Hybrid Static-Dynamic Wavelength/Waveband Allocation Scheme for Novel Broadcast and Select Star-Ring Optical Regional Network

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Abstract—We have proposed a novel star-ring optical regional network architecture with dynamic wavelength/waveband broadcast and select based on bandwidth reservation. In this network, the large number of wavelength resources generated by a single multi-carrier light source can be shared and utilized in a flexible and simple way. In this paper, a hybrid static-dynamic wavelength/waveband allocation scheme combined with dynamic traffic banding has been proposed to reduce the network cost and complexity. To achieve this goal, we define one hybrid static-dynamic wavelength/waveband partition scheme, and develop two wavelength/waveband allocation algorithms based on it. One is Maximum Waveband First (MWF) allocation and the other is Waveband Round Robin (WRR) allocation. Both physical implementation analysis and computer simulation have been carried out to verify our ideas. According to the results, our proposal can effectively reduce the number of used optical switching ports and simplify the edge node architecture.

I. INTRODUCTION

With the rapid development of broadband access technologies and emerging internet multimedia applications, internet traffic is growing dramatically nowadays. To meet the large bandwidth demand of this traffic explosion, photonic network using WDM (Wavelength Division Multiplexing) technology is one of the most promising solutions so far. With the advances in WDM technology and the use of ultra-dense WDM, one fiber being able to carry more than 1,000 wavelengths, each operating at 2.5 Gbps has been successfully demonstrated in the field experiment by NTT [1]. How to efficiently utilize and control such a large number of wavelengths to design the high performance and cost effective future photonic networks is still an open question.

Regional networks, also named as feeder networks [2], aggregate high tributary traffic (eg. 2.5Gbps or 10 Gbps) collected from access networks and send them to the backbone networks or the other access networks, while access networks interface with the user premises and perform traffic grooming and distribution. Because of the penetration of broadband internet access, the traffic from access networks is not only large in volume but also yields highly dynamic nature, which presents great challenges to the SONET/SDH (Synchronous Optical Network / Synchronous Digital Hierarchy) based regional networks today.

Considering the problems of current regional networks and the ultra-dense WDM technologies, we proposed a novel star-ring optical regional network architecture with dynamic wavelength/waveband broadcast and select in [3]. One of the key advantages of the novel network architecture is to share the large number of wavelength resources by dynamic wavelength/waveband broadcast and select based on reservation. In this paper, we will mainly focus on the problem of how to allocate wavelength/waveband according to dynamic traffic requests, while simplify the operation and reduce device cost at the same time.

The rest of the paper is organized as follows: section II will describe the architecture of novel broadcast and select star-ring optical regional network; section III is about the hybrid static-dynamic wavelength/waveband allocation scheme, which includes the following four subparts: routing method, traffic modeling and dynamic banding, static-dynamic wavelength/waveband partition scheme and wavelength/waveband allocation algorithms; section IV illustrates the physical implementation and computer simulation of our proposal; section V concludes the research work.

II. NETWORK ARCHITECTURE

A. Network Topology

The fiber layer of our proposed network architecture has an overlay star-ring topology, with two RN (Regional Nodes): RNs connecting with each EN (Edge Node) in a star topology and RNr connecting with them in a ring topology respectively, as illustrated in Fig. 1, while the underlying cable layer is still in a classical ring topology. Both RNs and RNr are connected to two PoPs (Point of

Figure 1. The overlay star-ring fiber network topology
Presence) of backbone network for protection purpose and they are also connected to each other with two fibers for communication between each other. EN grooms traffic from access networks and sends it into regional network destined to other EN or RN. We divide the traffic from EN into two types: one is hubbed traffic which is from EN to RN; and the other one is any-to-any traffic, which is from EN to EN inside the regional network.

B. Network Functional Procedures

The general network functional procedures can be demonstrated as shown in Fig. 2 for hubbed traffic.

First, RNr will send out the reservation frame to each EN to collect their bandwidth requirements in the ring part network, after that, the RNr will allocate bandwidth (wavelength or waveband) to each EN according to their reservation information and write the results into allocation frame. Next, the allocation frame will loop in the ring part network again. Each EN will configure itself to be ready for wavelength/waveband selection, data transmission and receiving according to the allocation information. The allocation frame will also be sent to RNs for configuration of wavelength/waveband generation, switching and multiplexing. After all finish, the RNs turns on the multi-carrier light source to generate multiple wavelengths and distribute them to all EN, and then each EN will select the wavelength/waveband allocated to it by band pass filters, then modulate the wavelengths and send them to RNs. Finally the RNs will switch, group and multiplex the wavelengths or wavebands according to their destinations.

C. Node Functions

WBS (WaveBand Switching) technology combined with MG-OXC (Multi-Granular Optical Cross Connect) has been proposed as an efficient solution to reduce the optical switching and transmission cost in WDM networks [4]. Besides the multiple wavelength generation and broadcast ability, RN will also have a MG-OXC structure and have the ability of waveband level multiplexing, de-multiplexing and switching, which will help to reduce the number of optical switching ports and also simplify the operation. The key functions of EN include: wavelength/waveband selection, modulation and data receiving. In the later section of this paper we will simply illustrate the device support of such EN functionalities.

III. HYBRID STATIC-DYNAMIC WAVELENGTH/WAVEBAND ALLOCATION SCHEME

RWA (Routing and Wavelength Allocation) problem in wavelength routed optical WDM networks has been extensively researched in the past decade. The RWA problem itself is proved to be NP-hard and a lot of heuristic algorithms have been proposed [5]. Therefore, if we consider waveband and wavelength routing and allocation problems together, they are more complex. We can use the following scheme and method to solve this problem in our proposed network architecture.

A. Routing Method

In our proposed network, under normal network situation (no failure happens such as node failures, fiber cuts and so on), we use the fixed routing method for simple control purpose. For hubbed traffic, it only needs to be forwarded to RNs in one hop and then sent to backbone network. For any-to-any traffic, their normal routes in the regional network are fixed, which are from source EN to RNs, and then from RNs to the destination EN, in two hops.

B. Traffic Modeling and Dynamic Banding

We measure the traffic volume generated at EN in terms of number of connection requests or calls and each call needs to setup a lightpath for communication between each other. In our proposal, there is no wavelength conversion, so wavelength continuity constraint should be applied. In other words, a single lightpath for one call must occupy the same wavelength on all of the links that it spans. We use traffic vector to represent the hubbed traffic and square traffic matrix to represent the any-to-any traffic. The entry of traffic vector and matrix stands for the number of calls. For example, entry \( t_{ij} \) of traffic matrix \( T \) means that there are \( t_{ij} \) calls from source \( EN_i \) to destination \( EN_j \) at this time. In order to model the dynamic traffic, traffic matrix \( T \) may change over time due to call arrival and departure. In this way, we can model the dynamic nature of traffic without making any statistical assumptions about the call arrival and departure, which is usually modeled as a Poisson process and the holding time of call is exponentially distributed and thus the traffic load is expressed in Erlang [5].

In order to reduce the number of optical switching ports at RNs and prepare for wavelength/waveband allocation, we use
the destination based dynamic traffic banding method to partition traffic of each EN. For hubbed traffic, the partition is based on their destination regional networks, while any-to-any traffic is partitioned based on their destination EN. Traffic to the same destination from different sources will be banded together. After this partition and banding process, the traffic banding results will be sent to R Nr and R Ns for wavelength/waveband allocation and MG-OXC configuration.

C. Static-Dynamic Wavelength/Waveband Partition Scheme

Although internet traffic yields a highly dynamic or bursty nature, we observe that even in this kind of situation, the traffic often exhibits a certain degree of predictability according to traffic statistics in a time period. In other words, the dynamic traffic consists of two parts: mean traffic and variant traffic. So we think that hybrid static-dynamic wavelength/waveband allocation scheme will be more efficient and cost-saving. And therefore, we define the hybrid static-dynamic wavelength/waveband partition scheme, which can be illustrated in the following Fig. 3:

![Static-dynamic wavelength/waveband partition scheme](image)

Figure 3. Static-dynamic wavelength/waveband partition scheme

From Fig. 3, we can see that the available wavelengths generated by the multi-carrier light source at R Ns will be first divided into GWP and LWP. The wavelengths in GWP are used for communications between regional networks and usually occupy the low optical loss region of wavelength grids for long distance transmission. The GWP is further divided into GWP that is reserved for this regional network and GDWP that is shared among all regional networks. The wavelengths in LWP are used for communication between each EN in the same regional network and this part of wavelengths can be reused at other regional networks. The LWP usually occupies the low dispersion region and is not so sensitive to optical loss because of the short transmission distance in regional network. Same as the GWP, the LWP is divided into LSWP and LDWP. Wavelengths in LSWP are reserved for each EN respectively and LDWP wavelengths are shared by all EN in the same regional network.

D. Wavelength/Waveband Allocation Algorithms

After the dynamic traffic banding process, the traffic vector and traffic matrix will be divided into traffic band set, and the remaining problem is how to allocate wavelength/waveband to each call in the traffic band set. Our target here is to simplify the wavelength/waveband selection at EN. Before describing the detailed allocation algorithms, one common allocation process based on static-dynamic wavelength/waveband partition scheme for each call will be introduced first, which is shown in Fig. 4:

![General wavelength allocation process to a call](image)

Figure 4. General wavelength allocation process to a call

By this wavelength allocation process for each call, we have proposed two detailed wavelength/waveband allocation algorithms among all EN: one is Maximum Waveband First (MWF) allocation algorithm and the other is Waveband Round Robin (WRR) allocation algorithm. The detailed descriptions of the two algorithms are shown in the following Fig. 5 and Fig. 6 respectively:

**Algorithm MWF:**

- **Input:** Traffic band set (Each traffic band consists of calls to the same destination)
- **Output:** Each call in the traffic band set is assigned a wavelength or is blocked (All wavelengths in the same traffic band form a larger waveband for selection at destination)
- **Procedure:**
  1. while (traffic band set is not empty)
  2. do { select the current maximum traffic band
  3. for each call in the traffic band
  4. using general wavelength allocation process for the call;
  5. delete this traffic band from traffic band set;
  6. }// Always select the maximum traffic band for allocation first;

![Description of MWF allocation algorithm](image)

Figure 5. Description of MWF allocation algorithm

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The following Fig.7 is a simple device diagram of partial EN. We try to design the EN with currently available optical devices in a cost-effective way. A wavelength/waveband allocation scheme can be supported by currently available optical devices that can support our proposal in a cost effective way. As shown in Fig.7, broadcast wavelengths will be duplicated by coupler first, and then fixed band pass filter and tunable band pass filter will be used to select the allocated static and dynamic part of wavelengths respectively. After that, wavelengths will be modulated, multiplexed and sent out. Data transmission and receiving at the same time can be implemented thanks to the use of circulator for bidirectional operation. In this way, our hybrid static-dynamic wavelength/waveband allocation scheme can be supported by currently available devices in a cost-effective way.

![Figure 7. Device diagram of partial EN](image)

### IV. Physical Implementation and Computer Simulation

#### A. Physical Implementation Analysis

The following Fig.7 is a simple device diagram of partial EN. We try to design the EN with currently available optical devices that can support our proposal in a cost effective way. As shown in Fig.7, broadcast wavelengths will be duplicated by coupler first, and then fixed band pass filter and tunable band pass filter will be used to select the allocated static and dynamic part of wavelengths respectively. After that, wavelengths will be modulated, multiplexed and sent out. Data transmission and receiving at the same time can be implemented thanks to the use of circulator for bidirectional operation. In this way, our hybrid static-dynamic wavelength/waveband allocation scheme can be supported by currently available devices in a cost-effective way.

![Figure 6. Description of WRR allocation algorithm](image)

#### B. Computer Simulation

Computer simulation has been performed to compare the optical port efficiency ratio R among the following three situations: without traffic banding, banding with MWF allocation and banding with WRR allocation under different traffic loads. The simulation parameters include: number of EN is 10; wavelength size is variable; average traffic load L is from 0.4 to 1.6; total available number of wavelengths is 160. Simulation results are shown in Fig.8:

![Figure 8. Comparison of port efficiency ratio R among three situations](image)

According to Fig.8, R is larger with traffic banding than without banding; R is the same between MWF and WRR when traffic load L is below 1, as L increases, MWF outperforms WRR in terms of R.

### V. Conclusion

In this paper, we have proposed a hybrid static-dynamic wavelength/waveband allocation scheme combined with dynamic traffic banding for the novel broadcast and select star-ring optical regional network. It is effective in reducing the number of optical switching ports and simplifying the edge node design. By physical implementation and computer simulation we verified the effectiveness of our proposal.

### REFERENCES


