An Optical Circuit-based Switching Architecture with Destination Number Control in Broadband Optical Ring Access Networks

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***Abstract* - A circuit-based switching network architecture with high provision rate is still more favorable than a packet–based architecture in broadband optical access networks in near future. Traffic transferring in a light path can be PtoMP, MPtoP and MPtoMP in the circuit-based switching architecture. PtoMP schemes provide efficient traffic allocation but suffer low wavelength utilization. MPtoP schemes perform well for unicast traffic but not for multicast. MPtoMP schemes, such as Light Trail, provide both unicast and multicast traffic at the same time. However, Light Trail should optimize light path creation which is NP hard and it should set up new light paths again to accommodate new network conditions, which is time-consuming. This paper discusses the effect of the destination number control in a light path and proposes modified network architecture with limited destination number in a light path. This study describes the details of our proposed architecture and traffic transmission rule for unicast and multicast traffic. Due to the properties of our proposed architecture, we expect it to possess accommodating ability and transfers multicast traffic without loss of high wavelength utilization. Through numerical result, we can prove proposed architecture has ability to construct efficient and costly broadband access ring networks.**

***Keywords*— broadband optical ring access network; destination number control; PtoMP; MPtoP; MPtoMP;**

1. INTRODUCTION

Optical network techniques development meets the huge bandwidth demands of current multimedia and data applications and it currently dominates as the backbone of metropolitan area networks. This study focuses on optical metropolitan area networks, usually with a ring network topology. In the broadband optical ring access networks, light paths are created to transfer traffic. Each path needs one wavelength to complete its transmission, called as “wavelength continuous constraint”. Statistic multiplexing is not possible under such circumstances. Hence, optical networks have low wavelength usage of light paths. Further, due to the limited number of wavelengths in a fiber and limited optical buffer, optical packets are dropped if its channel is occupied. To achieve the goal of high performance and low cost in such broadband optical ring access networks, how to provide efficient wavelength usage is hot topic.

Current researches focus on development of well designed routing and wavelength assignment algorithms for light paths [16]. It can solve the high blocking probability and improved traffic performance. However, optimal algorithms are NP problem. To achieving accepted algorithm, each node should be equipped with high cost transceivers or converters to tune its transmitter or receiver to the adequate channel while transmitting or receiving optical packets. Due to these characteristics, optical networks are costly and wavelength usage inefficient. Consequently, the current work proposes the optical-electronic-optical solution (O/E/O) to improve performance. The O/E/O conversion at each optical node should process optical packets electronically, such as the RPR network [1-2]. Full switching among channels in this architecture makes efficient link bandwidth usage, but the conversion is still time-consuming and costly [3].

An idea of allowing multiple simultaneous transmissions on the same wavelength obviously improves the capacity in broadband optical ring access networks. Hence, based on this opinion, recent researchers [4-14] propose several schemes to improve wavelength usage and increase utilization in all-optical networks. These studies could be classified into two categories, packet-based and circuit-based switching ring networks.

Packet-based switching broadband optical ring access networks are potential in future communication [20] and recent researches have begun the discussion of this study [21-25]. Famous transmissions for optical packets in the packet-based broadband optical ring access networks are either timing slotted [4] or an aggregation of several packets [5][17].In the first transmission, called photonic slot routing, time is slotted and packets at each node to the same destination node are allowed to transmit at the same time slot. Each node at a time slot has to process and transmit packets to a specified destination node. Each node should be equipped with high-speed configurable switching ability. This cost is tremendously high. The second transmission, optical burst switching, aggregates several optical packets to the same node into a burst and then the burst is sent to an egress node. Control packets are used to reserve network resource. The reservation schemes are also another hot research. In addition to the electronic reservation, assembling and disassembling packets to and from a burst need high speed capacity. Furthermore, burst loss could cause high network performance damage even if loss rate is low [18, 19]. Hence, the circuit-based switching solution should be more feasible in the near future.

The circuit-based switching ring networks create a light path for each transmission. Point-to-point transmission is intuitive but leads to low wavelength utilization since wavelength reuse does not exist. Recent researches design transmission schemes to allow sharing resource of a light path, such as point-to-multipoint (PtoMP) [6,7,12,13], multipoint-to-point (MPtoP) [8] and multipoint-to-multipoint (MPtoMP) approaches [9-11,13,14]. PtoMP allows a node to construct connections to multiple destinations within a light path. Intermediate nodes receive optical packets by retrieving sufficient energy from the optical signal with the splitter. Hence, it needs power amplifier or light path length is not scalable due to limited transmitting power. In PtoMP scheme, no other nodes can share wavelength of a light path and it has low wavelength usage and wastes optical network resource consequentially. Contrasted to PtoMP, MPtoP scheme sets up a light path to only one destination and allows multiple intermediate nodes for sharing a light path to the same destination. Hence, wavelength utilization is improved. However, MPtoP scheme performs badly for multicast traffic which carries out several applications, such as online games, videoconference, and remote e-learning. With the MPtoP approach, a node must duplicate several optical packets to transmit multicast traffic and injects them into different light paths. Unfortunately, the characteristics of multicast, saving the volume of traffic, disappear. Existing PtoMP or MPtoP circuit-based switching networks in the literature could not perform well and lead to either low wavelength usage or high cost while provisioning both unicast and multicast traffic. Light Trail [10], an MPtoMP circuit-based switching network, was proposed to improve the inefficiency of PtoMP or MPtoP. The Light Trail could achieve better performance than any MPtoP or PtoMP scheme. However, the issue of optimal light paths creation is NP hard [15]. Furthermore, a set of light paths in MPtoMP optical access ring networks should be designed dynamically for the various traffic states and it is time-consuming [9,10,13].

Basically, MPtoMP scheme is much better suitable to be implemented in circuit-based switching optical ring access networks. Intermediate nodes along a light path can receive and transmit their traffic through the same wavelength. However, it is very difficult to design a set of light paths accommodating various traffic input and output states and we call this as accommodating ability. This study will discuss the hardness of accommodating ability for MPtoMP scheme systematically and propose a more suitable architecture to achieve our goal, high wavelength utilization and low cost no matter for unicast and multicast traffic

The remainder of this paper is organized as follows. Section II describes discussion for various circuit-based switching network architectures. Section III gives details of our proposed optical network architecture. In Section IV, numerical results are provided. We give the future work in Section V. Finally, Section VI concludes the paper.

2. DISSCUSSION

Optical networks provide large network resource for current applications. Packets in an all-optical network are transmitted from the source to the destination completely in the optical domain. Circuit-based switching optical networks provide possible solution. However, light paths creation in such optical networks should be well-designed or it leads to low wavelength utilization. Further, it is usually time-consuming to modified current light paths and hence a set of light paths should keep their states in a long time as far as possible. Based on these two observations, we find it is important that a well-designed set of light paths should accommodate various network conditions. However, accommodating ability is quite different for three schemes, MPtoP, PtoMP and MPtoMP and we give a discussion as follows. To show the difference among three schemes, we observe characteristics of the traffic transferring in a light path.

1. In MPtoP scheme, a light path can be shared by all intermediate nodes in order to transfer traffic to its corresponding destination. Ideally, one destination receives traffic from only one light path and all intermediate nodes join this path to transfer their traffic to this destination in broadband optical ring access networks. Hence, the utilization of light path is high. Practically, to carry traffic for a specified destination node, more than one channel is needed. Hence, each light path owns more than one channel and is responsible to carry the traffic of some nodes to specified node. To show the performance of MPtoP, we assume each node sends α traffic to each destination averagely. A light path with MPtoP scheme carries $n\alpha$ traffic to transfer their traffic to corresponding destination where n is the number of nodes served by a light path. We can find utilization is high with this scheme in backbone metropolitan area networks and hence save much cost. Further, since the traffic in a light path originates from several nodes, the volume of traffic should not vary much. The change of light paths is not needed and accommodating ability of MPtoP scheme is good. However, if a node wants to transfer multicast traffic, it should generate duplicated packets to multiple destination nodes. It leads to add additional cost to increase network capacity for these duplicated packets.
2. In PtoMP scheme, a node can send all its traffic via some light paths created by it. Since a light path is only responsible for traffic of one source node, it causes low channel utilization and needs much cost. Furthermore, it needs usual change of light paths due to the variant of traffic in this node and it is time-consuming. PtoMP owns bad accommodating ability. It is not adequate scheme in order to achieve high channel utilization and low cost.
3. MPtoMP allows multiple nodes for sharing a light path and the nodes along this path are also destination nodes. Hence, it solves the drawbacks of MPtoP and PtoMP. It is very possible that there are multiple paths destined to the same destination node and hence each node can choose one path among candidate light paths to specified destination nodes. Consequently, characteristics of traffic transferring are quite different from MPtoP and PtoMP. The design of light paths in this scheme should be planed well for low cost and high channel utilization. Unfortunately, the design of light paths in this scheme is NP hard. Furthermore, the traffic carried by a light path varies much based on the rule of path decision on each node. MPtoMP scheme lacks accepted accommodating ability.

We can observe the number of destination of a light path is key point. Too much destinations in a light path makes the design of light paths complex and nodes choose one of possible light paths to transfer traffic, which leads to much variant volume of traffic in a light path. In such case, it is uncertain how much traffic a light path carries. Dynamically tracking the traffic state in a light path becomes significant. Based on this observation, we try to control the number of destination nodes in a light path and modify MPtoMP network architecture to make new broadband optical ring access network possess accommodating ability and transfer multicast traffic without loss of high wavelength utilization. However, in order to show the effect of destination number control in a light path, we use the variable, n, to represent the number of destination in a light path. If n approaches large, the drawbacks of bad accommodating ability appear. Since the number of destination nodes in a light path in our proposed approach is limited, we call our proposed approach as Limited-Drop multiple point to multiple point approach (LD-MPtoMP).

3. OUR PROPOSED ARCHITECTURE

The circuit switching-based technique is practical since high electronic processing speed of the optical switch is still high costly in optical networks. Multipoint-to-point in optical circuit switching is much more flexible than point-to-multipoint. Nodes in a MPtoP light path can inject their traffic to light paths according to their destinations but PtoMP cannot. Sharing the light path among intermediate nodes improves link usage and hence saves cost. However, this advantage disappears for carrying multicast traffic. PtoMP allows a node to send multi-destination traffic efficiently but MPtoP needs to generate several copies to multiple destinations. MPtoMP is a feasible solution for supporting not only unicast but also multicast traffic. However, previous MPtoMP architecture lacks good accommodating ability and too complex design of light path. We propose a new architecture based on MPtoMP, which carries unicast and multicast traffic efficiently at the same time. Basically, the proposed optical network architecture exhibits the following properties.

1. The proposed network architecture owns N nodes as shown in Fig. 1. Each node creates two light paths with multiple specified destinations at the end part of the path in the ring network and the two light paths terminate at the furthest node. Fig. 1 just shows one light path.

2. Each intermediate node in a light path inserts traffic according to its destinations and shares bandwidth at the same wavelength with other nodes. With multiple nodes sharing the same light path, the proposed architecture improves bandwidth usage in an all-optical network and utilization of the optical network.

3. The number of specified destinations in a light path should be bounded. Hence, our proposed network architecture supports unicast and multicast traffic and provides transmission among nodes transparently in the optical domain.

This study focuses on the new light path creation and traffic transferring methodology and hence the medium access control scheme and the fairness issue are out of the scope of this study.

Based on above property, every node in our proposed scheme must create two light paths with multiple drops to

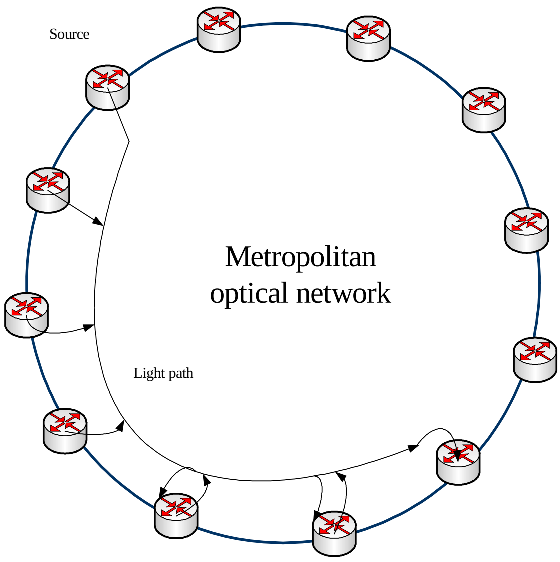

Fig. 1 The architecture of our proposed broadband optical ring access network

the furthest node with the shortest path routing in clockwise and counterclockwise directions, respectively. This work focuses on light paths in the clockwise direction due to symmetry. The last light path node is responsible for terminating this path like the destination stripping with wavelength spatial reuse. Contrasted to the MPtoP technique, the number of light path destinations in the optical network is more than one. In our broadband optical ring access network, a light path i has n destinations at the last n nodes, (d_{i1}, d_{i2} , …,d_{in}) where d_{ij} denotes the jth destination in the light path i. Figures 2 and 3 shows a light path and light paths with three drops in an N-node optical ring network (n=3, N=10), respectively.

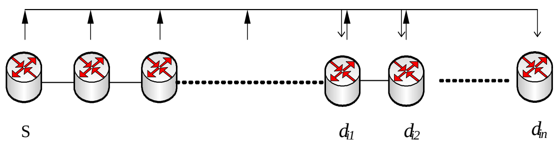

Fig. 2 A Light path in our optical networks

Each of the last n-1 destinations of a light path receives optical packets by an optical splitter. Each node in a light path, except the last node, injects its traffic to one or more multiple destinations at the end of the light path. Hence, a light path delivers traffic to n destinations. Due to the property 1, each node in the ring network receives traffic originating from n possible light paths. Assume that a node sends α traffic to each other nodes. Since light path destinations are overlaid in order, the node sends α/n, α/(n-1), …, α to (d_{i1}, d_{i2} , …,d_{in}) on the light path i on average, respectively.

A transmission rule in our broadband optical ring access network architecture is a guide to select one light path to transfer traffic. The transmission rule for unicast traffic is easy. A node transmitting unicast traffic, according to the destination, randomly selects one available light path of at most n possible light paths to the destination. This selection achieves load balance among light paths. For a multicast flow, a node should generate at most $N/2n$ copies for multicast traffic and injects these copies to different light paths. The traffic assignment rule for multicast traffic is shown as follows.

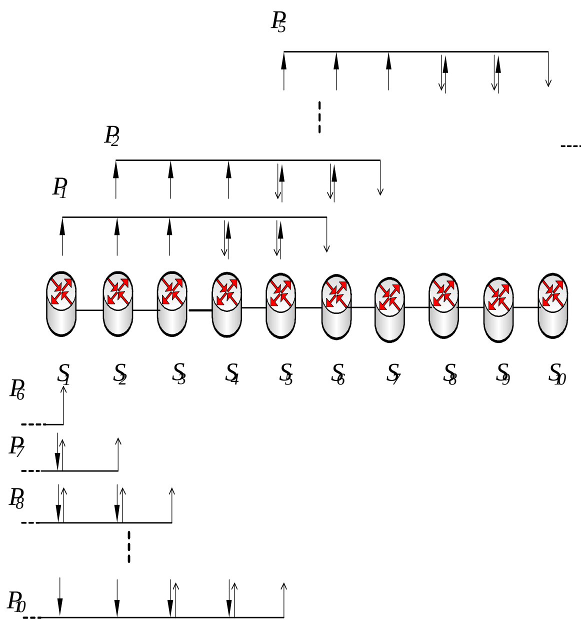

Fig. 3 Light paths in our optical networks(LD-MPtoMP)

1. The source node should identify and number multicast flow destinations in the order of distances. Fig. 4 presents the assignment for a multicast flow originating from the source node to four destinations.
2. These multicast destinations are divided into multicast groups with two steps. Here, these multicast groups are numbered as G_t, where t is the multicast group number. The first step is to find the last node of a multicast group. This work tries to classify multicast groups from the furthest multicast node to the source. The number of members in a multicast group is the drop limit, n. Here, the first node in a group must be a multicast node but other nodes may not be. (e.g. G_1 and G_2 in Fig. 4, not all nodes are multicast nodes) For instance, finding the first multicast node of G_1 is easy (the furthest one). Then, the location of the last multicast node of G_1 must be the nth node apart from the first multicast node. G_2 and the other sequential groups are also found accordingly.
3. Then, we find the light paths for each multicast group. A node in our optical network attempting to send traffic to a destination node should select one from at most n light paths because the destinations of sequential n light paths are overlaid partially in order due to the property 1. For each multicast group, we should pick a light path where the terminating destination is the first multicast node of each multicast group. This path can always be found due to the property 1 and 3. Hence, we can find light paths for G_1 and G_2.

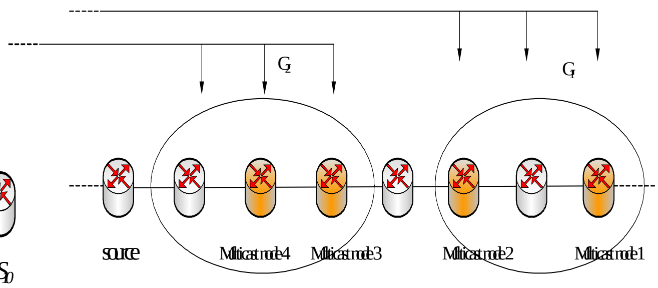

Fig. 4 The transmission of multicast traffic in our optical networks (LD-MPtoMP) (n=3, N>15)

Lemma 1: Our network architecture always finds a light path where the terminating destination is the last multicast node in a multicast group

Proof: Due to our light path creation, each node creates a light path to the furthest node with the shortest path routing. Each light path has n destinations. Hence, a node may be $d_{i1},d_{(i+1)2},\ldots,d_{(i+n-1)n}$ at light paths $i, i+1,\ldots, i+n-1$, respectively. Each node must be the terminating destination node in a specified light path. In other words, each multicast node in any given G_t should also be the terminating destination node of a light path. This means that our network always finds a light path where the terminating destination is the first node in a multicast group.

Lemma 2. Minimal path count must find minimal number of light paths to transfer multicast traffic.

Proof: From lemma 1, we can find a light path where the terminating destination is the first multicast node in a multicast group. The length of a multicast group is equals *n*. Hence, after searching a light path for a multicast group in Lemma 1, this light path is sufficient to carry all traffic to multicast nodes in the multicast group. In other words, in this assignment, a light path carries traffic to maximal number of destinations. Hence, the minimal number of light paths is equal to the number of multicast groups. A light path for a multicast group in this assignment is minimal path count.

This procedure finds light paths of other multicast groups. This study uses minimal path count to find the minimal number of light paths to transfer multicast group traffic. By the definition of the multicast group, we exactly find the minimal number of light paths. The proposed optical network carries unicast and multicast traffic at the same time based on both transmission rules. We take Fig. 4 as an example. First, we number the four multicast nodes. Then, we divide these multicast nodes into groups. The last multicast node is numbered as 1 and G_1 by step 2. G_2 is also obtained accordingly. In step 3, we know a light path can carry one multicast group. Hence, it needs two light paths where the last destinations are multicast nodes 1 and 3, respectively.

4. NUMERICAL RESULTS

Now, we try to prove our proposed network (LD-MPtoMP) architecture can still perform better than MPtoP and PtoMP. We use two network parameters, R and duplicated packet of multicast traffic. Due to the limited space in this paper, we omit the detail analyses and just define two parameters and show numerical results. The first interesting performance parameter is the amount of redundant traffic for a given link. This parameter is for the performance of unicast traffic. We define two kinds of traffic in a link, one is real traffic whose destination is not yet reached and the other is redundant traffic whose destination has been passed by. This condition occurs if destination nodes of a light path are numerous. Here, we define the *R* as the amount of redundant traffic. The higher *R* means more redundant traffic in a link. For instance, the sending node with source stripping scheme takes its own traffic down after the traffic has traveled the whole broadband optical ring access network and *R* in some link must be higher, which means links should carry too much more redundant traffic. The scheme does not provide simultaneous transmissions with the same wavelength in optical networks and has a large amount of redundant traffic in the optical links. A node must waste more network resource to process these redundant traffic and it usually needs higher network cost (more transceivers). For multicast traffic, we discuss multicast traffic performance with another parameter, the number of multicast packet duplications. Firstly, we consider the worst network condition for unicast traffic, where each node sends α traffic to other nodes. Assume that $\frac{N-1}{2}=15$,and the amount of traffic of a unicast flow, α=0.1. *R* in our approach is normalized with R_{ptomp} in the PtoMP approach. As depicted in Fig. 5, our approach carries less redundant traffic for a given link than PtoMP, especially at small *n*. But even when *n* is near to 15, redundant traffic is only half of the PtoMP approach. For MPtoP, R is 0.

We also make multicast traffic analysis. As shown in Fig. 6, we change the values of multicast nodes of a multicast flow, *m* and destination number in a light path, *n*. First, seeing the case of *m*=5, our approach presents less additional multicast traffic copies than MPtoP. While *n*>4, the number of copies is less than two. This confirms that our approach saves much network resource. While *m* increases, the performance of our approach is much better than MPtoP. For PtoMP, multicast traffic copies is the most least.

5. FUTURE WORKS

This study observes the key way to provide simple and efficient scheme for achieving high utilization and excellent accommodating ability in broadband optical access ring network is to control the destination number in a light path. Section II gives the detail discussion and observation. Based on our observation, we propose our approach, LD-MPtoMP. Numerical result also confirms our viewpoint. However, the observation in this study still needs mathematical study to prove it. The difference of accommodating ability among schemes can show our observation clearly and we leave it to the future work and try to find more evidence to confirm our observation. However, this study still provides a new view to improve the performance of circuit-based switching broadband optical access ring network.

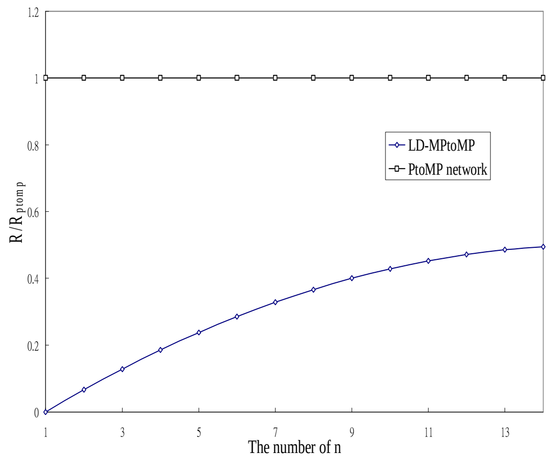

Fig. 5 The R comparison between our proposed network and PtoMP for unicast traffic($\frac{N-1}{2}=15$, α=0.1)

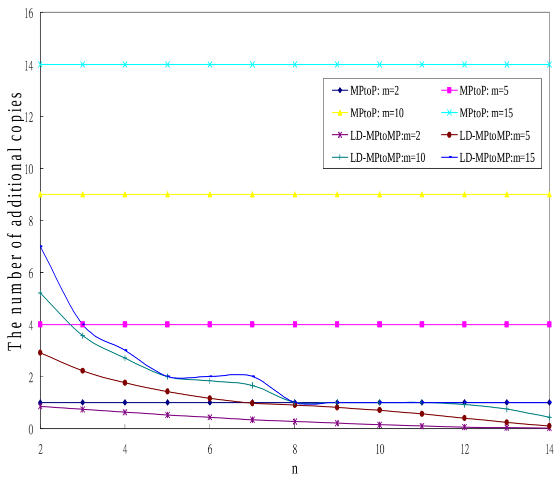

Fig. 6 The number of additional traffic copies for our proposed network and MPtoP network

6. Conclusions

This paper proposes a novel MPtoMP circuit-based switching broadband optical access ring network, called Limited-Drop MPtoMP (LD-MPtoMP), based on optical circuit-switching techniques. LD-MPtoMP solves PtoMP and MPtoP insufficiency and supports unicast and multicast traffic at the same time. LD-MPtoMP creates light paths with multiple destinations. Intermediate nodes in a light path inject their traffic on the light path with the traffic assignment rule. LT, a proposed MPtoMP technique, needs optimal scheme for creating light paths and is NP hard. Furthermore, frequently setting up light paths in optical network is also needed for accommodating various network states. Through our discussion, we observe the destination number in a light path is key point. The bounded number of light path destinations in our discussion obtain good link usage and achieve cost saving. Each node in LD-MPtoMP creates two light paths to the furthest node with the shortest path routing. The proposed simple scheme has the advantage over the MPtoP technique, with high utilization and low cost. Compared to LT, PtoMP, and MPtoP, LD-MPtoMP provides efficient and simple unicast and multicast traffic deployment in metropolitan area broadband optical ring access networks.

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