Novel photonic packet WDM ring networks with tunable transmitters and fixed receivers using multi-token protocol

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A kind of novel architecture of unslotted photonic packet switching wavelength division multiplexing (WDM) ring network with tunable transmitters and fixed receivers was proposed. In the network the wavelength was used as optical packet label and node media access controller (MAC) address. Optical packets transmitter was made up of tunable laser that was modulated at 10, 40 Gb/s or higher. Optical packet receiver was made up of Bragg grating, circulator, and fixed receiver. Used as metropolitan access network, it is shown through simulation how a multi-token MAC protocol can be implemented to avoid packet collision and achieve efficient bandwidth utilization. Packet delay, throughput, and packet dropping probability results are presented under uniform and none uniform Possion traffic.

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In the past few years, the bandwidth requirement of modern telecommunication networks has an enormous increase. It is mainly due to the massive and ever increasing popularity of the internet and its related multimedia applications. Dense wavelength division multiplexing (DWDM) technique has undoubtedly become the solution to increase the capacity of long-haul wide area networks and metropolitan area networks. The bottleneck of network transfers from links to nodes. The wavelength router can dynamically set up lightpath directly between edge nodes without optical-electrical-optical (OEO) conversion at intermediate nodes[1,2]. But the granularity of these is "wavelength", in fact, the photonic router acts as circuit switch in networks. We note that IP traffic is busty, if the wavelength-switching network is used to carry IP traffic, the utilization efficiency of resource will be very low. It is expected large improvements in wavelength resource utilization efficiency, so the optical packet switching (OPS) system[3] must be developed.

Contrary to most of the existing all-optical packet networks, which are based on star[4−6] and slotted ring[7], in this paper, we proposed a kind of unslotted optical packet WDM ring networks architecture that can be utilized in metropolitan area networks (MANs) and also in wide area networks (WANs). With this architecture the wavelength can be used as packet label that indicates the media access controller (MAC) address of destination node, the variable length IP packet can be carried by wavelength directly. The control information of optical packet can be transmitted by control channel in 1510 nm. With the development of tunable laser, the cost and the performance of tunable transmitter reach accepted level. So we can use it as optical packet transmitter. With the tunable transmitter, fixed receiver, and multi-token MAC protocol, the technique of optical packet header extraction, packet header process[8] and packet synchronization[4,9] can be avoided. So the cost and complexity of the packet switched network can be reduced very much. In the following sections, we introduced the architecture of optical packet switching ring network and the architecture of network node. We analyzed the performance of network, in terms of queuing delay and the network throughput through numeric simulation.

Figure 1 shows the architecture of the optical packet switching WDM ring Network. It is a single-fiber and multichannel unslotted ring, which is designed to interconnect access nodes on a metropolitan scale. We considered that there are W nodes in the ring network that were connected by a single (unidirectional) fiber. The considered network architecture makes use of W data channels and one control channel, for total $W + 1$ wavelengths. The dedicated wavelength with 1510 nm was used as control channel for the purpose of access control and ring management. The data rate of control channel was 100 Mb/s, the data rate of data channel can be 10, 40 Gb/s or higher. The optical signal on the control channel does not propagate through the node as it is separately handled by a control receiver and control transmitter. Each node has one fixed receiver and several tunable transmitters as shown in Fig. 2. The erbium-doped fiber amplifier (EDFA) was used to compensate the propagation attenuation and all kinds of inserted attenuation. The fixed receiver was made up of fiber Bragg grating and circulator. The splitter was used to split the data signals and control signal. If the control packet arrived, it will be separated, and then make OEO conversion. The electronic controller receives the control packets, and then controls the tunable transmitters to transmit the suitable optical packets in assigned wavelength. If the data packets arrived and the wavelength equals the Bragg grating wavelength, the data packets will be dropped and received by the fixed receiver. The electronic control can send optical control packets with wavelength of 1510 nm, the optical control packets will be combined to the transmission fiber by the star coupler.

The node can only receive the optical data packets that have the same wavelength with Bragg grating. So the wavelength can be used as optical packet label that indicates the destination node. For example, if node 1 wants to send optical packets to node 4, the node 1 will transmit the packets in wavelength 4, because wavelength 4 indicates the destination node 4. Each node has $W-1$ queues that aggregate the electronic packet sent from edge router

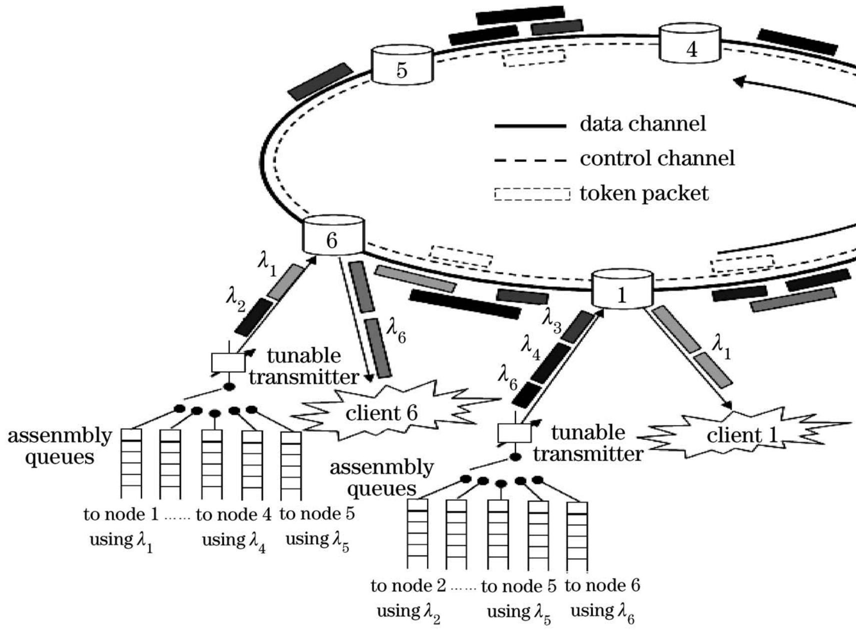

Fig. 1. Architecture of packet switching ring network.

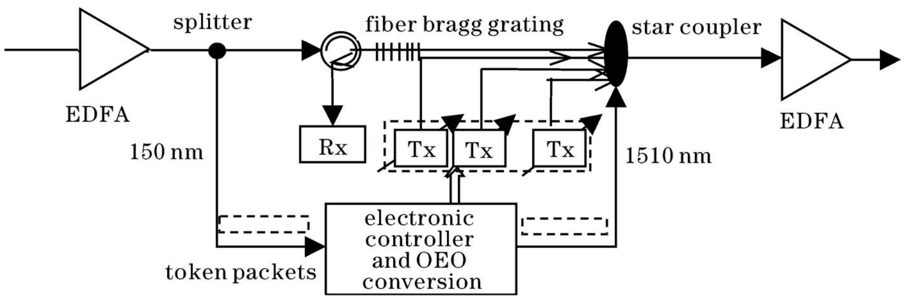

Fig. 2. Scheme of network node architecture (Tx, Rx stand for a tunable transmitter and O/E receiver, respectively).

or edge switch. The packet that has the same destination will be inserted into the same queue. For example in node 1, there are 5 queues (q2, q3, q4, q5, q6), the packet in q2 has the same destination node 2, the packet in q3 has the same destination node 3. This architecture allows the node to transmit and receive packets independently (and simultaneously) on any data channel. The node can receive the optical packets at any time, but can transmit optical packet only when the node gets the token. The control mechanism is described in the following section. This architecture can prevent optical recirculation in the ring.

In order to avoid packet collision on the link and to guarantee fair sharing the WDM ring bandwidth, access to the data channels is controlled by multi-token MAC protocol. Each data channel is associated with one specific token that is circulated among the network nodes (using the control channel) to control the access of the corresponding data channel. If there are W data channels, a total of W tokens will circulate in a single fiber ring. The multi-token protocol allows a node to transmit multiple packets on a data channel (or wavelength) if the corresponding token is held by the node. Control mechanism determines the token holding time, i.e., how many packets can be transmitted by the node before transfer the token to the next downstream node. There are two control mechanisms: 1) the token will not transfer to the next downstream node until all the packets in the corresponding queue were transmitted; 2) the token will transfer to the next node when the fixed number (the maximum number of packets that allowed to transmitted once) of packets in queue were transmitted. If the number of packet in queue is smaller than the maximum number, all the packet will transmitted. The queue has the capacity limitation, if the queue is full, the new arrival data packets will be dropped.

The node can only hold one token at any time if there is only one tuneable transmitter in the node, it can hold several tokens if there are more than one tunable transmitters in the node, the number of tokens that the node can hold is the same as the number of tunable transmitters in the node. If there is not any free tunable transmitter, the tokens will pass through the node without any process and delay, i.e., node 1 that has only one tunable transmitter gets the token 3 and there is available tunable transmitter at that time, the node 1 will send packets storage in queue 3 in wavelength 3 to the node 3. If other token arrives to the node during transmit packet, it will be transferred to the next downstream node. The token 3 will be transferred to node 2 when the packets were transmitted completely.

In our analysis we assume that the packets arrivals have "Possion" distribution, with packet length exponentially distributed. Traffic is uniform or none uniform among all the nodes in the network. It is important to note that the simulation was run for a long time to reach steady-sate results. Table 1 gives some simulation parameters. The traffic information includes the average network load and traffic matrix. For each node pair i, j, we define the traffic load $\rho_{ij} = \overline{\rho} \cdot L_{ij}$, where $\overline{\rho}$ is average network load and L_{ij} is a random number. In uniform traffic pattern, L_{ij} always equals 1. In none uniform traffic model, L_{ij} is a random number in range of (0,2), the average of L_{ij} is 1.

Performance features of interest include mean packet delay (including transmission, packet delay and queue delay), average node throughput and packet dropped probability.

Figures 3 and 4 show the average packet delay in different network loads with different number of tunable transmitters using the first control mechanisms. We can conclude that the mean packet delay will increase with the increases of network load and number of network node. When network load increasing, the packet queue delay $D3$ will become larger. When the number of network node becomes larger the transmission length of the optical packet will increase, the propagation delay $D1$ will increase. When the network load equals 1 erlang and the number of network node is 16, the packet delay is less 0.15 second. We also found that the packet delay in uniform traffic pattern is less than that in none uniform traffic pattern. Adding the number of transmitters in each node can decrease the packet delay.

Table 1. Parameters in Simulation

Fiber Length between Adjacent Nodes: L (km)	100
Transmission Data Rate: R (Gb/s)	10
Light Velocity in Fiber: V (km/s)	2×10^5
Propagation Delay: $D1$	L/V
Mean Packet Length: B (Mb)	1
Packet Delay: $D2$	B/R
Queue Delay: $D3$	$D3$
Number of Access Node: N	4, 8, 16
Number of Transmitters in Each Node: T_n	1, 2
Capacity of Each Queue: C (Mb)	C

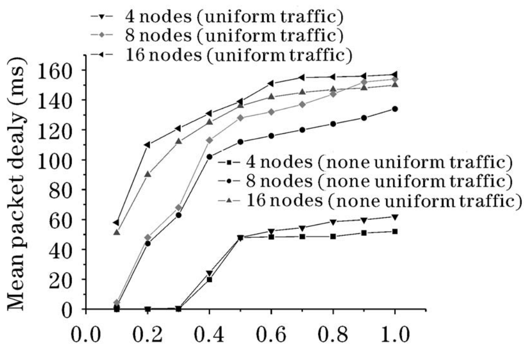

Fig. 3. Mean packet delay versus network load (1 transmitter in each node).

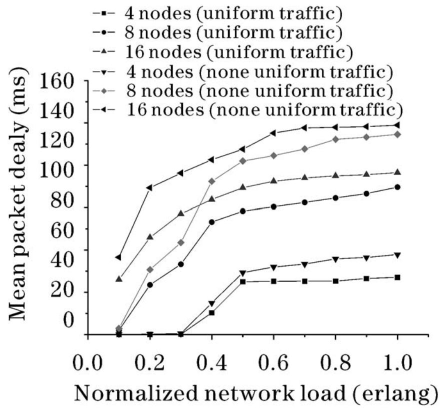

Fig. 4. Mean packet delay versus network load (2 transmitters in each node).

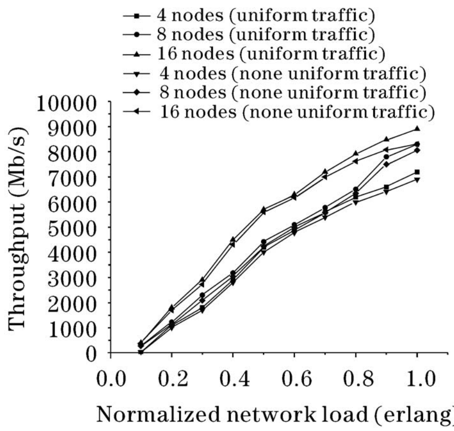

Fig. 5. Average node throughput versus network load (only 1 transmitter in each node).

Figure 5 shows the average throughputs per node for different network loads in uniform traffic pattern and none uniform traffic pattern. The number of access nodes is 4, 8, 16. From Fig. 5 we can conclude that with increasing the network load the average throughput will increase and reach 9 Gb/s. That means that the resource utilization increases with increasing the network load. The throughput of node in uniform traffic pattern is larger than that in none uniform pattern.

Figure 6 shows the relationship between network load and packet dropping probability in different traffic patterns. We assume that there are 8 nodes in network and there is only one tunable transmitter in each node. With the network load increasing, the packet dropped probability will become larger. When the network load equals 1 erlang and the capacity of each queue is 500 Mb, the packet dropping probability can reach about 10%. The packet dropping probability is reduced when the capacity of each queue equals 1000 Mb. The probability of dropping probability in none uniform traffic pattern is larger than that in uniform traffic pattern. So we can conclude that increasing the capacity of each queue in the network node can reduce the packet dropping probability.

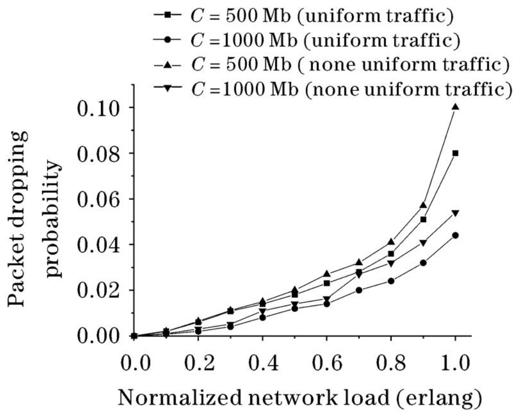

Fig. 6. Packet dropped probability versus network load (8 nodes in network, each node has 1 transmitter).

In summary, a kind of novel architecture of all optical packet switching WDM ring network without OEO conversion and optical fiber delay line was proposed in this paper. In the network the wavelength was used as optical packet label and node MAC address. The packet collision was avoided by multi-token MAC protocol. When network load and node number increasing, the packet delay will increase. The packet delay in uniform traffic pattern is less than that in none uniform traffic pattern. Adding the number of transmitters in each node can decrease the packet delay. The resource utilization increases with increasing the network load. Increasing the capacity of each queue in the network node can reduce the packet dropping probability.

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References

1. K. Sato, N. Yamanaka, Y. Takigawa, M. Koga, S. Okamoto, K. Shiomoto, E. Oki, and W. Imajuku, IEEE Commun. Mag. **40,** 96 (2002).
2. S. Chaudhuri, E. Bouillet, and G. Ellinas, in *Proceedings of OPF2000* TuO5 (2000).
3. D. K. Hunter and I. Andonovic, IEEE Commun. Mag. **38,** 116 (2000).
4. G. R. Pieris and G. H. Sasaki, IEEE/ACM Trans. Networking **2,** 105 (1994).
5. M. Azizoglu and R. A. Mokhtar, IEEE J. Select. Areas Commun./J. Lightwave Technol., Special Issue on Optical Networks **14,** 959 (1996).
6. M. J. Karol and R. D. Gitlin, IEEE J. Select. Areas Commun. **8,** 1439 (1990).
7. M. A. Marsan, A. Fumagalli, E. Leonardi, F. Neri, and P. Poggiolini, Computer Networks ISDN Syst. (to be published).
8. Y. Yamada, M. Togashi, K. Habara, and T. Matsunaga, Electron. Lett. **32,** 1500 (1996).
9. M. C. Cardakli and A. E. Willner, in *Proceedings of OFC2001* TuW2 (2001).