A Novel High Performance Multicast Scheme on Virtual Ring-Based 2D Torus Topology in DWDM Networks

I-Shyan Hwang, San-Nan Lee and Kuo-Chang Chien

1Department of Computer Science and Engineering, Yuan-Ze University, Chung-Li, Taiwan 32003, R.O.C.
2Department of Computer Science and Information Engineering, Vanung University, Chung-Li, Taiwan 32061, R.O.C.

Abstract

Wavelength Division Multiplexing (WDM) not only can increase the bandwidth of backbone transmission network significantly, but can also decrease the network cost and make the controlling and maintaining of transmission easy. The applications of multipoint-to-multipoint multicast communication, such as Video on demand and video conference, are important on Internet. The characteristics of multipoint-to-multipoint multicast communication are massive data, the transmission from different sources in the same multicast session and real-time. A novel high performance algorithm, virtual 2D Torus Topology Conversion-Two-hop virtual rings routing-EAC wavelength assignment algorithm (TTCA-TVRR-EAC) for multicast, is proposed in this paper. The TTCA-TVRR-EAC includes (1) the TTCA algorithm is employed to convert the real networks into torus networks; (2) the TVRR algorithm is utilized for routing; and (3) EAC algorithm is used for wavelength assignment. The simulation results show that the proposed algorithm outperforms RTRWA and SMT algorithm in terms of call blocking probability, different user capacity and channel utilization.

Key Words: WDM, Multicast, TWDM, RTRWA, TTCA-TVRR-EAC

1. Introduction

Fiber networks provide high bandwidth transmission, long distance transmission and low transmission error rate. Wavelength Division Multiplexing (WDM) [1] can divide the single fiber into multiple channels and transmit the different rates in different channels. It is also likely to be widely used in systems ranging from the local and metropolitan area networks to the backbone of the Next Generation Internet.

Multicast scheme demands simultaneous transmission of messages from the source to a set of destinations [2]. The routing and wavelength assignment (RWA) problem in WDM multicasting networks is studied with the objective to minimize the Call Blocking Probability (CBP) given a certain number of channels. The routing solutions in multicast can be categorized as lightpath-based, light-tree-based [3] and ring-tree-based schemes [4]. In the lightpath-based solution, the links between the transmitting nodes and receiving nodes must establish their own lightpath. The light-tree-based solution with Cross-connect (OXC) is a virtual topology of one-to-many multicasting and the popular topology is Steiner Minimal Tree (SMT) [5–8]. It establishes connections from source to different destinations respectively and wastes links. In [4], we proposed the Ring-Tree-based RWA (RTRWA) algorithm that uses the ring-tree to connect the Multicast Session Members (MSM) for multi-point-to-multipoint multicast communication. However, the RTRWA algorithm wastes the bandwidth when the channel utilization for one connection is low due to the characteristic of reservation-based algorithm.
The TWDM [9,10] is a solution for low channel utilization. In this paper, the Torus Topology Conversion-Two-hop virtual rings routing-EAC wavelength assignment algorithm (TTCA-TVRR-EAC) based on TWDM is proposed to enhance the RTRWA algorithm. There are three steps in the TTCA-TVRR-EAC algorithm: (1) torus topology conversion algorithm, (2) TVRR algorithm and (3) EAC algorithm for wavelength assignment and scheduling. First, the TTCA algorithm converts the real network to a two-hop torus [11,12] topology and each row (column) has a virtual ring to connect the nodes in a row (and in a column). This virtual rings topology can apply TWDM to reduce the wastage of bandwidth. TWDM combines the advantages of using WDM and TDM: with WDM, data can be transmitted through different channels at the same time. TDM is used for transmission schedules and WDM is used for wavelength assignments in this paper. Table 1 summarizes the terminologies used in this paper.

The rest of this paper is organized as follows. The Torus Topology Conversion-Two-hop virtual rings-EAC Algorithm (TTCA-TVRR-EAC) is proposed in section 2. The proposed algorithm compares the system performance with the SMT and RTRWA in section 3. Finally, conclusion is given in section 4.

2. The Proposed Algorithm

2.1 TTCA (Torus Topology Conversion Algorithm)

The flowchart of the conversion algorithm is shown in Figure 1, where $N$ is the number of nodes in the network, $n$ is the maximum number of nodes for each group (the row of the torus topology), $T$ is the number of remaining nodes and $m$ is the column of the torus. It is assumed that the number of nodes in the network is:

$$
\begin{align*}
N &= n \times m, \text{ if } T \text{ is zero} \\
N &= (n - 1) \times m + T, \text{ if } T \text{ is not zero}
\end{align*}
$$

![Figure 1. Flowchart of the TTCA algorithm.](image)

Table 1. Terminologies

<table>
<thead>
<tr>
<th>Terminology</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>RTRWA</td>
<td>Ring-Tree-based RWA</td>
</tr>
<tr>
<td>TTCA-TVRR-EAC</td>
<td>Torus Topology Conversion-Two-hop virtual rings-EAC Algorithm</td>
</tr>
<tr>
<td>SMT</td>
<td>Steiner Minimal Tree</td>
</tr>
<tr>
<td>EAC</td>
<td>Earliest Available Channel</td>
</tr>
<tr>
<td>CBP</td>
<td>Call Blocking Probability</td>
</tr>
<tr>
<td>MSM</td>
<td>Multicast Session Member</td>
</tr>
<tr>
<td>DUC</td>
<td>Difference of User Capacity</td>
</tr>
</tbody>
</table>

The first While loop is used to select nodes of each group to establish rings of each row. The time complexity of RTRWA algorithm is $O(d^N)$, where $d$ is the maximum degree of nodes and the time complexity of the first While loop is $O(Nd^N)$. The second While loop is used to select the $i$th node of each group to establish the ring of the $i$th column, and the time complexity is also $O(Nd^N)$. The time complexity of TTCA algorithm is $O(Nd^N)$ which is the sum of the first and the second While loop. The proposed algorithm is used for backbone network and the physical degree ($d$) is less than 10 (such as NSFNet, USA Net, ChinaNet, and etc). So the time complexity $O(Nd^N)$ is suitable for backbone network.

2.2 TVRR-EAC Algorithm

Before discussing the TVRR-EAC algorithm, the time division multiplexing (TDM) for the torus network [12], shown in Figure 2, will be described briefly. The to-
rus network is synchronized by dual-rings. The TVRR algorithm tries to establish a routing connection from the source to the destination in a one-hop or two-hop ring. If the source and the destination are on the same row or on the same column, the connection is one-hop ring and the connection is established immediately. If the source and the destination are not on the same row or on the same column, one intermediate node is found to connect two rings (one row and one column).

Then, the Earliest Available Channel (EAC) algorithm, which is easy and suitable for real-time transmission, is used to select a suitable channel for the routing connection. It searches for the Channel Available Time Table to find the earliest available channel for packet transmission. Every node has a Channel Available Time Table and a Slots Allocation Table, shown in Figure 3. The flowchart of the TVRR-EAC algorithm is shown in Figure 4.

When a node has the token, it consults the Channel Available Time Table to find the earliest available channel. Then the used time slots of each node on the path are reserved by fitting in the Slots Allocation Table. After the reservation, the information of the Channel Available Time Table and the Slots Allocation Table are broadcasted to the other nodes in the network. Then the node releases the token to the next node. When a node releases the token, it enters the data phase immediately.

3. Simulation Results

The system performance of the TTCA-TVRR-EAC is compared with that of the RTRWA and the SMT in terms of CBP, DUC, mean maximum transmission time and channel utilization of multicast session for different number of channels, request rates and session sizes in NSFNet and USANet. The CBP is defined as follows:

\[
CBP = \frac{\text{the number of failed Request Connection}}{\text{the number of total Request Connection}}
\]  

<table>
<thead>
<tr>
<th>Channel_ID</th>
<th>Start_Node</th>
<th>End_Node</th>
<th>Start_Slot</th>
<th>End_Slot</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>13</td>
</tr>
<tr>
<td>2</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>13</td>
</tr>
<tr>
<td>3</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>13</td>
</tr>
<tr>
<td>...</td>
<td>...</td>
<td>...</td>
<td>...</td>
<td>...</td>
</tr>
</tbody>
</table>

(a)

![Figure 3. (a) Channel available time table and (b) part of slots allocation table for the NSFNet.](image)

(b)
Figures 5 and 6 show the Call Blocking Probabilities (CBPs) for different session sizes and channels in the NSFNet, respectively. The simulation results show that the CBPs increase when the request rates and the session size are increased, and the number of channels is low. The CBP of the proposed TTCA-TVRR-EAC is lower than that of both RTRWA and SMT in any number of channels given the same session size. Overall, the CBP of the TTCA-TVRR-EAC can be reduced 10% to 20% and 35% to 50% more than that of the RTRWA in NSFNet.

Figures 7 and 8 show the CBP for different channels and for different session sizes in USANet. The results are similar to those in NSFNet. In Figure 7, the CBP of the TTCA-TVRR-EAC can be reduced 20% more than the SMT when the number of channel is 64 and the request rate is 5. The SMT uses more links to establish a connection and leads to high CBP when session size is medium. The Difference of User Capacity (DUC) between the TTCA-TVRR-EAC and RTRWA can be defined as follows:
The Difference of User Capacity (DUC) between the TTCA-TVRR-EAC and RTRWA in NSFNet and USANet

\[
DUC = \left( \frac{\text{CBP of RTRWA}}{\text{CBP of TTCA-TVRR-EAC}} \right) \times \text{Request Connection}
\]
for different channels and session sizes are shown in Figures 9 and 10. Under the same request rates, TTCA-TVRR-EAC can allow more users to transmit data than RTRWA. Under the RTRWA, each node in the same MSM is used for a certain connection. Before the connection is finished, the channels for this connection are
This limits the user capacity. Under the TTCA-TVRR-EAC, the channel share different connections and the user capacity can be increased. The DUC between the TTCA-TVRR-EAC and RTRWA is grown as the session size increases.

Figure 9. The Difference of User Capacity (DUC) between the TTCA-TVRR-EAC and RTRWA in NSFNet with different channels for (a) session size = 5, (b) session size = 7, (c) session size = 10.

Figure 10. DUC between the TTCA-TVRR-EAC and RTRWA in USANet with different channels for (a) session size = 5, (b) session size = 7, (c) session size = 10.
Figures 11 and 12 show the channel utilization for different channels and different session sizes in NSFNet. The TTCA-TVRR-EAC uses the TDMA to efficiently divide channels into several slots, and the usage of the channel can be minimized. Furthermore, the TTCA-TVRR-EAC can even save 40% free channels more than the RTRWA, and establish more connections than the RTRWA.

**Figure 11.** Channel utilization vs. request rate with different channels for (a) session size = 5, (b) session size = 7, (c) session size = 10 in NSFNet.

**Figure 12.** Channel utilization vs. request rate with different session sizes for (a) channel = 16, (b) channel = 32, (c) channel = 64 in NSFNet.
4. Conclusion

In this paper, the TTCA-TVRR-EAC is proposed to divide the topology into several small RTRWA sessions and convert them to a torus topology to construct a two-hop transmission model for multipoint-to-multipoint multicast communication. Then the EAC algorithm is employed to find the earliest available channel to transmit data. Finally, the information of source, destination and selected channel is allocated into the slot allocation table to schedule the transmission. The simulation results show that the TTCA-TVRR-EAC outperforms the RTRWA and SMT in terms of the call blocking probability and the channel utilization. The DUC between TTCA-TVRR-EAC and RTRWA is also increased. It implies that a new connection with the TTCA-TVRR-EAC uses channels more efficiently than that with the RTRWA. Although the transmission time is increased, the total network throughput is more important when compared with the transmission time. On the other hand, the network size does not affect the performance with TTCA-TVRR-EAC. In the future, how to find the optimal virtual ring conversion algorithm to reduce the maximum transmission time and to increase channel utilization is an interesting issue.

References


Manuscript Received: Dec. 14, 2008
Accepted: Nov. 24, 2010