Research on Congestion Control Algorithm Based on New Network Model and Wavelength Buffering in IONs

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***Abstract*—This paper studied the congestion control algorithm in the IONs and put forward two innovative algorithms. Firstly, designed a wavelength conversion algorithm which based on Partial-sparse-Limited network model (for short PLWC); Secondly, presented another wavelength conversion algorithm which based on Partial-sparse-Limited network model and Wavelength Buffering (for short PLWC_WB); Finally, analyzed and verified PLWC and PLWC_WB algorithm by system simulation. The simulation results shown that PLWC algorithm achieved an outstanding performance of the network improvement compared with the existing SPWC algorithm, and comparing with the PLWC algorithm the PLWC_WB algorithm can decrease the blocking probability about 13% and increase network resource utilization about 10%.**

Keywords- intelligent optical networks; congestion control; wavelength conversion; wavelength buffering.

I. INTRODUCTION

Network congestion problem is one of the important indicators to impact the network performance. Recently, most of the researches are concentrated on packet-based IP networks, but not the IONs. Therefore, the research about congestion control algorithm in IONs is of great significance. The reasons of IONs congestion include limited wavelength resources, Wavelength-Continuity Constraint (WCC) and Link Cascade Effect (LCE). Recently, there are several techniques to solve congestion control problems, such as routing and wavelength assignment, wavelength conversion and preemption.

The paper is organized as follows. In the next section, proposed the PLWC algorithm to place wavelength converter optimally. In Section 3, the PLWC_WB algorithm is designed to solve the time imbalance problem of network. In Section 4, the simulation is made to illustrate the efficiency of the algorithm. Finally, we conclude our paper in section 5.

II. PLWC ALGORITHM DESIGN

In Fig.1, reference 1, 2, 3 are sequentially classified into three categories: a device-level, an architecture-level, and a network-level. And it also shows the Sparse-Partial (SP)[4] and Sparse-Limited (SL)[3] network model. Although wavelength conversion algorithms based on these network models show a better performance than based on the above three basic network models, they all explore only a face of the cube. All the internal points of the cube in Fig.1 stand for the Partial-sparse-Limited (for short PSL) network model which combine all the three basic network models in a integrated manner. Thus, we expect that wavelength conversion based on Partial-sparse-Limited network model (PLWC) algorithm can achieve much better performance than the existing approaches.

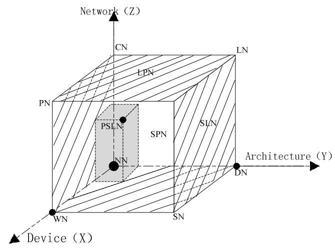

Figure 1. Conceptual view of nodes in network

The main idea of PLWC algorithm is based on PSL network model, configurating wavelength converter in the node which has the largest blocking traffic until the whole blocking probability less than the threshold B_{wcc} . The difficult point of PLWC algorithm is how to calculate blocking probability B and the threshold B_{wcc} .

A. Calculation of Blocking Probability

As shown in Fig. 2, path r consists of a set of ordered nodes and links, and a node can be a either wavelength-selective node (WSN) or wavelength-convertible node (WCN) depending on the capacity of wavelength conversion. Each WCN has a wavelength converter pool (WCP) which consists of n wavelength converters whose conversion range is d .

The blocking probability B_{WCC} is given by Formula (1). α is defined as 0.9.

$$B_{WCC} = (B_{FWC})^{a} (B_{NWC})^{1-a} \qquad a \in [0,1] \tag{1}$$

Where, B_{FWC} and B_{NWC} are the blocking probability of network after all nodes configurate WC and not configurate WC separately.

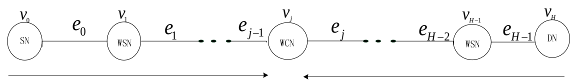

Figure 2. An H-hop path model and the corresponding notations

The network-wide blocking probability can be represented in terms of the end-to-end blocking probabilities, as shown in Formula (2). And a_r is the traffic load, B_r is the blocking probability of path r and R is the total number of requests.

When a_r is given, in order to obtain B, B_r should be calculated firstly. B_r can be divided into two parts: the blocking probability of nodes and links.

$$B = \sum_{r\in R}\alpha_r B_r \Big/ \sum_{r\in R}\alpha_r \qquad (2)$$

(1) Blocking Probability of Multi-wavelength Link

The amount of reduction in the offered load contributed by path r is given by $\alpha_r(1-B_{r|X_j=m})$. Aggregating all contributions of such paths, $a_j(m)$ be defined as Formula (3).

And $B_{r|X_j=m}$ Conditional blocking probability of path r, given that the number of free wavelengths on link e_j is equal to m.

$$\alpha_j(m) = \sum_{\forall r: e_j\in\xi_r} a_r(1 - B_{r|X_j=m}) \qquad (3)$$

Given $a_j(m)$, the free wavelength distribution on link j, is given by Formula (4).

$$P_j(m) = \frac{W(W-1)...(W-m+1)}{a_j(1)a_j(2)...a_j(m)}P_j(0) \quad ,$$

$$P_j(0) = \left[1 + \sum_{m=1}^{W}\frac{W(W-1)...(W-m+1)}{\alpha_j(1)\alpha_j(2)...\alpha_j(m)}\right]^{-1} \qquad (4)$$

(2) Blocking Probability of WCN

There are two sources of call blocking at the WCP in a WCN, they are the range blocking and the capacity blocking.

1) Model for LWC

We adopt the combinatorial LWC model to compute the conditional probability $Q(l \mid m)$ that the number of free wavelengths after wavelength conversion at WCN is equal to l, given that the number of free wavelengths on segment $v_0 \to e_{j-1}$ is m. From the assumption of random wavelength assignment, $Q(l \mid m)$ is given by Formula (5).

$\underline{W}(m) = min(m+d,W), \overline{W}(m) = min((2d+1)m,W)$

$$Q(l \mid m) = \frac{F(W,m,l)}{C_W^m}, \qquad \underline{W}(m) \le l \le \overline{W}(m) \qquad (5)$$

We refer to reference 4 for the recursive formulations of $\Phi(W,m,l)$.

2) Model for WCP

Fig.2 is an equivalent model of WCP. δ_{sel} and δ_{con} are given by Formula (6). δ_{sel} and δ_{con} are the amount of blocked traffic in WSN and WCN. β is the amount of range-blocked traffic of WCP, and be expressed as $\delta_{sel} - \delta_{con}$.

$$\delta_{sel} = \sum_{\forall r: v\in V_{r,I}} \alpha_r B_{r|Y_{j=1}} \quad , \quad \delta_{con} = \sum_{\forall r: v\in V_{r,I}} \alpha_r B_{r|Y_{j=0}} \qquad (6)$$

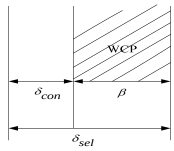

Figure 3. A model for WCP

Then, WCP can be viewed as a $M/M/n/n$ queuing system with the Poisson arrival rate β and the unit-mean exponential service time. Therefore, the probability of capacity blocking in a WCP, denoted by γ, is given by Formula (7).

$$\gamma = \frac{\beta^n}{n!}\left[1 + \sum_{i=1}^{n}\frac{\beta^i}{i!}\right]^{-1} \qquad (7)$$

(3) Blocking Probability of a Multi-hop Path

1) Blocking probability of a path

The blocking probability of path r can be obtained by calculating the free wavelength distribution of either $v_0 \to e_H$ or $e_0 \leftarrow v_H$. For the simplicity, we only present the formulations of $v_0 \to e_H$.

$$B_r = U^-_{H-1}(0) = U^+_0(0) \qquad (8)$$

Where, $U^-_j(m)$ and $U^+_j(m)$ are the probability of $v_0 \to e_j$ and $e_j \leftarrow v_H$ has free wavelengths.

This problem can be disposed into two sub-problems: the computation of $V^-_j(k)$ in terms of $U^-_{j-1}(m)$, given by Formula (9).

$$V^-_j(k) = \sum_{m=0}^{W} U^-_{j-1}(m)\left[\gamma I(k=m) + (1-\gamma)Q(k \mid m)\right] \qquad (9)$$

$$I(cond.) = \begin{cases}1 & cond.=true\\ 0 & cond.=false\end{cases} \qquad (10)$$

The computation of $U^-_j(f)$ in terms of $V^-_j(k)$, given by Formula (11). And $V^-_j(k)$ is probability of $v_0 \to v_j$ has free wavelengths.

$$U^-_j(f) = \sum_{k=f}^{W} V^-_j(k)\sum_{m=f}^{W} P_j(m)R(f \mid k,m) \quad ,$$

$$R(f \mid k,m) = \binom{k}{f}\binom{W-k}{m-f} \Big/ \binom{W}{m} \qquad (11)$$

2) Conditional blocking probability

By Formula (3), get to know that $\alpha_j(m)$ can be obtained given $B_{r|X_j=m}$. To calculate $B_{r|X_j=m}$, path r be partitioned into three dependent parts: $v_0 \to v_j$, e_j

and $v_{j+1} \leftarrow v_H$. x and y be denoted by the free wavelengths in two segments, z be denoted by the common free wavelengths between them. If path *r* is blocked, there should be no common free wavelengths in the three parts. Therefore, $B_{r|X_j=m}$ can be expressed as Formula (12).

$$B_{r|X_j=m} = \sum_{x=0}^{W} V_j^-(x) \sum_{y=0}^{W} V_{j+1}^+(y) \sum_{z=max(0,x+y-W)}^{min(x,y)} R(z \mid x,y) R(0 \mid z,m) \tag{12}$$

Where, $V_j^+(k)$ is the probability of $v_j \leftarrow v_H$ has free wavelengths.

To obtain the capacity blocking probability of WCP, $B_{r|Y_j=k}$ should be calculated firstly. Path r is partitioned into three segments: $v_0 \rightarrow e_{j-1}, v_j$ and $e_j \leftarrow v_H$. x and z be denoted by the free wavelengths in two segments, y be denoted by the common free wavelengths between them. If path *r* is blocked, there should be no common free wavelengths in the three parts. Therefore, $B_{r|Y_j=k}$ can be expressed as Formula (13) and (14).

$$B_{r|Y_j=1} = \sum_{x=0}^{W} U_{j-1}^-(x) \sum_{j=0}^{W} U_j^+ R(0 \mid x,z) \tag{13}$$

$$B_{r|Y_j=0} = \sum_{x=0}^{W} U_{j-1}^-(x) \sum_{y=\underline{w}(x)}^{\bar{w}(x)} Q(y \mid x) \sum_{z=0}^{W} U_j^+ R(0 \mid y,z) \tag{14}$$

B. Wavelength Conversion Based on PSL Network Model.

The basic procedure of PLWC algorithm is listed as follow.

Step 1: Assume LWC algorithm, find the smallest conversion range d_{min} in which the blocking probability B is less than or equal to B_{WCC} .

Step 2: Assume PSL network model, start Dijkstra and First-Fit algorithm to achieve routing and wavelength assignment.

Step 3: After all requirements have finished routing, compare the computed blocking probability B , if $B \leq B_{WCC}$, go to step 5, else, go to Step 4.

Step 4: Compute the amount of blocking traffics at each node. If a node is a WSN, calculate the range blocking δ_{sel} , otherwise , calculate the capacity blocking $\beta\gamma$. Find the node yielding the maximum traffic blocking, and add a wavelength converter to the corresponding WCP. Go to Step 2.

Step 5: Finish placing the wavelength converter.

III. Wavelength Buffering Scheme

The main idea of wavelength buffering scheme is to set a wavelength buffer in the network, and put some wavelengths in the zone, when the whole network traffic load is low, we just start routing and wavelength assignment in the non wavelength buffer, and in the peak phase of the traffic load “release" the resources in wavelength buffer to improve the network resource utilization. We can use the following procedure to get the curve of the optimal wavelength buffer.

Step 1: Assume all the network traffics are high-priority.

Step 2: For the given network traffic load, wavelength buffer increases from zero, and increases its minimum size every time.

Step 3: When the wavelength buffer has increased to a fixed value, observe the change of blocking probability of the whole network until the fluctuation range less than 1% of its value, record the blocking probability. And continue to increase wavelength buffer. Repeat the operation of Step 3 until the emergence of the recorded minimum value of blocking probability.

Step 4: Find the smallest blocking probability in the recorded values, and the corresponding buffer capacity is the optimal wavelength buffer.

Step 5: Increase network traffic load, repeat Step 2 to Step 4 until blocking probability indicator is over the upper limit of its value. In general, this limit can be set 20%. Finally, we get the optimal wavelength buffer trends with traffic load.

Table 1 is the wavelength buffer in NFSNET network topology with 128 wavelengths.

TABLE I. Optimal Value Of The Wavelength Buffer

Traffic Load (Erl)	5	10	15	20	30	40	60	80	100
Value (wavelength)	64	45	45	44	44	42	41	37	39

A. Starting of Wavelength Buffer

In order to make better use of the network resource in wavelength buffer, only high-priority traffic and low-priority traffic meeting certain conditions can start wavelength buffer. To low-priority traffic, it should meet two conditions.

i) Instantaneous traffic load of the network is greater than the setting threshold.

ii) The rate of resources utilization of wavelength buffer is less than the setting threshold.

B. Design of PLWC_WB

The basic procedure of PLWC_WB algorithm is listed as follows.

Step 1: Initialize the network topology, and compute the network link state database.

Step 2: Optimize the allocation of wavelength converters based on PSL network model.

Step 3: Calculate wavelength buffer. Then, divide the corresponding link-state database into wavelength buffer and non wavelength buffer link state database.

Step 4: Routing and wavelength assignment for the new traffic in non wavelength buffer with Dijkstra and First-Fit algorithm. If the shortest route exists and wavelength assignment success, calculate the network resource utilization of non wavelength buffer, else, go to Step 5.

Step 5: According to pre-setting level traffic priorities, for low-priority traffic, go to Step 6, for high-priority traffic, go to Step 7.

Step 6: If low-priority traffic meets with the conditions, go to Step 7, else, go to Step 8.

Step 7: Start wavelength buffer, Routing and wavelength assignment for the blocked traffic. If existing the shortest route and wavelength assignment success, calculate the network resource utilization of wavelength buffer, else go to Step 8.

Step 8: If all business requests finish routing, algorithm ends, else go to Step 4.

IV. SIMULATION

Fig.4, Fig.5, Fig.6 are wavelength conversion costs, blocking probability, and network improvement of wavelength conversion based on SP, SL, and PSL network model.

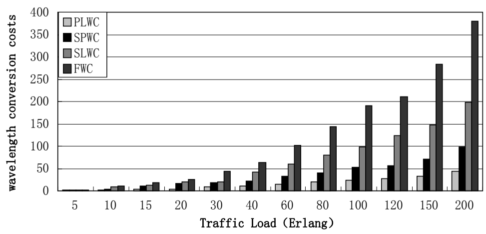

Figure 4. Wavelength conversion costs

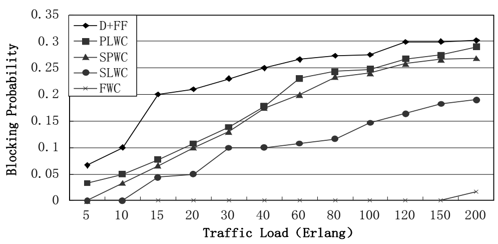

Figure 5. Network blocking probability

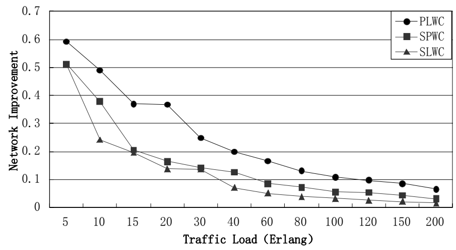

Figure 6. Network Improvement

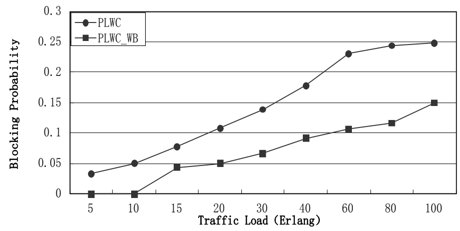

Figure 7. Network blocking probability

Fig.7, Fig.8 and Fig.9 are blocking probability, network resource utilization, network throughput, and end-to-end delay of PLWC and PLWC_WB algorithm. Fig.10 is the network resource utilization of wavelength buffer and non wavelength buffer of PLWC_WB algorithm.

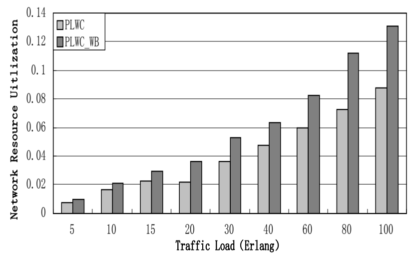

Figure 8. Network resource utilization

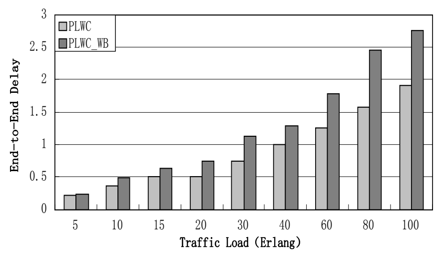

Figure 9. Network end-to-end delay

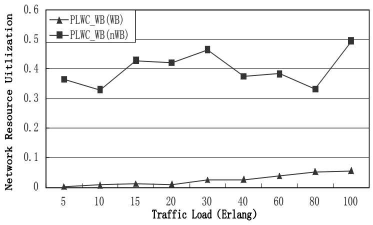

Figure 10. Network resource utilization of wavelength buffer and non wavelength buffer

V. CONCLUSIONS

This paper analyses congestion control algorithm in IONs. In order to minimize the blocking probability of the IONs, we proposed two algorithms: PLWC and PLWC_WB algorithm. PLWC algorithm solves the wavelength continuity constraint, and achieves compromise between the wavelength conversion costs and network congestion probability. The wavelength conversion costs decrease to 55 wavelengths and network improvement increases by 20% than the SPWC algorithm. On the basis of PLWC algorithm, PLWC_WB algorithm adds the WB scheme. It increases the network resource utilization by 10% and reduces the blocking probability by 13%.

VI. ACKNOWLEDGEMENTS

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