

## Asymmetric Optical Path Ring

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### Abstract

Internet traffic volume keeps on growing with no end in sight. If we are to support huge IP (internet protocol) traffic flows with an economical network configuration, it is necessary to develop a new transport network technology that minimizes the amount of hardware as much as possible by utilizing the intrinsic IP traffic characteristics. As such a technique, this paper proposes the asymmetric optical path ring. It is a modification of the WDM (wavelength division multiplexing) ring technique based on optical ADMs (add-drop multiplexers). It requires less hardware than the conventional WDM ring, and so is more economical, because it utilizes the transmission direction asymmetry in traffic flows often observed in the Internet. The paper describes the hardware configuration of the method and shows how it works. The effectiveness of the method is evaluated through simulations. Implementation issues are also discussed.

## 1. Introduction

The Internet traffic is growing relentlessly. It is believed that traffic is increasing twice to 10 times every year, and the available data supports this statement [1, 2]. If this tendency continues, the required network bandwidth must be increased by a factor of one hundred or one thousand within a few years. Fortunately, very broadband transmission systems [3] and network elements such as routers [4] are now available as tools for accommodating this increase. Nevertheless, the introduction of these technologies requires additional investment from the telecommunication service providers. Thus, if they have to provide services through such a very large bandwidth network with reasonable price, it is indispensable to develop a technique that builds the network with the least hardware resources.

This paper studies a transport network that supports the “huge bandwidth Internet.” The paper looks to minimize the hardware cost with utilizing the asymmetry of traffic, namely the difference in the traffic volumes in bit stream directions. The method, the asymmetric optical path ring, is based on the current ADM (add drop multiplexer) ring architecture and the current WDM (wave division multiplexing) technique. The proposed method modifies the ADM structure, to handle the symmetric Internet traffic more efficiently. The paper explores the hardware structure of the method and evaluates its effectiveness through simulations. The paper also assesses technical problems that will occur when applying the method.

## 2. Internet Traffic Asymmetry

There are several studies that support the existence of Internet traffic volume asymmetry in transmission direction. Reference [5] reports the Internet traffic measured between an academic network (called SINET) and a commercial service provider network (called OCN). The paper observes that the traffic from OCN to SINET was always 2.6 times larger than that in the reverse direction. Another traffic measurement is found in Ref. [6]. Among the data published in [6], the international link traffic measured between the US and the UK is particularly noteworthy. Namely, the byte traffic from the US to the UK was more than twice that from the UK to the US.

The current backbone transport network is not very efficient for such traffic. Almost all transmission systems used in the backbone provide the same bandwidths in both bit stream directions. With such systems, the resource amount is determined by the larger of the bandwidths. That is, if the bandwidth is larger in one direction, the system capacity will not be fully utilized in the reverse direction. Obviously, this wastes the resource capacity.

In achieving the huge bandwidth Internet, we must use as few network resources as possible to provide service at reasonable cost. From this viewpoint, the capacity waste caused by traffic asymmetry is a serious problem to be overcome. Thus, it is necessary to establish a technique that enables resources to be fully utilized by the asymmetric traffic.

## 3. Hardware Configuration

The ring topology based on ADM is the most frequently used transport network. A wide bandwidth variant of the ADM ring is the WDM ring [7, 8]. Figure 1 shows the basic

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hardware configuration of the ADM used in such a system. In this configuration, the bit stream direction is fixed to either clockwise or anti-clockwise in a fiber ring for every wavelength channel. Thus, if  $n$  wavelength channels are available between node  $a$  and node  $z$ , at most  $n$  optical paths can be set up from  $a$  to  $z$ . In this case,  $n$  more paths can be set up in the counter direction, from  $z$  to  $a$ . Thus, this configuration is well suited to symmetric, bi-directional paths.

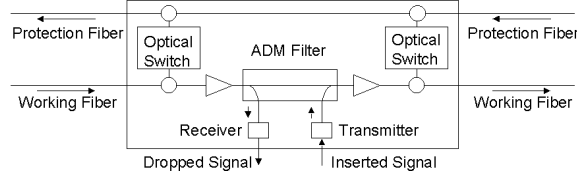


Fig. 1. A basic, conventional WDM ADM configuration.

The asymmetric optical path ring is build around the ADM shown in Fig. 2. This ADM features an optical switch between fibers, transmitters, and receivers as well as WDM demultiplexers and WDM multiplexers. Since these optical devices are currently available, it is not technically difficult to build such a device.

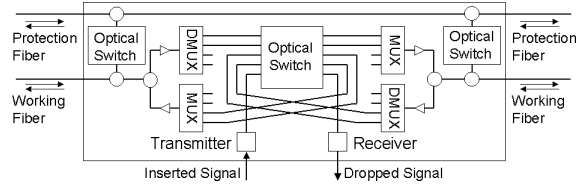


Fig. 2. An asymmetric WDM ADM configuration.

The most notable feature of the ADM is that the optical switch is capable of connecting any bit stream incoming from fibers and transmitters into any bit stream outgoing to fibers and receivers as illustrated in Fig. 3. In Fig. 3(a), the optical signal inserted from transmitter  $T_1$  is first sent to the switch, and connected to the left side multiplexer. The signal is finally transmitted to the left side working fiber. By contrast, the signal inserted from  $T_2$  is connected to the right side fiber. Similarly, Fig. 3(b) depicts the case that signals arriving from both fibers are dropped. Although signals of two opposite directions coexist in a fiber, they never interfere with each other because every optical path is assigned to a different, unique wavelength.

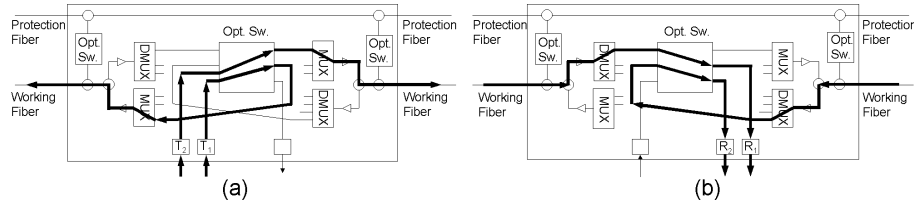


Fig. 3. A signal insertion example (a) and a signal drop example (b) with the asymmetric WDM ADM.

As seen above, bit streams can be transmitted over the ring in both directions, clockwise and anti-clockwise, with the asymmetric ADM. Because of this, the asymmetric optical path ring

can more efficiently provide a different number of wavelength channels in each direction between a node pair. Namely, if  $n$  wavelengths are available between node  $a$  and node  $z$ , it is possible to set up  $2n$  optical paths from  $a$  to  $z$  by placing  $n$  paths in the clockwise direction and  $n$  paths in the anti-clockwise direction. This means that the method can handle larger asymmetric traffic with the same number of wavelengths and fibers than the conventional ring topology. It is also possible to set up  $n$  paths from  $a$  to  $z$  and  $n$  paths from  $z$  to  $a$  which basically yields the conventional ADM ring. The asymmetric configuration can flexibly, and economically, support to both extremely unbalanced traffic and perfectly balanced traffic.

## 4. Evaluation

This section compares the hardware amount required by the asymmetric WDM ring to that required by the conventional WDM ring. Let  $S = \{0, 1, \dots, M\}$  be the set of nodes in a WDM ring. Let  $b_{ij}$  be the traffic bandwidth demanded from node  $i$  to  $j$  ( $i, j \in S$ ). If the capacity of an optical path is  $C$ , then the number of uni-directional paths from node  $i$  to  $j$ ,  $n_{ij}$ , is:

$$n_{ij} = \lceil b_{ij} / C \rceil. \quad (1)$$

Let the number of the ring systems required be  $y_a$  for the asymmetric ring and  $y_s$  for the conventional ring. Then,

$$y_a = \left\lceil \frac{1}{N} \sum_{\substack{i < j \\ i, j \in S}} \left\lceil \frac{n_{ij} + n_{ji}}{2} \right\rceil \right\rceil, \quad (2)$$

$$y_s = \left\lceil \frac{1}{N} \sum_{\substack{i < j \\ i, j \in S}} \max(n_{ij}, n_{ji}) \right\rceil, \quad (3)$$

where  $N$  is the number of wavelengths available per fiber. It is easy to see that  $y_a$  is not larger than  $y_s$ . Additionally,  $y_a$  can be as small as half  $y_s$ , for the extreme case of  $n_{ji} = 0$  ( $i < j$ ). In this case, the asymmetric ring can reduce the number of fibers and ADMs by 50% compared to the conventional ring. It should be also noted that the number of uni-directional paths equals that of optical receivers and transmitters. Thus, the asymmetric ring also decreases the cost of receivers and transmitters.

Next, let us examine the effectiveness of the asymmetric ring in minimizing the hardware resources through realistic simulations. The physical network model is shown in Fig. 4. For the network model, the average number of WDM ring systems required was evaluated against randomly generated traffic demand for the asymmetric optical path ring and for the conventional WDM ring. WDM was assumed to offer 32 wavelength channels, each of which has the capacity of 2.5Gb/s. The traffic demand is given as a number of optical paths defined between node  $N_0$  and  $N_i$  ( $i = 1, \dots, 6$ ) for each direction, assuming that the traffic is concentrated at  $N_0$ . The number of paths was determined from a randomly generated bandwidth value. The bandwidth was set according to the normal distribution of the average  $b$  and the variance  $\sigma^2$ . The bandwidth average  $b$  is determined as follows:

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$$b = \begin{cases} (1+k)b_0, & \text{from } N_0 \text{ to } N_i \ (i=1,\dots,6) \\ (1-k)b_0, & \text{from } N_i \ (i=1,\dots,6) \text{ to } N_0 \end{cases} \quad (4)$$

where  $k$  ( $0 < k < 1$ ) is the asymmetry parameter and  $b_0$  is the base bandwidth. That is, as  $k$  approaches 1, the traffic becomes more asymmetric. In the evaluation, value  $k$  was varied from 0.0 to 0.8 to see the impact of traffic asymmetry on the degree of resource saving for a constant total network bandwidth. The standard deviation  $\sigma$  was selected at 25% of the average bandwidth  $b$ . The system number was examined for large and small total traffic by setting value  $b_0$  to 8Gb/s and 40Gb/s.

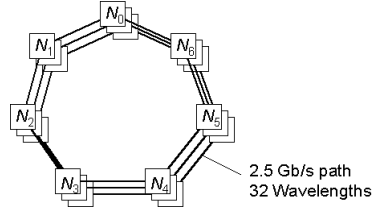


Fig. 4. Model network for numerical evaluation.

Figure 5 shows the evaluation results. As the figure shows, the number of required ring systems effectively decreases as the asymmetry factor  $k$  increases, particularly for the large total traffic case. The saving in average system number is greater than 27% for  $k > 0.2$  and large traffic. For small traffic, the effectiveness of the asymmetric ring is smaller. This is because only one ring system is sufficient in most cases for such traffic not depending on the ring architecture. Nevertheless, the proposed method is still effective in decreasing resources for small traffic as well if  $k > 0.4$ .

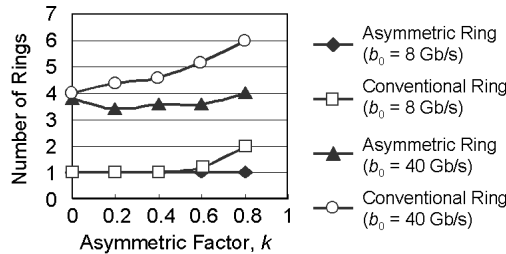


Fig. 5. The number of rings against the asymmetric factor.

The above evaluation confirms that the asymmetric optical ring effectively decreases the network resources for large, unbalanced traffic. Since the proposed ADM is more complicated than the conventional one, it may be more expensive. However, such disadvantage will be well offset because fewer ring systems will be needed.

## 5. Implementation Issues

Existing telecommunication systems, including transmission systems and IP (internet protocol) routers, are made on the assumption of symmetric communications. Thus, the described asymmetric ring may cause some compatibility problems when it is introduced into the real network. The very first problem is how to put IP packets into the asymmetric optical paths. The well known PPP protocol (point-to-point protocol) is based on bi-directional

communication channels. Therefore, some modifications may be necessary to send IP packets over an asymmetric ring that has  $m$  paths in one direction and  $n$  paths in the reverse direction.

Problems may also occur in network management. First, the existing alarm signals such as RDI (Remote Defect Indication) or FERF (Far End Received Failure) [9] are useful if the paths are bi-directional. Thus, the existing alarm signals must be reconsidered to support uni-directional paths. Another issue is the management information stored in the network management system. In the conventional network management system, transmission paths are modeled as bi-directional. Thus, new information models must be established that can represent uni-directional, asymmetric paths appropriately. In particular, it will be difficult to develop the models that handle a mix of conventional bi-directional paths and uni-directional paths.

As described above, there are technical problems to be solved when introducing the asymmetric WDM ring into the real world. However, if the huge bandwidth Internet becomes a major service, some asymmetric path architecture is very likely to be introduced. Thus, the above problems must be solved in the near future regardless of whether the asymmetric optical path ring is used or not.

## 6. Conclusion

This paper introduced the asymmetric optical path ring. First, the paper surveyed reports on the traffic asymmetry observed in the Internet. A new hardware architecture was presented, and its effectiveness was evaluated. Finally, the paper studied technical problems that will arise when introducing the proposed system into the real network. Although the described method creates some technical problems that must be overcome, it is expected to be beneficial in building a future communication network that carries extremely large volumes of Internet traffic.

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