第33卷第9期
2004年9月

光 子 学 报
ACTA PHOTONICA SINICA

Vol. 33 No. 9
September 2004

An Efficient Signaling Protocol for Distributed-Controlled Optical Networks*

Liu Jimin, Zeng Qingji, Luo Xuan, Huang Jun, Xiao Pengcheng
Center for broadband optical networking technology, Shanghai Jiaotong Univ, Shanghai 200030

Abstract An efficient signaling protocol, Tell-and-go, is proposed to perform fast lightpath provisioning for distributed-controlled optical wavelength-routed networks, in which switch reconfiguration can be performed in parallel at each node along the path. Simulation results indicate that the Tell-and-go signaling protocol achieves better network performance than the backward signaling protocol, in terms of lower blocking probability, shorter average lightpath setup time, in spite of slightly higher control bandwidth requirement.

Keywords Optical networks; Signaling protocol; Distributed control; Resource reservation
CLCN TN929.1 **Document Code** A

0 Introduction

In general, connection provisioning in optical networksl can be divides into route selection and signaling mechanism. For optical networks, the route selection problem is known as routing and wavelength assignment (RWA)[1], which has been extensively studied. In order to set up a lightpath, a signaling protocol is required to exchange control information among nodes and reserve wavelengths at each link along the path[2,3]. In the literature, two kinds of distributed signaling mechanism, namely forward and backward signaling protocol, have been explained[4].

In this paper, an efficient signaling protocol is proposed to perform rapid connection provisioning across distributed-controlled optical networks. This protocol improves the backward signaling protocol to reserve, occupy and release wavelengths as rapid as possible by employing the tell-and-go (TAG) mechanism. The goal to develop the efficient signaling protocol is to shorten average lightpath setup time through performing switch reconfiguration in parallel along the request routes. The main features of the protocol are: 1) No global state information exchange among network nodes is required; 2) The scheme is able to achieve a low average lightpath setup time (ALST) compared to that of BSP; 3) Signaling messages are transferred rapidly and the possibility of resource contention among contemporary requests are greatly reduced. These features lead to lower call blocking probability.

1 Background

In the network model we considered here, the optical core network consists of multiple optical cross-connects (OXC) nodes interconnected by optical links. An electronic controller at each node controls its local switch fabric and handles signaling messages transferring among them in the data communication network (DCN). We assume that each node performs wavelength switching by configuring purely optical switch and that none of OXCs have wavelength conversion. Reliable messages are delivered in sequence over the DCN either in-band or out-of-band.

In each optical switch, a local connection status table (LCST) is used to maintain the details about connections passing through. Every wavelength at a link has one of three statuses: RESERVED, FREE or ALLOTTED. Here, if the status of a wavelength is RESERVED, the wavelength is being reserved by a connection but is not occupied by other connections; FREE indicates that the wavelength is free and can be used to establish a connection; ALLOTTED means that the wavelength is allotted by a connection.

When a node need to establish a lightpath, a few control packets will be exchanged among the nodes on the path. Here we only explain the backward signaling protocol (BSP) breifly. As shown in Fig. 1(a), at the source, a Prob packet, in the backward signaling protocol, is sent to next nodes up to the destination along the forward path to collect the set of common wavelengths among all the physical links in the route. If no common wavelength is available, as shown in Fig. 1(b), a NACK message is sent back and the call is blocked. Here no retry is considered. When the Prob packet reaches the destination, the destination may choose a wavelength from the set of available wavelengths and send a Setup message to the source

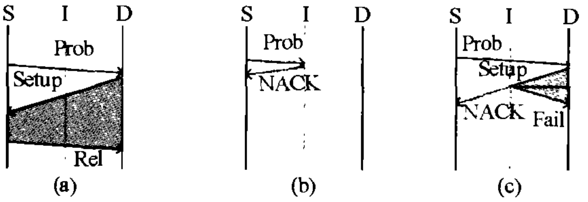
---

*Supported by National Hi-tech Project of China(863), with the project No. 2001 AA121073

Tel: 021-62933303-8010 Email: liujimin@sjtu.edu.cn

Received date: 2003-08-11

node along the reverse path. When an intermediate node receives the Setup message, they configure their switches to allot the wavelength to the connection and forward the Setup message to its previous. If the status of the selected wavelength is not FREE, a NACK message may be sent to the source node and a Fail message to the destination node to release the occupied wavelength on the forward path, as illustrated in Fig. 1 (c), and then the call is blocked. Note that in Fig. 1 (a) the interval transferring the Setup packet from the destination to the source node is much longer than that of delivering the Prob message, since switch fabric is reconfigured in sequence while the Setup proceeds to the source node.



(a) (b) (c)

(a)Successful reservation; (b)Unsuccessful reservation due to insufficient resources; (c)Unsuccessful reservation due to race condition

Fig. 1 The signaling process of BSP

In the BSP, insufficient resource and race condition among multiple contemporary calls may lead to call blocking[5]. The former is an issue resolved via effective routing algorithms and is out of our scope. Shadow areas in Fig. 1 represent the occupation of network resources as a connection is established. Efficient signaling protocols are required to be designed to reduce the connection establishment time as well as the blocking possibility. Therefore, we propose the TAG (tell-and-go) signaling protocol for optical networks to perform connection establishment efficiently.

2 Proposed scheme

In the signaling process of the BSP, when an intermediate node receives a Setup message, it checks the status of the selected wavelength. If it is FREE, the wavelength is allotted and the optical switch is required to reconfigure. The Setup message is forwarded until the reconfiguration is over. Thus the reconfiguration operation at each node is executed serially while the Setup message flows to the source along the reverse path. Thus the connection setup time is

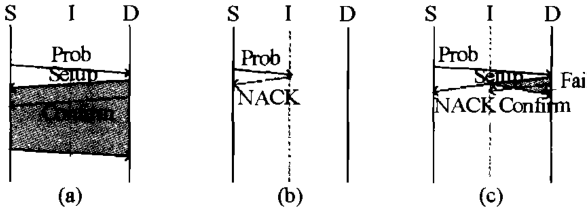
$$T_c = (2H+1)P + 2HD + C(H+1) \tag{1}$$

Here, C is the switch time of switch matrix at each node; P is the average message processing time; D and H are the average propagation delay and average hop distance between any two nodes, respectively.

Formula (1) shows that the switch time has a significant impact on the connection setup time since the switch time is generally much larger than others in mediate-sized networks.

We propose tell-and-go (TAG) signaling protocol to improve the BSP signaling process via performing switch fabric reconfiguration at each node in parallel. It results in shorter connection setup time, as well as lower blocking probability.

As illustrated in Fig. 2 (a), a new message, Confirm, is introduced into the TAG signaling protocol. Unlike the BSP, the Setup message is forwarded without waiting for the completeness of switch reconfiguration and the Confirm message is delivered in order to inform that switch reconfiguration is over at all nodes that Setup packet passes. Therefore, while the Setup message proceeds forward to the source node, each node along the path configures its switch matrix in parallel. After the source receives the Confirm packet, the connection is established successfully and the data may be transferred at once. Unsuccessful reservation shown in Fig. 2 (b), is similar with the signaling process of BSP. If at intermediate nodes the selected wavelength is unavailable, a Fail message is sent to the destination and a NACK message to the source, as shown in Fig. 2 (c). In addition, after the connection is already released, the Confirm messages received later are discarded.



(a) (b) (c)

(a)Successful reservation; (b)Unsuccessful reservation due to insufficient resources; (c)Unsuccessful reservation due to race condition

Fig. 2 The signaling process of the TAG protocol

At each intermediate node, the TAG algorithm is executed as follows:

```
Receive a Setup message.
Check the status of the selected wavelength.
If the status = FREE
The status = RESERVED
A setup message is forwarded to the previous immediately
Perform reconfiguration
Wait until the reconfiguration finishes or no reconfiguration is performed
If a Confirm message is not received
Wait for the confirm message originated from the next node
End If
```

```
    The wavelength status = ALLOTTED
    A Confirm message is sent to the previous
Else
    A Fail message is sent to its next node up to the destination
    A NACK message is also delivered to its previous node
    The call is blocked.
End If
```

For the TAG signaling protocol, one round trip propagation delays and processing time are also required to establish the connection. But compared with the BSP algorithm, the last item in formula (1) is reduced to only one unit of switch reconfiguration. Therefore, the time required by the TAG algorithm to set up a connection is

$$T_t = (2H+1)P + 2HD + C \qquad (2)$$

3 Performance evaluation

For evaluating the impact on the network performance of our proposed approach, we conduct a series of simulations to obtain numerical results for TAG compared with BSP in distributed control environment implemented by C + +. Our experiments use the Pacific-Bell network in Fig. 3, which has 21 links and 15 nodes. Each link in the network has two unidirectional fibers, which have 8 wavelengths. Each node has enough transceivers. The traffic is uniformly distributed on all node pairs. Request arrives one by one following Poisson process and holding time is exponentially distributed with mean 100 ms. The switch time, C is fixed at 10ms and the average processing time P is set to be 1.5 ms. Shortest-path fixed routing and random wavelength assignment are used as specified RWA algorithm.

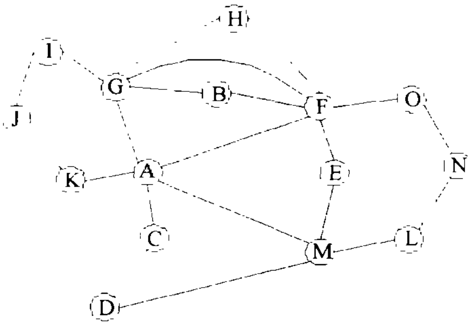


Fig. 3 The pacific-bell network topology

We obtain simulation results on the Pacific-Bell network topology by simulating 105 requests that arrive and depart over time. Three metrics are employed to evaluate the performance:

1) Blocking probability: probability that a connection cannot be established due to resource unavailability or contention.

2) ALST (Average Lightpath Setup Time): average time interval required to establish a connection between a call arrival and the acceptance of the RESERVEACK message at the source node.

3) ACP (Average Control Packets): ratio of total number of control packets in the network to the total number of requests that are tested with the network.

3.1 Average lightpath setup time

In Fig. 4, the relationship of the ALST vs. traffic load is illustrated. It is shown that the TAG can achieve lower ligthpath setup time than the BSP. The reason is that switch reconfiguration at each node on the path is performed in parallel for the TAG rather than in sequence for the BSP. The plot also supports the above analysis of the connection setup time.

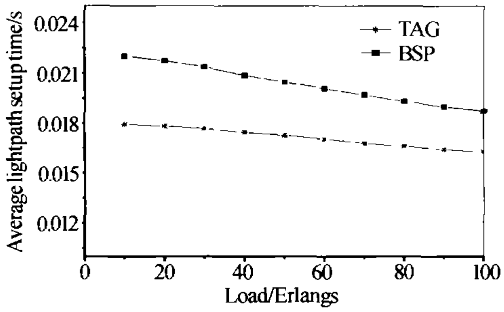


Fig. 4 ALST vs. traffic load

3.2 Blocking probability

Fig. 5 shows the plot of blocking probability vs. load for the TAG and BSP, in which the blocking probability of the TAG decreases significantly compared with that of the BSP. When the network load is low, the advantage of the TAG is very apparent. This is because the TAG can reduce the connection setup time greatly and shorten the time interval of occupation when the connection is established, as well as the possibility of race condition is greatly reduced.

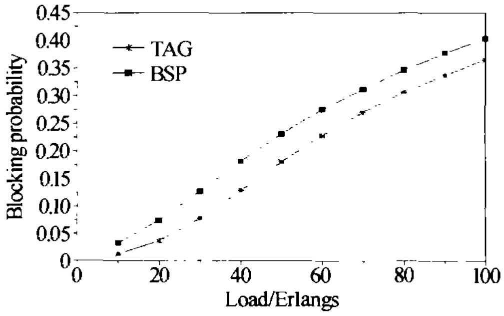


Fig. 5 Blocking probability vs. traffic load

3.3 Average control packets

In Fig. 6, the plot of ACP vs. network load is illustrated. Because the Confirm message is introduced into the TAG, the ACP of TAG is higher than that of the BSP. The worst case emerges when the traffic load is relatively low. However, it is not a serious problem since the control bandwidth requirement for the TAG increases only almost 12.9% in the worst case.

Moreover, while the load increases, the distinction of them decreases rapidly. Note that when the load is higher than 90, the TAG performance is better than the BSP. It is because for the TAG more lightpaths are established than the BSP and fewer control packets are required.

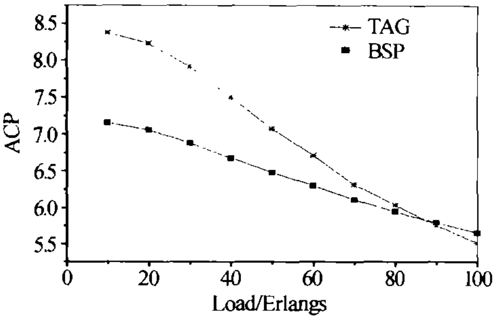


Fig. 6 Average control packet vs. traffic load

4 Conclusion

We have proposed an efficient TAG signaling protocol for GMPLS-based optical wavelength-routed networks, in which switch reconfiguration may be performed in parallel at each node along the path through introducing a Confirm message . Simulation results show that the TAG signaling protocol achieves better network performance than the BSP signaling protocol, in terms of lower blocking probability, shorter ALST and MLST, in spite of slightly higher control bandwidth requirement.

Reference

1 Zang H, Jue J P, Mukherjee B. A Review of routing and wavelength assignment approaches for wavelength routed optical WDM networks. *Optical Networks Magazine*, 2000, **1** (1):47 ~ 60

2 Ramaswami R, Segall A. Distributed network control for optical networks. *IEEE/ACM Transactions on Networking*, 1997, **5**(6): 936 ~ 943

3 Zang H, Jue J P, Sahasrabuddhe L, *et al.* Dynamic lightpath establishment in wavelength-routed WDM networks. *IEEE Communications Magazine*, 2001, **39**(9):100 ~ 108

4 Yuan X, Melhem R, Gupta R, *et al.* Distributed control protocols for wavelength reservation and their performance evaluation. *Photonic Network Communications*, 1999, **1**(3): 207 ~ 218

5 Lu S, Ramamurthy B. Centralized vs. distributed connection management schemes under different traffic patterns in wavelength-convertible optical networks. in: IEEE ICC 2002, 2002. 2712 ~ 2716

分布式控制光网络的一种高效信令协议

刘继民　曾庆济　罗　萱　黄　俊　肖鹏程
(上海交通大学宽带光网中心,上海 200030)

收稿时间:2003-09-06

摘　要　为了在光网络中建立连接,信令协议需要依次配置路径沿途节点上的光交叉矩阵完成. 提出了一种高效的信令协议,使各节点的光交叉矩阵的切换过程并行完成,可在光网络中实现快速光路供给. 在分布式离散时间仿真平台上所做出的深入仿真结果表明此信令协议能够获得比反向预留信令协议更好的网络性能,可获得更低的阻塞概率、更短的平均连接时间和最长连接时间,尽管可能付出了稍高一些的控制带宽的代价.

关键词　光网络;信令协议;分布式控制;资源预留

Liu Jimin received the B. S. from Xia'men University in 1997, the M. S. degree in computer science from the 204th Institute of China Aerospace Science and Industry Corporation in 2000, and is pursuing the Ph. D. degree in Shanghai Jiaotong University. His research interests include the control and management of intelligent IP over WDM optical networks.