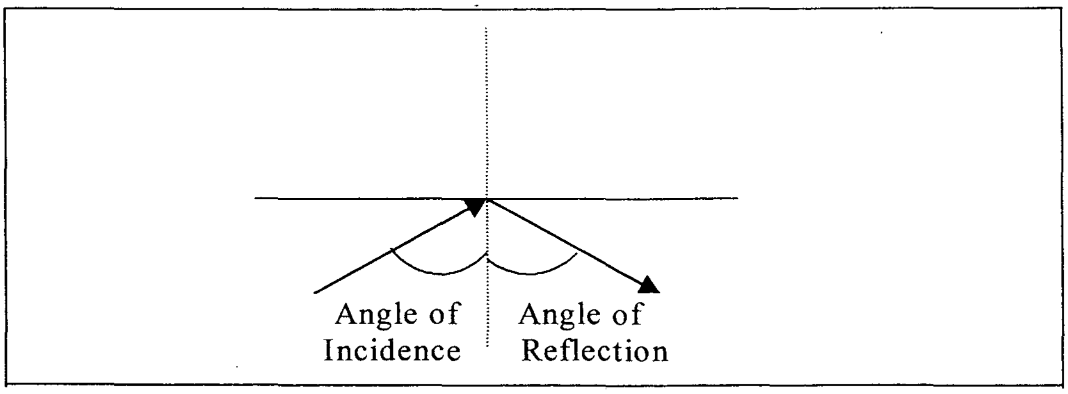


Fig 1.4 REFLECTION



When the angle of incidence becomes greater than the critical angle, a new phenomenon occurs called reflection (or, more accurately, completes reflection, because some aspect of reflection always remains with refraction). Light no longer passes into the rare medium at all. In this case the angle of incidence is always equal to the angle of reflection.

Optical fibre use reflection to guide light through the channel. A cladding of less dense material (glass or plastic) surrounds a glass or plastic core. The difference in the density of the two materials must be such that a beam of light moving through the core is reflected off the cladding instead of being refracted into it. Information is encoded into a beam of light as a series of on-off flashes that represents 1 and 0 bits.

Current technology supports two modes for propagating the light along the optical channels, each requiring fibre with different physical characteristics: *multimode* and *singlemode*. Multimode, in turn can be implemented in two forms: *step-index* or *graded-index*

Multimode is so named because multiple beams of light source move through the core in different paths. How these beams move in the cable depends on the structure of the core.

In the Multimode step-index fibre, the density of the core remains constant from the centre to the edges. A beam of light moves this constant density in a straight line until it reaches the interface of the core and the cladding. At the interface, there is an abrupt change to the lower density that alters the angle of the beam's motion. The term step-index refers to the suddenness of this change.

In this case the some beams in the middle travel in the straight lines through the core and reach the destination without refracting and reflecting. Some of the beams strike the interface at angle smaller than the critical angle and these beams penetrate the cladding and are lost. Still others hit the edge of the core at angle greater than the critical angle and reflect back into the core and off the other side, bouncing back and forth down the channel until they reach the destination.

Every beam reflects off the interface of an angle equal to the angle of incidence. The greater the angle of incidence the wider the angle of reflection. The beam with the smaller angle of incidence will make many more bounces to travel the same distance than a beam of the larger angle of incidence. Consequently the beam with, the smaller angle of incidence will travel farther to reach the destination. This difference in path length means that different beams reach the destination at different times. As these beams are recombined at the receiver, they result in the signal that is no longer a replica of the signal that was transmitted. Such a signal has been distorted by the propagation delays. This distortion limits the Multimode step-index cable inadequate for certain precise applications.

A second type of the fibre, is called as Multimode graded-index fibre, decreases this distortion of the signal through the cable. The word index refers to here the index of refraction. As the index of refraction is related to density. A graded-index fibre, therefore, is one with varying densities. Density is highest at the centre of the core and decreases gradually to its lowest at the edge.

The signal is introduced at the centre of the core. From this point, only the horizontal beam moves in the straight line through the constant density at the centre beams at the other angle move through a series of constantly changing densities. Each density differens causes each beam to refract into a curve. In addition, varying the refraction varies the distance each beam travels in a given period of time, resulting in different beams intersecting at regular intervals. Careful placement of the receiver at one of these intersections allows the signal to be reconstructed with far greater precision.

Singlemode uses step-index fibre and highly focussed source of light that limits beam of small range of angles, all close to the horizontal. The single mode fibre itself is manufactured with much smaller diameter than those of Multimode fibres, with substantially lower density. The decrease in the density results in the critical angle that is close enough to 90 degrees to make the propagation of the beam almost horizontal as in Fig 1.4. In this case, propagation of different beams is almost identical and delays are negligible. All of the beams arrive at the destination "together" and can be combined without distortion to the signal.

Since the purpose of fibre-optical cable is to contain and direct a beam of light from source to the target. For transmission to occur, the sending device must be equipped with a light source and the destination device with a photosensitive cell (called a photodiode) capable of translating the received light into current usable by a computer. The light source can be either a *light emitting diode* (LED) or an *injected laser diode* (ILD). LEDs are cheaper source, but they provide unfocussed light that strikes the boundaries of the channel at uncontrolled angles and diffuse over distance. For this reason LEDs are limited to the shorter distance usage.

Lasers, on the other hand, can be focussed to a very narrow range, allowing control over the angle of incidence. Laser signals preserve the character of the signal over considerable distances.

Connectors for optical-fibre must be as precise as the cable itself. Any misalignment of one segment of the core either with another segment or photodiode results in the signal reflecting back to the sender, and any difference in the size of the two connected channels results in the change in the angle of the signal. In addition, the connection must be complete yet not overly tight. A gap between two cores results in a dissipated signal; an overly tight connection can compress the two cores and alter the angle of reflection.

The major advantages offered by fibre-optic cable over the coaxial cable are noise resistance, less signal attenuation, and higher bandwidth.

Noise resistance because fibre-optic transmission uses light rather than electricity, noise is not a factor. External light, the only possible interference, is blocked from the channel by the outer jacket.

Fibre-optic transmission distance is slightly greater than of other guided media. A signal can run for miles without requiring regeneration.

Fibre-optic cable can support dramatically higher bandwidths (and hence data rates) than either twisted-pair or coaxial cable. Currently, the data rates bandwidth utilisation over fibre-optic cable is limited not by the medium but by the signal generation and reception technology available.

A local lightwave network can be constructed by exploiting the capabilities of emerging optical technology, e.g., dense WDM and tunable optical transceivers. The vast optical bandwidth of the fiber is carved up into smaller capacity channels, each of which can operate at peak electronic processing speeds (over a small wavelength range) of a few bits per seconds. By tuning its transmitter(s) to one or more wavelength channels, a node can transmit into that channel(s); similarly, a node can tune its receiver(s) to receive from the appropriate channels. The system can be configured as a broadcast-and-select network in which all the inputs from various nodes are combined in a WDM passive star coupler and the mixed optical information is broadcast to all outputs. An $N*N$ star coupler, as show in the Fig1.5, can be considered to consist of an $N*1$ combiner followed by $1*N$ splitter; thus the signal strength incident from any input can be equally divided among all N outputs. The passive star topology is attractive, first because its logarithmic splitting loss in the coupler and second because of no tapping or insertion loss.

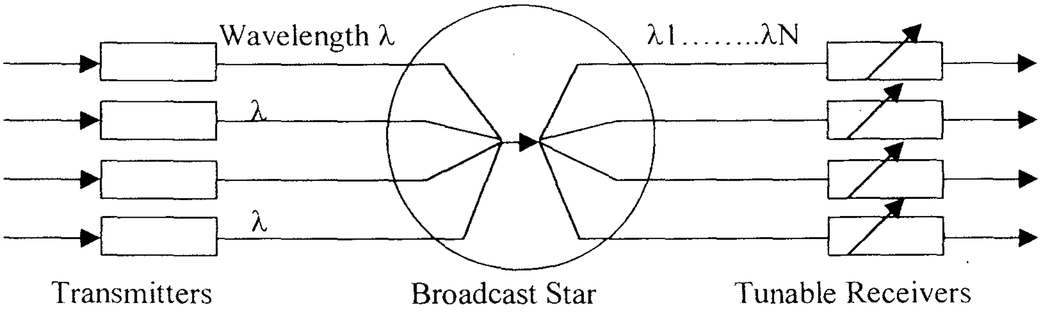


Fig 1.5 A Broadcast-and-select WDM network

In a WDM network, each network node is typically equipped with a small number of transmitters and receivers, with some of these transceivers being dynamically tunable to different wavelengths.

The tunable transceivers are used differently depending on the type of network architecture chosen. In multihop networks, a node is assigned one or more channels to which its transmitters and the receivers are to be tuned. These assignments are only rarely changed, usually to improve the network performance. Connectivity between any pair of nodes is achieved by having all nodes also to act as the intermediate routing nodes. The intermediate nodes are responsible for routing the data among lightwave channels such that the data sent out on one of the sender's transmit channels finally get to the destination on one of the destination's receive channels, possibly after multihopping through a number of intermediate nodes.

In single-hop networks, there are no intermediate nodes. As a result, a significant amount of dynamic coordination between the nodes is required. For a packet transmission to occur, one of the transmitters of the sending node and one of the receivers of the destination node must be tuned to the same wavelength for the duration of the transmission. In the single-hop environment, it is important that the transmitter and receivers be able to tune to different channels quickly, so that packet may be sent or received in quick succession. Currently, the tuning time for transceivers is relatively long in comparison to packet transmission times, and the tunable range of these transceivers is small. Thus the key challenge in the single-hop architecture is to develop protocols for efficiently coordinating the data transmissions.

Due to advances in low-loss single -mode fiber technology, optical networks have been proposed to meet the bandwidth demand of emerging applications. In this dissertation an effort has been made to propose a preallocation-based WDMA scheme for providing temporal quality of service (QoS) guarantees for message transmission in single-hop star-coupled optical networks.

In a WDMA-based optical network, different channels correspond to different optical wavelengths that can be multiplexed on to a single fiber. Station may transmit/receive packets on different channels using a fixed-tuned or tunable laser transmitter/receiver. Several physical network topologies have been proposed, among which the passive star topology using a broadcast-and-select star coupler has been most commonly used. In this configuration all the inputs from the various stations are combined in a star coupler and the mixed optical information is broadcast to all outputs. Each station is equipped with tunable and/or fixed tuned transmitter(s) and receiver(s). The transmitter of a source station or the receiver of a destination station, or both must be appropriately tuned to the same wavelength for data transmission/reception.

Two main approaches have been proposed for WDMA-based star-coupled optical networks. In the multi-hop approach, fixed wavelengths are assigned to stations in advance and each station uses fixed wavelength transmitters and receivers. Usually there is no full physical connectivity between stations and the packets travelling between stations make several hops through intermediate stations before they reach their final destination. On the other hand in, single-hop approach, any pair of stations establish direct communications over a channel by employing tunable transmitter(s) and/or receiver(s). Both the transmitter of the source station and the receiver of the destination must be tuned to the same wavelength for the transmission duration. Efficient dynamic coordination of channel access is then needed to maximize the network throughput and to minimize the network delay. A number of media access control (MAC) protocols have been proposed for single-hop WDMA-based optical networks all of which can be further divided into *reservation-based* and *preallocation-based* schemes, depending on the methods used to arbitrate the demand for the network resources. Reservation-based techniques designate one or more wavelength channels as the control channels and use them to reserve/coordinate access on the remaining channels for the data transmission. Preallocation-based techniques pre-assign channels to stations either for data transmission or for data reception. The channel that a station uses to transmit or receive is prespecified using time division multiple access (TDMA) or its variation. Pre allocation-based techniques have several advantages over reservation-based ones: No control channel is required, less hardware (one transmitter and one receiver per station) is needed, low per-packet processing overhead is incurred, and no collisions during control/data packet transmission may occur and hence higher throughput can be achieved.

We are considering star-coupled broadcast-and-select-network architecture in which N stations are connected to a star coupler with W

different wavelength channels. Each of the W wavelength channels is slotted and shared by the N stations by the time-division-multiplexing (TDM). Each station is equipped with one transmitter and one receiver. Depending on the tunability characteristics of the transmitter/receiver, we consider tunable transmitter/fixed tuned receiver (TT-FR) systems, fixed tuned transmitter/tunable receiver (FT-TR), and tunable transmitter/tunable receiver (TT-TR) system, respectively. In any time interval, no source station should be scheduled to transmit to multiple destination stations, and no more than one station should be scheduled to transmit to the same destination station. The formal is the source conflict constraint and the latter is the destination conflict constraint. Each real-time message Mi is characterized with two parameters, relative message deadline Di, and maximum (total) message size Ci, that can arrive within any interval of length Di. First the a restricted case of TT-FR system is considered in which message streams from a source station is assumed to be all destined to the same destination station. Under this assumption, no source conflict may occur and destination conflict can be easily resolved. A preallocation-based slot assignment scheme has been proposed to allocate the slots to a set of isochronous message streams, $\{Mi = (Ci, Di) \mid 1<=i<=n\}$, in such a way that, in any window of size Di slots, at least Ci slots on a wavelength channel is allocated to Mi for all i.

We then relax the assumption, and consider slot assignment in TT-TR system. We propose a preallocation-based scheme, called binary splitting, to assign to each message stream sufficient and well-spaced slots, subject to the source/destination conflict constraints and with objective of using as few wavelengths as possible.

CHAPTER 2

SYSTEM AND MESSAGE MODEL

2.1 SYSTEM MODEL

We consider a network of N stations, each equipped with one transmitter and one receiver, and interconnected through an optical broadcast medium, i.e., a pass star coupler that can support W wavelength channels, $\lambda 1$, $\lambda 2 \ldots . \lambda w$. Since the transmitter/receiver tuning range that can be supported by current technology is usually limited and, hence only a few wavelengths can be available, in our network it is assumed that $W<=N$. In other words, each station may have to share a wavelength channel with other stations.

A WDM-based network can be classified into three categories depending on the tunability characteristics (tunable or fixed tuned) of the transmitter/receivers. We refer to the three resulting systems as tunable transmitter/fixed tuned receivers (TT-FR), fixed tuned transmitter/tunable receiver (FT-TR) and tunable transmitter/tunable receiver (TT-TR), respectively. For the TT-FR (FT-TR) system, channel wavelengths are assigned at system initialization time to receivers (transmitters) and are fixed during system operation

Data transmission is in slotted mode and so every wavelength channel is time slotted and slots are synchronized to the slot boundaries. Each wavelength channel is shared by possibly up to N stations in the network. The slots on each wavelength are preallocated to stations for data transmission/reception. No control channel is required and all channels are used for data transmission.

A schedule specifies, for each wavelength channel, which slots are required for data transmission from station *i* to station *j*. since each station is equipped with only one transmitter and receiver, so a schedule is valid only if following two conditions hold, in any time interval [t-1, t]:

C1. No multiple stations are scheduled to transmit to the same destination station;

C2. No source station is scheduled to transmit to multiple destination stations.

Violation to C1 and C2 is usually referred to as destination and source conflict, respectively.

As the exact time when a message in a message stream *Mi* arrives is not known a priori and message arrivals do not necessarily align with one another. Hence one way for a slot assignment scheme to meet the timeliness criteria is to assign at least *Ci* slots to *Mi* for any time interval of length *Di* subject to the constraint that:

1) At most one slot is assigned to any message stream in $\{Mi \mid N^s_i = k\}$ for all *k* at any time *t*.
2) At most one slot is assigned to any message stream in $\{Mi \mid N^s_i = k\}$ for all *k* at any slot time *t*.

2.2 MESSAGE MODEL

Let M={*Mi* | 1<=*i*<= n} be a set of n isochronous message streams in the network. For each station there can be zero, one or more real-time message stream emanating from it. In our message model we are using 4-tuple to describe real-time message Mi as (Ci, Di, N^i_s, N^i_d):

1. *Ci* is the maximum number of packets in Mi that can arrive in any time interval of length *Di*.
2. *Di* is the relative transmission deadline for message in *Mi*, i.e. if any message arrives at time t, then it must be transmitted by the time t + *Di*.
3. N^i_s belongs to set [1,*N*] is the source station of *Mi*.
4. N^i_d belongs to set [1,*N*] is the destination station of *M*i.

We further assume that both time and timing parameters are expressed in slots and the message arrivals are aligned with beginnings of slots.

Another term of importance in our model is of message density of the real-time message stream *Mi* given as $\rho(Mi) = Ci/Di$ and the total message density of the set of real-time message streams

M={ *M1*,*M2*,....,*Mn*} is:

$$\rho(M) = \sum\rho(Mi) = \sum Ci/Di$$

CHAPTER 3

PROBLEM DEFINITION

3.1 FORMULATION OF SLOT ASSIGNMENT PROBLEM FOR PREALLOCATION-BASED SINGLE-HOP WDMA PROTOCOLS:

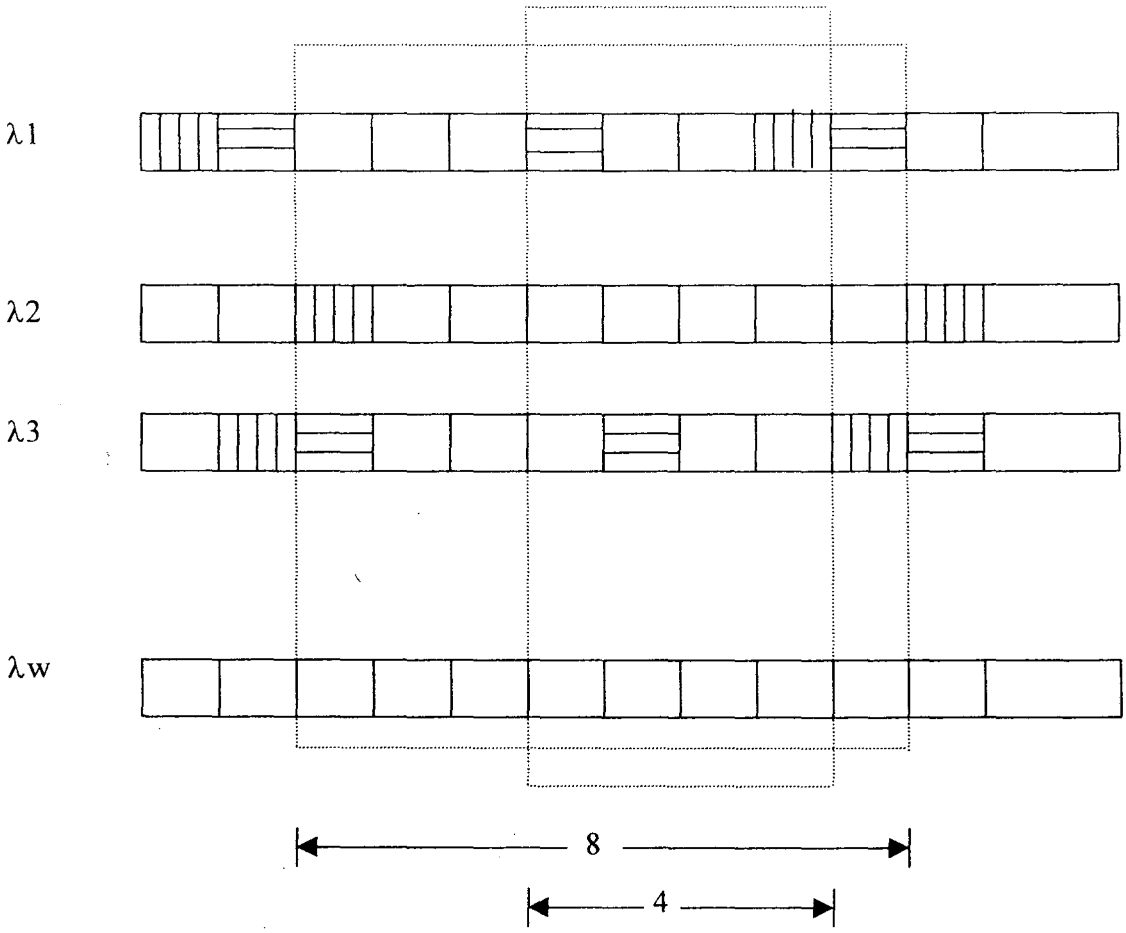
We can state the temporal QoS for the real-time messages as: the slots available in the W wavelength channels must be properly assigned to each message stream Mi so that every message in Mi is transmitted within time period $<= Di$ after its arrival as long as the maximum message size in any time interval of length Di is $<= Ci$.

Problem1 (Slot Allocation Problem). Find a slot allocation scheme such that, given a set of real-time message streams $M = \{Mi = (Ci, Di, N^i_s, N^i_d) \mid 1 <= i <= n\}$ and W $(W <= N)$ wavelength channels, the scheme can allocate time slots over the W wavelength channel in such a way that each message stream Mi is guaranteed to transmit each of its message before its deadline Di, subject to these constraints:

C1. No multiple stations are scheduled to transmit to the same destination station.

C2. No source station is scheduled to transmit to multiple destination stations (possibly on different wavelength channels).

As the exact time when a message in a message stream *Mi* arrives is not known a priori and message arrivals do not necessarily align with one another. Hence one way for a slot assignment scheme to meet the timeliness criteria is to assign at least *Ci* slots to *Mi* for any time interval of length *Di* subject to the constraint that:



▥ Is allocated to *Mi*

▤ Is allocated to *Mj*

Fig 3.1 Real Time Message Scheduling Scheme for TT-TR System With $Mi = (3,8, N^s_i, N^d_i)$ and $Mj = (2,4, N^s_j, N^d_j)$

1. At most one slot is assigned to any message stream in $\{Mi \mid N^s_i=k\}$ for all k at any time t.
2. At most one slot is assigned to any message stream in $\{Mi \mid N^s_i=k\}$ for all k at any slot time t.

A valid slot schedule for isochronous message stream $Mi = (3,8,N^s_i,N^d_i)$ and $Mj = (2,4,N^s_j,N^d_j)$ in the TT-TR system

3.2 A RESTRICTED SLOT ASSIGNMENT SCHEME FOR TT-FR SYSTEMS:

In this case we have the slot assignment scheme for TT-FR systems with the following assumption:

A1. All the message streams of a source station are destined for the same receiver station (i.e., if $N^s_i = N^s_j$ for two message streams Mi and Mj, then $N^d_i = N^d_j$)

Since the receiver of each station is tuned to a fixed wavelength in the TT-FR system and the messages have to be transmitted using the wavelength to which the destination stations receiver is tuned, so we can group the message streams that are transmitted over a wavelength channel λc into message set $M_{\lambda c}$, i.e., $M_{\lambda c} = \{Mi \mid \lambda(N^d_i) = \lambda c\}$. Now the slot assignment scheme that is designed to allocate slots on each wavelength channel independently will do so in such a way that, in any time interval of length Di slots at least Ci slots are allocated to $Mi \in M_{\lambda c}$

On the wavelength channel λc for all i and c, the final slot schedule then consists of all the slots schedules, one for each wavelength channel.

In our effort we will first focus our attention to the case in which the deadline constraints set consists of multiples, i.e. Di divides Dj for all $i<j$. In this case for the valid schedule, we use the rate-monotonic scheduling discipline [1]. Treat Ci as the computation time and Di as the period and assign Ci slots over wavelength channel λc to message stream Mi during each period $[(j-1) * Di, j * Di]$ for all $Mi \in M_{\lambda c}$ and all $j >= 1$.

The theoretical basis for the above slot assignment method has been established in [4] that is summarized below:

3.3 Theorem 1.

3.3 Theorem 1. For a set of real-time message stream that are transmitted over a wavelength channel λc,

$M_{\lambda c} = \{Mi = (Ci, Di, N^s{}_i, N^d{}_i) \mid \lambda(N^d{}_i) = \lambda c\}$,

If Di divides Dj for all $i<j$ and $\rho(M_{\lambda c}) <= 1$, the above rate monotonic based slot assignment scheme will allocate Ci slots over the wavelength channel to Mi in any time window of size Di slots, for all $Mi \in M_{\lambda c}$

3.4 Specialization Operation:

For an arbitrary message set, $M' = \{M'_i = (Ci, D'i, N^i{}_s, N^i{}_d) \mid 1 <= i <= n\}$, the deadline constraint set does not necessarily consist solely of multiples, i.e., $D'i$ divides $D'j$ may not be true for all $i<j$. In this case, we first transform it to another stream set $M = \{Mi = (Ci, Di, N^i{}_s, N^i{}_d) \mid 1 <= i <= n\}$ in which the transformed deadline constraint set $D = \{D1, D2, \ldots, Dn\}$ consists solely of multiples and $Di <= D'i$ for all i. Here we find a Di for each $D'i$ such that Di satisfies

$$Di = x.2^j <= D'i < x.\ 2^{j+1} = 2.Di$$

For some integer $j >= 0$, where x is an integer $\in (D'i/2, D'i]$ that result in the minimum total density increase.

CHAPTER 4

GENERAL SLOT ASSIGNMENT SCHEME

The previous slot assignment scheme works under only the assumption A1. This is because the slot assignment scheme considers the slot scheme for each wavelength channel independently, hence, if multiple message streams from the same source station may be destined for different receiver stations, the source station may be scheduled to transmit messages over distinct wavelength channels in the same slot in the composite slot schedule.

Our work is to relax the assumption A1 and design a more general scheme for TT-TR systems.

For the purpose we first decompose the message stream into a set of message substreams and then group the time slots on each of the wavelength channel into subchannels to facilitate the slot assignment. At the same time we also assume that the arbitrary message set is specialized with respect to {2}.

4.1 DECOMPOSITION OF MESSAGE STREAMS:

We decompose each message stream into a set of message substreams and will then assign slots to them. This decomposition is based on the property that for each message stream $Mi = (Ci, Di, N^i_s, N^i_d)$, the message density Ci/Di can be expressed as

$C_i/D_i = \sum C_{i,j}/D_{i,j}$

Where $mi = log_2Di$, $D_{ij} = 2^j$ and 0 or1,for $0 < = j < = m_i$. Hence, we can decompose Mi into a set of substreams.

$\{M_{ij} = (C_{ij}, D_{ij}, N^s{}_i, N^d{}_i) \mid 0<=j<= m_i$ and $C_{ij} = 1\}$.

We call C_{ij} and D_{ij} the slot requirement and deadline of the substream M_{ij} respectively.

If we can assign slots in such a way that, for each j, at least one slot is assigned to substream $M_{ij} =(C_{ij}, D_{ij}, N^s{}_i, N^d{}_i)$ in any time window of size $D_{ij} = 2^j$ then the timeliness criteria is satisfied for M_i.

The specialized set of substream in the network is given as $M_s = \{M_i = (Di, N^s{}_i, N^d{}_i, posi,\lambda i) \mid 1<=i<= ns\}$, where the slot requirement is dropped just because of the reason that it is always 1 and

- Di is the deadline constraint;
- $N^s{}_i$ and $N^d{}_i$ are the source and the destination stations, respectively;
- *posi* is the sequence of log_2Di "L" (left) and "R" (right) characters if completely specified and denotes the position of the slot assigned to *Mi* in the time frame of size *Dn*; *pos*i is initially set to null and will be incrementally specified by the proposed scheme in each iteration of the operations:
- λi is the wavelength channel the slot on which *Mi* is assigned. λi will also be specified by the proposed scheme.

Here the value of posi and λi will completely specify which slot on which wavelength channel are assigned to *Mi*

A message substream *Mi* is said to be related to another substream *Mj* if they are either from the same source station or destined to the same receiver station.

4.2 CONCEPT OF THE SUBCHANNEL:

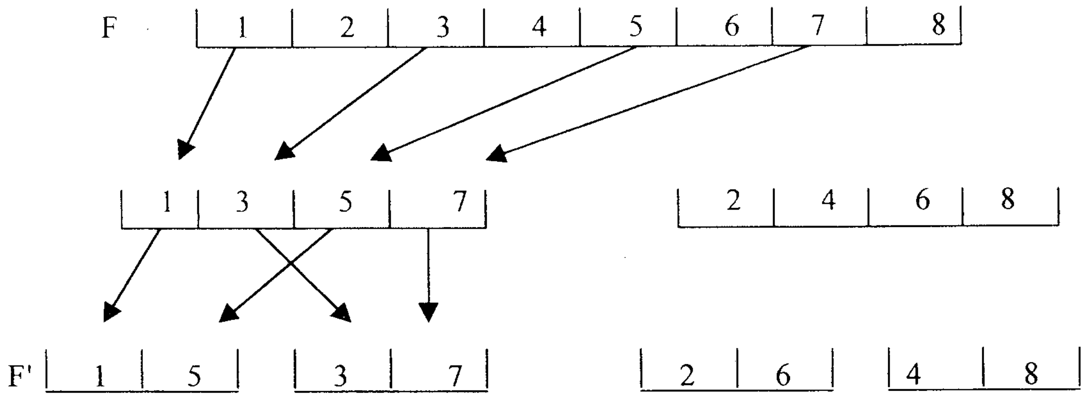
We have to group the time slots on each of the wavelength channel into subchannel and will assign to each substream a subchannel to satisfy its deadline constraint. Specifically, a 1/d subchannel consists of evenly spaced slots of which any two consecutive ones are separated by d slots. An efficient subchannel assignment scheme should assign a 1/*Di* subchannel to each substream *Mi*.

4.3 BASIC AND TRANSFORMED TIME FRAMES:

Give a specified set of message streams, M= {*Mi* = (*Ci*, *Di*, $N^s{}_i$, $N^d{}_i$,)| 1<=*i*<= *ns*}, we define a basic time frame F of duration *Dn* as the time period [(j-1).*Dn*, j.*Dn*), for some *j*>=1. Since the slot assignment repeats every *Dn* slots, for simplicity and without ambiguity, we will henceforth denote F as {1,2....,*Dn*}. Moreover to facilitate slot assignment we transform F to a transformed time frame, F', using the following steps

1. Form a new time frame F' by reordering the slots such that slots in the odd-numbered positions are followed by slots in the even-positions.
2. Divide F' into left and right subframes, F_L and F_R .
3. If F_L and F_R consists of two slots, proceed to step 4; else perform step 1-3 on F_L and F_R respectively.
4. Combine F_Ls all F_R s and into F'.

Fig 4.1 TIME FRAME TRANSFORMATION:



F is the basic time frame for Dn =8

F' is the transformed time frame

4.4 ASSIGNMENT OF SUBCHANNELS TO SUBSTREAMS (BINARY SPLITTING):

After our present position when we have the idea of the substreams and subchannels our problem now is reduced to the following:

Problem2 (Subchannel Assignment Problem). Find a subchannel assignment scheme such that given a set of substreams,

$$Ms = \{Mi = (Di, N^s_i, N^d_i, posi, \lambda i) \mid 1 <= i <= ns\},$$

Where posi, and,λi, are yet to be determined and *W* wavelength channels, device a Subchannel assignment scheme to assign $1/Di$ subchannel on one of the wavelength channels to each message substreams *Mi*. The objective is to use as few wavelength channels as possible, subject to temporal QoS requirement of $Mi \in$ Ms and source/destination conflict constraints.

We now have the solution scheme called binary splitting. Given (a specialized and ordered) set of message substreams

$$\text{Ms} = \{Mi = (Di, N^s_i, N^d_i, posi, \lambda i) \mid 1 <= i <= ns\},$$

The scheme assigns to each message substream *Mi* sufficient slots to fulfill its temporal QoS requirement, subject to source/destination constraints, as long as the following schedulability condition holds:

$\rho(\{Mj \mid Mj$ is ordered ahead of Mi in Ms and is related to $Mi\}) + \rho(Mi) <= 1$;

for every $Mi \in$ Ms.

4.5 BINARY SPLITTING PROCEDURE:

The binary splitting procedure is given in the figure. Given a specialized set of message streams, M, we first decompose each message stream into a set of message substreams and will henceforth consider the composite set of message substreams, Ms $=\{Mi = (Di, N^s_i, N^d_i, posi, \lambda i) \mid 1 <= i <= ns\}$. Second we sort the message substreams in Ms in the nondecreasing order of their deadline constraint. Then we recursively

1) Divide the corresponding transformed time frame F' of the duration $\max i\{Di\}$ into two subframes F_L and F_R and
2) Split Ms into two smaller subsets M_L and F_R substreams of which are assigned to F_L and F_R, respectively until the density of each subset is less than that of the time subframe. After the splitting stops, we then apply the rate-monotonic scheduling discipline to schedule

message substreams in each subset in the corresponding time subframe.

Specifically, let F(k) and M(k) denote the time (sub)frame and the substream set under consideration in the kth iteration. Initially, F(1)=F' and M(1) =Ms. In the kth iteration of the binary splitting (k>=1), we divide the time frame, F(k), of density $1/2^{k-1}$ into two subframes, FL(k) and FR(k), each of the density $1/2^{k}$. We also split the set of the message substreams, M(k) into two subsets, ML(k) and MR(k), by assigning each substream in M(k) to either ML(k) or MR(k), subject to source and destination conflict constraints.

The recursive splitting operation in the kth stage is done by first constructing the substream set pairs. A substream set pair is a pair of substream sets, (Pi,Qi), which are related to each other and will hence be assigned to two different subframes. The substream set pairs will be so constructed that different pairs are independent of one other. Specifically, let $RL_i^a(k)$ denote the substream set that consists of all the substreams that are related to, and are ordered ahead of, Mi in the ordered set M(k) in the kth stage. In the kth stage of binary splitting, initially there is no substream set pair. There are three cases to consider for the assignment of a substream *Mi*,

Case 1: if *Mi* is not related to any existing pair(s), a new pair, (Pi,Qi), is created and *Mi* is arbitrarily assigned to Pi.

Case 2: if *Mi* is related to only one pair say (Pj,Qj), *Mi* is assigned to either Pj, or Qj using the following principle

P1. If $\rho(RL_i^a(k) \cap Pj) < \rho(RL_i^a(k) \cap Q)$, assign *Mi* to Pj, where $(RL_i^a(k) \cap Pj)$ denotes the subset that consist of message substreams that are related to *Mi* and are assigned to Pj prior to *Mi* being assigned.

A tie is broken by assigning *Mi* to Pj if ρ(Pj)<= ρ(Qj). Otherwise, assign *Mi* to Qj.

Case 3. If *Mi* is related to two substream set pairs, say (Pj,Qj) and (Pl,Ql), assigning *Mi* to either pair makes both the pairs related. In order to maintain the independence between the substream set pairs we need to combine these two pairs into a new pair, say (Pi,Qi), and assign *Mi* to either based on P1.

There are two issues to be considered:

1) how to combine the (Pj,Qj) and (Pl,Ql) either Pi = Pj $\cup$Pl and Qi = Qj $\cup$Ql, or Pi = Pj $\cup$Ql and Qi = Qj $\cup$Pl and
2) to which stream subset (Pi or Qi) *Mi* is assigned.

We here consider both the combinations in 1 and assign *Mi* to Pi or Qi based on P1.Then we select the combination that results in a more balanced density distribution between Pi and Qi.

Since *Mi* related to other message substreams through either the source or the destination stations, *Mi* can not be related to more than two pair. Also, by the fact that all the substream pair are independent of one another, if *Mi* is assigned to a set pair (Pi,Qi), then all substreams that are related to *Mi* in M(k) are also in Pi $\cup$Qi

After all the message substreams are assigned to the substream set pairs, we consider each set pair, (Pi,Qi) and assign Pi to one of the two substream sets, M_L(k) and M_R(k), and Qi to other, with the objective of reducing the density difference between M_L(k) and M_R(k). As the message substreams in M_L(k) and M_R(k) will be assigned and scheduled in subframe F_L and F_R respectively, the above objective hence reduces the number of channels needed.

After we decompose M(k) into M_L(k) and M_R(k), we assign a $1/2^k$ subchannel in F_L(k) to each substream, Mj, in M_L(k) with the deadline constraint $Dj=2^k$ by properly specifying *posj* and λj. We then remove *Mj* from $M_L(k)$ since it has been completely assigned a subchannel (as specified by the *posj* and λj)

After the recursive_split algorithm terminates, both *posj* and λj of each message substream, *Mi* will be completely specified provided that the number of the wavelengths needed does not exceed *W*.

THE BINARY SPLITTING ALGORITHM (PSEUDOCODES):

```
/* The main binary splitting algorithm Binary_split takes the argument
as the message stream M */
  Binary_split(M)
      {
              M':= Specialize(M);
               /* Specialize is the act through which the arbitrary
              message steam M gets specialized with respect to 2 for
              convenience */
              Ms := Substream(M');
              /* Substream will convert the set of message stream M
              into the set of message substreams Ms */
              Sort(Ms);
              /* Through the procedure Sort we will sort the Ms into
              non- descending order of deadline constraint */
              for every Mi∈Ms
                      do
                              posi:=0;
              fail:=0;
              Re_split(Ms,1,1);
              If(!fail)trans_pos(Ms);
              Else
                      Schedule does not exist for W;
}


/* The Re_split algorithm splits the message Substream into $M_L$ and $M_R$
with deadline constraint >= $2^k$ */
```

```
Re_split(M,$\lambda$,k)
 {
        /* Termination condition */
        if($\lambda$>W)
                {
                        fail=1;
                return;
}
else if($\rho$(M)<= $2^{k-1}$)
        {
         apply the rate monotonic scheduling on M on the current time
         sub- frame;
         return;
        }
(Pj,Qj) := construct_pair(M); /* 1<=j<=np, where np is the number of
the resulting pairs*/
($M_L$,$M_R$):=Set_pair(Pj,Qj); /* 1<=j<= np */
($M_L$, $\lambda_L$) := Assign ($M_L$, $\lambda_L$,'L');
($M_R$, $\lambda_R$) : = Assign ($M_R$, $\lambda_R$,'R');
Re_split($M_L$, $\lambda_L$,k+1);
Re_split($M_R$, $\lambda_R$,k+1);
}

/* construct_pair is the procedure that divides the message Substream
into Substream-set pairs */
construct_pairs(M)
{
 for every Mi $\in$ M
```

```
      do
      {
       if(there exist at most two sub-stream set pair that are related to Mi)
      {    {
             $P1i:=Pj \cup Pl$;
             $Q1i:=Qj \cup Ql$;
             (P1i,Q1i)     := add_pair(Mi,P1i,Q1i);
             $P2i:=Pj \cup Ql$;
             $Q2i:=Qj \cup Pl$;
              (P2i,Q2i)     := add_pair(Mi,P2i,Q2i);
           }
/* here above we have considered both the combination of the substream set*/
  if($|\rho(P1i)- \rho(Q1i)| < (|\rho(P2i)- \rho(Q2i)|)$)
        Pi:=P1i;Qi:=Q1i;
Else
          Pi:=P2i;Qi:=Q2i;
Remove (Pj,Qj) and (Pl,Ql);
/* here above we have opted for that (Pj,Qj) pair which has resulted in less density variation*/
}
  else if(Mi is related to only(Pj,Qj))
  {
    (Pi,Qi):=add_pair(Mi,Pj,Qj);
     remove(Pj,Qj);
  }
  else
```

```
    {
     Pi:=Mi;
     Qi=0;
    }
return (Pi,Qi); /*1<=i<=np*/
}
/* This procedure is for adding the message Substream Mi to any Substream set pair (Pi,Qi) */
add_pair(Mi,P,Q)
{
 if($\rho(RL_i^a \cap P) < (\rho(RL_i^a \cap Q)$ OR $(\rho(RL_i^a,P) == \rho( RL_i^a,Q)$ AND $\rho(P) < = \rho(Q))$ /* here again the Substream Mi is assign to the set that has the minimum density to minimize the number of wavelengths finally used in the assignment*/
P:= P $\cup$ {Mi};
Q:=Q $\cup$ {Mi};
Return P and Q;
}

/* The set_pair procedure is used to assign the Substream set pairs to the ML and the MR Substream sets for the allotment of the time subframe assignment FL and FR*/
set_pair(Pj,Qj)
{
 for every(Pi,Qi)
    do
        if($\rho(Pi) < (\rho(Qi))$
            Exchange;
```

```
        Sort((Pi,Qi) pairs on descending order of ($\rho$(Pi)-($\rho$(Qi)));
    $M_L$:=0;
    $M_R$:=0;
For every(Pi,Qi)
    Do
     {
       if($\rho$($M_L$)< ($\rho$($M_R$))
          {
           $M_L$:=$M_L$+ Qi;
           $M_R$:=$M_R$+Pi;
        }
     else{
          $M_L$:=$M_L$+ Pi;
          $M_R$:= $M_R$+Qi;
        }
return $M_L$ and $M_R$;
}
/* The        final procedure assign will assign the slot to the message
Substream by specifying the exact wavelength an the position on that
particular wavelength */
assign(M,$\lambda$,position)
{
for all Mi $\in$M
 do
 {
  posi :=posi +position;
if(Di == 2k)
{
```

```
M:=M-{Mi};
λi:= λ;
λi:=λ+1;
}
}
return(M, λ);
}
```

CHAPTER 5

CONCLUSION

In this work where we considered the case of the temporal Quality of service in the WDMA-network, we considered the problem of providing the temporal QoS guarantees for messages with delivery deadlines in single-hop optical networks that employ a preallocation-based WDMA protocol to coordinate the packet transmission. We have proposed a slot assignment scheme such that given a set of real-time message stream $M=\{Mi = (Ci,Di, N^{i}_{s}, N^{i}_{d}) \mid 1<=i<=n\}$ and W wavelength channels, the scheme can allocate time slots over as few wavelength channels as possible in such a way that at least Ci slots are assigned to Mi in any time window of s size, subject to the source and destination conflict constraints. The proposed scheme is guaranteed to find a feasible schedule for the message stream set as long as schedulability condition holds. Although the effectiveness of the proposed scheme (in terms of the number of the wavelength channels needed to generate the feasible schedule) can not be analytically derived, the simulation results shows that 99.9967 percent of the message stream sets generated can be scheduled using $\lceil \rho(M) \rceil + 1$ wavelength channels, where $\lceil \rho(M) \rceil$ is the minimum possible number of wavelength channels that have to be used in order to generate a feasible schedule.

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