Multicasting in DWDM Optical Mesh Networks Using a Novel Hybrid Routing and Wavelength Assignment (HRWA) Algorithm

I-Shyan Hwang, ***San-Nan Lee** and **Chih-Chien Chen**

Department of Computer Engineering and Science

Yuan-Ze University, Chung-Li 32026, Taiwan, ROC

E-mail*: *ishwang@saturn.yzu.edu.tw, *grand@saturn.yzu.edu.tw

ABSTRACT

The DWDM (Dense Wavelength Division Multiplex) can provide high-speed and high-capacity transmission, and multicast schemes can be efficiently applied as part of the DWDM to support QoS guarantees and time-consuming multipoint-to-multipoint transmission services, such as video conferencing and video broadcasting. A Hybrid Routing and Wavelength Assignment (HRWA) algorithm in optical mesh networks with ring-tree-based virtual topology is proposed. First, the HRWA tries to connect all multicast group members on with a ring path as possible, and then applies tree paths to connect the remaining multicast group members. Then, the HRWA will proceed to multipoint-to-multipoint multicast transmission by reserving links and channels, and wavelengths are assigned by the LCC (Least Converter Counts) algorithm. Simulation results demonstrate that the proposed HRWA algorithm improves system resource utilization by increasing the number of multipoint-to-multipoint multicast sessions using fewer reserved channels, and reducing the call blocking probability to increase more user capacity.

Keywords: DWDM, multipoint-to-multipoint multicast, HRWA, ring-tree-based topology, user capacity.

1. Introduction

QoS of multicast in mesh DWDM [1,2], particularly in the routing and wavelength assignment (RWA) scheme [3,4,5,6], must guarantee that the bandwidth is sufficient; that the delay is reduced and the packet loss probability is reduced. The multicast RWA problem is normally studied with the objective of maximizing the number of multicast groups admitted, or equivalently, of minimizing the call blocking probability for a given number of wavelengths. Studies of the routing solution in multicast can be categorized as lightpath-based [7,8] or light-tree-based [9,10] solutions. Both of these solution waste resources and reduces network throughput. For a given traffic matrix, the light-tree-based virtual topology design problem is formulated as an optimization problem with one of two possible objective functions - (i) minimize the network-wide mean packet hop distance, or (ii) minimize the total number of transceivers in the network.

For multipoint-to-multipoint multicast transmission, lower resource utilization and higher call blocking probability reduce the network performance, especially on QoS schemes. This work proposes a multicast RWA algorithm, called the hybrid routing and the wavelength assignment (HRWA) algorithm, which is based on the light-tree-based solution [3,6] in WDM mesh networks. The HRWA tries to find a ring path that connects all multicast group members with unidirectional links, and to connect the remaining nodes to the ring path using the fewest hops. The HRWA can use fewer links to establish the multicast routing path and more multicast connections.

The rest of this paper is organized as follows: Section 2 describes the HRWA algorithm. The simulation results in Section 3 compare the call blocking probability, the user capacity and the mean maximum transmission time of both HRWA and SMT schemes. Finally, Section 4 draws conclusions.

2. Proposed HRWA Algorithm

The HRWA algorithm finds the hybrid path, which consists of a ring path and shortest path tree(s), connecting all multicast group member (MGM) nodes. It applies the LCC scheme to solve the wavelength assignment problem.

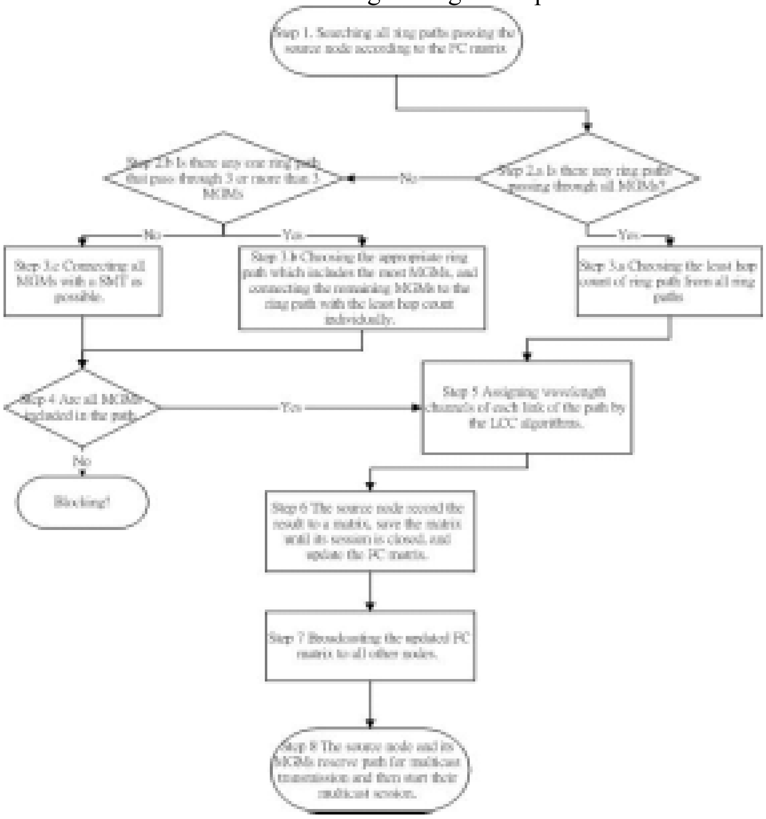

Fig. 1 Flow chart of HRWA algorithm

2.1 Network model and *FC* matrix

The following network model is assumed.

1.) The network topology is a mesh network, and no node or link failure is considered.
2.) Each node is fully capable of converting wavelengths.
3.) *f* fibers per link, *C* channels per fiber and all links are unidirectional.
4.) One control channel per link is required to send the token and to broadcast the *FC* matrix.
5.) A token is sent around all nodes in order in the network.

The status of the channels in each link is recorded in a matrix called the *FC* matrix. The *FC* matrix consists of *FC* values that represent the network. An *FC* value is the number of channels per fiber that can be used in the link between node *i* and node *j*;

2.2 HRWA algorithm

The problem with the HRWA algorithm design can be stated formally as follows. Given a traffic demand matrix and a network topology, find the network virtual topology that connects all MGM nodes and apply LCC to select dedicated channels. When a node sends a request for multipoint-to-multipoint multicast transmission, the HRWA algorithm is initiated to assign routing paths and wavelengths before transmission. Fig. 1 presents the flowchart of the HRWA algorithm.

The proposed algorithm is described as follows.

Step 1: The source C sends a multicast transmission request while it holds the token and searches all ring paths that begin at source C. Table 1 depicts the pseudo-code. Its time complexity is $\Theta(d^n)$ where *d* is the maximum degree of all nodes and *n* is the number of nodes. The proof of time complexity is presented as *Lemma 1*.

Step 2.a: Identify all possible ring paths that pass through all MGM nodes. If the ring path(s) exist, then go to Step 3.a; otherwise, go to Step 2.b.

Step 2.b: If one ring path passes through three or more MGM nodes, then go to Step 3.b; otherwise, go to Step 3.c.

Step 3.a: Choose the ring path with the fewest hops from all ring paths obtained in Step 1, and record each link in the ring path using a directional matrix *V*.

Step 3.b: Select the suitable ring path that includes most MGM nodes, and connect the remaining MGM nodes to the ring path with the fewest hops; then the hybrid routing path, which includes a ring and various SMT structures, is formed.

Step 3.c: Establish the routing path by connecting all MGM nodes as a SMT; then go to Step 4.

Step 4: Ensure that all MGM nodes are included in the path obtained in Step 3.b or Step 3.c. If they are, go to Step 5; otherwise, the request for multicast transmission will be blocked.

Step 5: After the path and the *V* matrix are obtained, wavelengths are assigned to the path according to the current *FC* matrix. First, a wavelength channel that can be assigned to all links in the *V* matrix must be determined. If it fails, wavelength channels are assigned to the links by the LCC algorithm [10]; then, go to Step 6.

Step 6: After the wavelengths have been assigned, the source must update the *V* matrix, yielding a new *V* matrix with assigned wavelengths, called the *U* matrix. The *FC* matrix is updated according to Eg. (1); go to Step 7.

$$FC = FC - U \;\ldots\ldots\ldots\ldots\; (1)$$

Step 7: New *FC* matrix is broadcasted to all nodes in the network from the source.

Step 8: The source and its MGM nodes reserve a path in multicast transmission, as determined by their *U* matrix. They then start their multicast session. A token is released to another node.

When some multicast groups close their multicast session, their source will release resources recorded in their own *U* matrices after the source received the token, and the *FC* matrix is updated again according to Eq. (2); then, the latest version of the *FC* matrix is broadcast to all nodes.

$$FC = FC + U \;\ldots\ldots\ldots\ldots\; (2)$$

Lemma 1: Consider the mathematical model of the network topology, the *V* matrix, and let *d* be the maximum degree of nodes and *n* be the number of nodes. The developed FINDRING algorithm which finds all possible ring paths that pass through all MGM nodes, uses $\Theta(d^n)$ comparisons in the worst case.

```
Pseudo FINDRING(RingStr, node i) {
        For all node j which let FC[i,j]>0{                    // d
                IF(CHECKNODE(RingStr,j)){                      // n
                        NewStr:=RingStr;
                        ADD node j to NewStr;
                        FINDRING(nowStr,j
                );                                              // T(n-1)}
        }
}
Pseudo CHECKNODE(RingStr, node j) {
        IF(node j has existed in RingStr){
                IF(node j is the source)
                        Record the RingStr, and RETURN FALSE;
                ELSE
                        RETURN FALSE;
        }
        ELSE
                RETURN TRUE;
}
```

Table 1 Pseudo-code of algorithm for searching for ring paths.

3. Simulation Results and Analysis

The system performance of the HRWA algorithm is compared with that of the Steiner minimal tree (SMT) [9] in terms of call blocking probability, user capacity and the mean maximum transmission time of each multicast session at various wavelengths, request rates and session sizes in the NSFnet, shown in Fig. 2. The simulation environments are assumed to be as follows.

1. Total number of wavelength channels per link is $W = F \times C = \{16,32,64\}$.
2. Multicast group size (Session Size) is $G = \{2,3,4,...,13,14\}$, and the holding time of each session is exponentially distributed (approximately a few minutes to hours).
3. Multicast request rate is $\lambda = \{1,2,...,9,10\}$ per minute.
4. Conversion time of each converter is 0.001ms [8].
5. Transmission time of each link is obtained from [7], using OPNET shown in Fig. 2, and the circulation of the token follows the order 0→1→2→5→9→8→12→13→11→10→3→4→6→7→0 in 0.345 seconds. The holding time of the token in each node is 20.3ms.
6. Each experiment involves 10000 connections.
7. Each node is treated as a user.

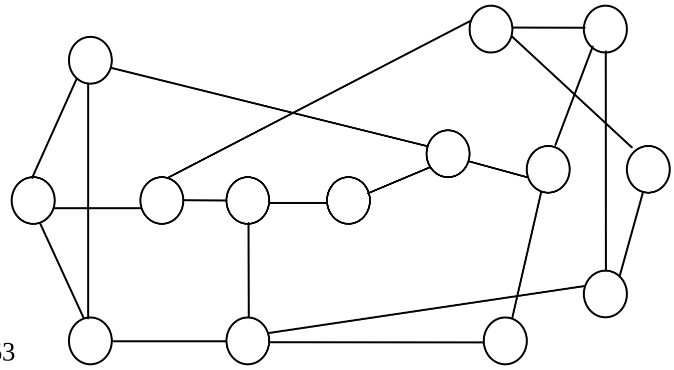

Fig. 2 Sample NSFnet (14 nodes and 21 links)

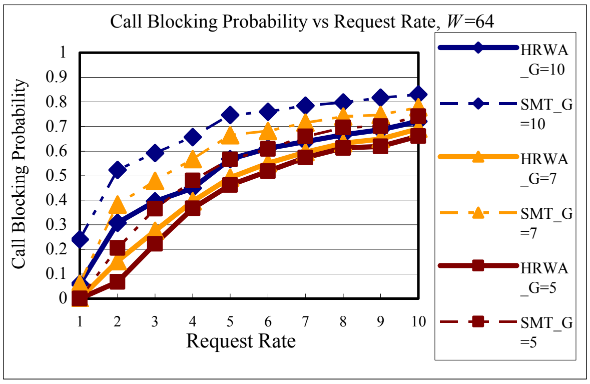

Fig. 3 Comparison of CBP of HRWA and SMT vs. request rate at G=10, 7 and 5 given W=64

Figures 3 and 4 depict the simulation results, comparing the call blocking probability and the session size at request rates of 10 and 64 wavelengths. The call blocking probability (CBP) normally increases with the request rate and session size increases because wavelength channels may not be available when the channels remain occupied by large sessions for a long holding time, or multicast requests arrive too soon to obtain wavelength channels before sessions release channels. The call blocking probability is reduced as the number of wavelength channels increases. Figures 3 indicates that the call blocking probability with HRWA_G=7 is lower than with SMT_G=5; even the call blocking probability with HRWA_G=10 is close at SMT_G=5 when λ exceeds 4.

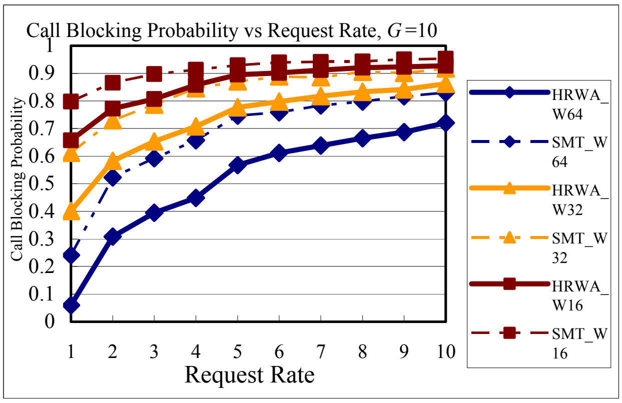

Fig. 4 Comparison of CBP of HRWA and SMT vs. request rate at W=64, 32 and 16 given G=10

In Fig. 4, HRWA has a low blocking probability when the request rate is lower than 2/min. This result reveals that HRWA will save more links than SMT when the session is large; when the total number of wavelength channels is few, the connections established by HRWA remain more than the number established by SMT. In Figs. 3 and 4, the performance of HRWA with large G is better than that of SMT with small G. Therefore, the proposed algorithm can improve network performance, regardless of the group size is. When λ exceeds 5, the call blocking probability of HRWA is saturated and the mean call blocking probability of HRWA is 6.7% - lower than that of SMT.

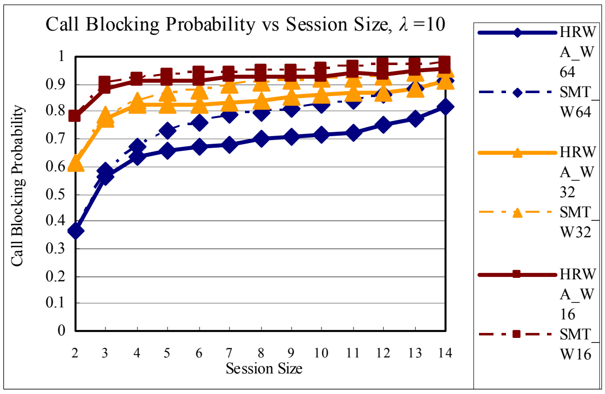

Fig. 5 Comparison of CBP vs. session size for W=64, 32 and 16 given λ=10

Figure 5 compares call blocking probability vs. session size for various wavelengths W=64, 32 and 16 given request rates λ=10. Figure 5 indicates that the difference between the call blocking probabilities of HRWA and SMT gradually increases as the session size increases over 4; The difference between the call blocking probabilities of HRWA and SMT is large when the wavelength channel is 32 and the session size exceeds 4. These characteristics reflect the result shown in Fig. 3 and the HRWA is more appropriate than SMT for larger multicast groups. Figure 6 compares the call blocking probability vs. session size for request rates λ=10, 5 and 1 given wavelength channels W=64, indicating that the call blocking probability of HRWA_λ=10 is close to that of SMT_λ=5 when the session is large, in turn indicating that the HRWA provides a higher probability of successful connections for large multicast groups, even when the request rate is almost double that of SMT.

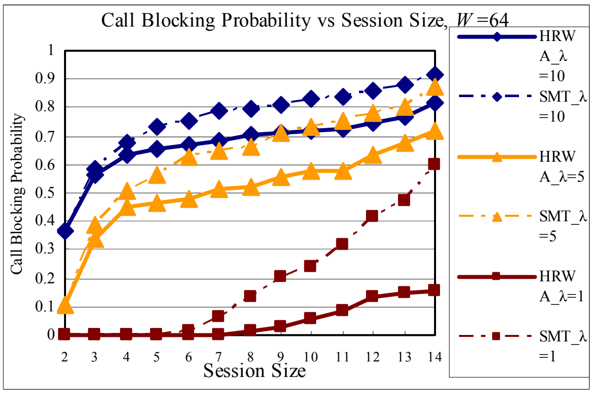

Fig. 6 Comparison of CBP vs. session size for λ=10, 5 and 1 given W=64

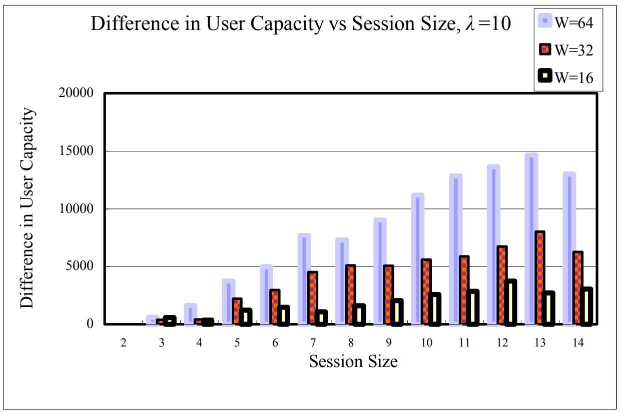

Fig. 7 Comparison of user capacities between HRWA and SMT vs. session size for W=64, 32 and 16 given λ=10

Figure 7 compares the user capacity (UC) between HRWA and SMT vs. session size for wavelength channels W=64, 32 and 16, given request rates λ=10. The difference in user capacity (DUC) is the number of users associated with HRWA minus the number associated with SMT. The DUC between HRWA and SMT is defined as follows.

(Call blocking probability of SMT – Call blocking probability of HRWA) × Request Connections × Session Size.

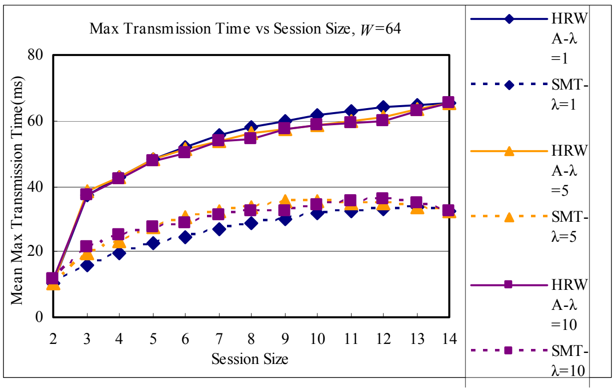

Fig. 8 Mean maximum transmission time vs. session size at λ=1, 5 and 10 with W=64, 32 and 16.

In Fig. 7, although the difference between the call blocking probabilities associated with HRWA and SMT is small when the call blocking probability of HRWA is higher and the session is larger, DUC remains high. The DUC increases with the session size at various wavelengths, especially when wavelength W=64. Some exceptions arise when the traffic is overloaded. For example, the DUC with the session size G=14 is less than that with session size G=13 at wavelength W=64. Therefore, the HRWA can support more user connections than SMT at the same time, with a lower request rate λ.

The "mean maximum transmission time" is defined as the sum of the maximum transmission time of all multicast sessions over the numbers of multicast sessions, and the mean max transmission time vs. session size for request rates λ=1, 5 and 10 given wavelength channels W=64 are as shown in Fig. 8. Only the session size affects the mean maximum transmission time, which is independent of the request rate λ and the wavelength channel W for both HRWA and SMT. Then, although the mean transmission time of HRWA is approximately 17 to 35 milliseconds longer than that of SMT, this short time has little effect on the transmission speed and quality after the connection has been established. In summary, more connections can be established and more users served using the HRWA, and the HRWA outperforms SMT in multipoint-to-multipoint multicast transmission in a large session with a long session holding time.

4. Conclusion

Multicasting support is a fundamental requirement of a WDM access network. This work presents an HRWA algorithm with ring-tree-based virtual topology for multipoint-to-multipoint multicast transmission, which reserves paths in the WDM mesh network and connects all multicast group members on single ring path. The simulation results demonstrate that the HRWA improves both the call blocking probability and the user capacity for various numbers of channels, request rates and session sizes. The HRWA outperforms SMT in terms of call blocking probability, with a larger multicast session, lower wavelengths and a higher request arrival rate. The call blocking probability of the HRWA is 45% lower than that of the SMT algorithm, especially when λ is 1, W is 64 and the session size is 14. The HRWA also yields a higher user capacity of the network than can be obtained with the tree, even when the call blocking probability is high. Moreover, the HRWA is suitable for large sessions and long holding times of multipoint-to-multipoint multicast transmission, serving more users than SMT, even if fewer wavelengths are available or multicast requests arrive frequently. The only cost is the long connection time, caused by the larger number of hops. The simulation results reveal that the transmission delay caused by the increased number of hops does not reduce the network performance. The optimal ring architecture and QoS schemes with various mesh topologies will be considered in the future.

References

[1]I.P. Kaminow et al., "A wideband all-optical WDM network," *IEEE Journal on Selected Areas in Communication*, Vol. 14, No. 5, pp. 780-799, June 1996.

[2]J.R. Kiniry, "Wavelength division multiplexing: ultra high speed fiber optics," *IEEE Internet Computing*, Vol. 2, pp. 13-15, March-April 1998.

[3]L. Sahasrabubuddhe and B. Mukherjee, "Light Trees: Optical Multicasting for Improved Performance in Wavelength Routed Networks," *IEEE Communication Magazine*, Vol. 37, No. 2, pp. 67-73, Feb. 1999. \

[4]A. Hamad and A. Kamal, "A Survey of Multicasting Protocols For Broadcast-and-Select Single-Hop Networks," *IEEE Network Magazine*, Vol. 16, No. 4, pp. 36-48, July-Aug. 2002.

[5]I. Chlamtac, A. Ganz, and G. Kami, "Lightpath communications: An approach to highbandwidth optical WAN's," *IEEE Transactions on Communication*, Vol. 40, pp. 1171-82, July 1992.

[6]Z. Ying and D. Sidhu, "An analysis comparing light-tree and lightpath in wavelength routed optical networks," 26th Annual IEEE Conference on *Local Computer Networks*, pp. 486-487, Nov. 2001.

[7]S. Arakawa and M. Murata, "Lightpath management of logical topology with incremental traffic changes for reliable IP over WDM networks," *Optical Networks Magazine*, pp. 68-76, May-Jun. 2002.

[8]M. Hayashi, H. Tanaka, K. Ohara, T. Otani and M. Suzuki, "OTDM transmitter using WDM-TDM conversion with an electroabsorption wavelength converter," *Journal of Lightwave Tech.*, Vol. 20, pp. 236-242, Feb. 2002.

[9]S. Ramanathan, "Multicast tree generation in networks with asymmetric links," *IEEE/ACM Transactions on Networking*, Vol. 4, No. 4, pp. 558-568, Aug. 1996.

[10]R. Libeskind-Hadas and R. Melhem, "Multicast Routing and Wavelength Assignment in Multihop Optical Networks," *IEEE/ACM Transactions on Networking*, Vol. 10, No. 5, pp. 621-629, Oct. 2002.