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Guaranteeing quality of service in optical burst switching networks based on dynamic wavelength routing

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Abstract

Optical burst switching networks have been receiving much attention as a promising approach to build the next-generation optical Internet. In this paper, we firstly describe the basic architecture of the optical burst switching network (OBS) based on dynamic wavelength routing (DWR), under which the guarantee of the quality of service (QoS) in the DWR-OBS network is discussed. Then we focus on two aspects: the transmission latency of the data packets and the blocking probability, which leads to a quantitative description of the transmission latency and the size of the edge node buffer. We also propose a method called dynamic preferred wavelength sets (D-PWS) to reserve the wavelength resource and based on the D-PWS entire-candidate path sets (E-CPS) wavelength assignment algorithm is given. Finally, we make a simulation on the DWR-OBS network by using the D-PWS method and take a comparison with the static preferred wavelength sets (S-PWS). The simulation shows that our approach excels traditional ones in QoS guarantee.

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Keywords: Optical burst switching; Dynamic wavelength routing; Dynamic preferred wavelength sets; Entire-candidate path sets

1. Introduction

With the rapid advance in dense wavelength division multiplexing (DWDM) technologies, it is possible to put 80–120 separate wavelengths on a single fiber, each supporting a data rate of more than 400 Gb/s [1]. Nevertheless, there is a relatively slower increase in the electronic processing speed, which means that data optically transmitted would be slowed down at each node if it is switched electronically. So it is hoped that IP packet can be transported directly over optical layer without any opto-electro-opto (O/E/O) conversion. However, both existing switching paradigms, namely optical circuit switching (OCS) and optical packet switching (OPS), have inherent shortcomings when using to support bursty traffic. OCS has very low bandwidth utilization because it has a large bandwidth provisioning timescale. OPS has a good adaptation

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to the bursty traffic, however, must face two major hurdles, one challenge is the current lack of optical random access memory and the other is the stringent requirement for synchronization [2]. Now optical burst switching (OBS) has been proposed as an optical switching paradigm to combine the advantages of both OCS and OPS. OBS not only can provide improvements over wavelength routing in term of bandwidth efficiently but also eliminate O/E/O conversion at the switching node, which make it possible to use OBS as the switching paradigm in IP over WDM network [3,4].

Although there is no unique definition of OBS until now, [2] has listed a number of its characteristics, such as burst size granularity (between OPS and OCS), separation of the control information and the payload, a one-way reservation scheme (for most cases), variable burst length, and no optical buffer. One-way reservation is used by most of the conventional OBS protocols, where header is sent into a bufferless switching network with a chosen offset time from the data to reserve the resource. But when the traffic load increases suddenly, the pre-chosen offset time will not be sufficient enough for the header to finish the resource reservation along the path. Since the switching network is assumed bufferless, bursts may be dropped at any point along the path, if a contention happens, therefore this approach cannot provide required quality of service (QoS) guarantees efficiently. Though in [2,3] another offset time termed QoS offset time is used to reduce the blocking probability of the high priority traffic, the blocking probability of the lower priorities will increase dramatically, especially for dynamically varying traffic loads.

In this paper, an alternative network architecture is studied, which is termed OBS network based on dynamic wavelength routing (DWR-OBS) [5]. The network requires end-to-end reservation to potentially meet the specific service criteria, such as latency and packet blocking probability. The DWR-OBS network can combine OBS with dynamic wavelength allocation under fast circuit switching to provide a scalable optical architecture with a guaranteed QoS in the presence of dynamic and bursty traffic loads. The architecture of the DWR-OBS network is shown in Fig. 1, in which there are three kinds of nodes: edge node, core node and control node. At the edge node, input packets are put into electronic buffers to aggregate into bursts, according to their QoS and destinations, with the timescale of milliseconds, which is a typical forwarding time of IP routers, making the reservation of resources along the path prior to burst trans-

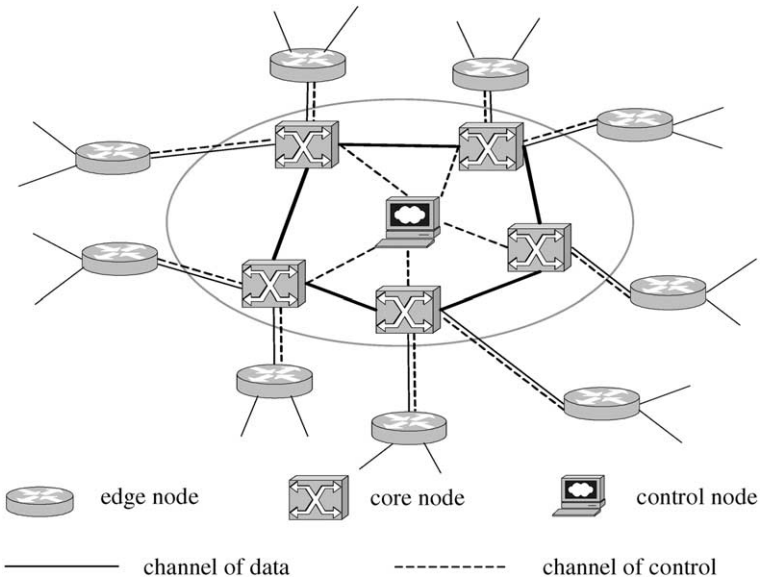

Fig. 1. Architecture of the DWR-OBS network.

mission feasible. Every edge node has $((n_e - 1) \times N_{QoS})$ electronic buffers (n_e is the number of the edge node, N_{QoS} represents the number of QoS) and each buffer belongs to a specific couple of the QoS and destination. When the quantity of the data in the buffer exceeds its threshold, which is decided according to QoS the buffer belongs to, the edge node will send out a resource reservation requirement to the control node. It is assumed that the requirement contains all the information about the burst, such as the source and destination edge routers, the QoS, the quantity of data in the buffer and the estimation of the wavelength holding time that is defined as the time necessary to empty the buffer and transmit the data between edge nodes. When the control node receives the requirement, it makes a DWR to reserve the wavelengths at corresponding core nodes. Once a free channel is found, the control node will return an acknowledgment of the resource reservation to the relevant edge node and the aggregated burst in the buffer will be assigned to the channel to be transmitted into the core network. Because the core nodes along the path have finished the resource reservation before the payload begins to be transmitted from the edge node, the further latency depends only on the propagation delay and the switch time at every core node without any undetermined delays. Concentrating all of the processing and buffering within the edge nodes of the network enables a bufferless core network simplifying the design of optical switches or routers/cross connects in the core significantly, which is particularly important for time-critical traffic, which cannot be achieved with the currently implemented IP-router infrastructure that provides hop-by-hop forwarding only.

The aim of this paper is to analyze the guarantee of QoS in the DWR-OBS network. We discuss this issue from two aspects: one is the transmission latency of packets and the other is the blocking probability. In Section 2, as a background knowledge, we provide a general process of how an OBS packet to be transmitted in the DWR-OBS network. In Section 3 we elaborate the QoS guarantee in the DWR-OBS network. In Section 4, we present a simulation model to evaluate the performance of the DWR-OBS network and discuss the simulation results. Conclusions are drawn in Section 5.

2. Burst transmission processes

Fig. 2 shows the burst transmission processes with the time scales as follows.t_0 is the beginning of the input packets aggregation. At t_{ask_wave} the edge node sends out a wavelength reservation requirement to the control node. We can get

$$t_{ask\_wave} = t_0 + f(S_0, b_{edge}, \rho_{buffer}), \tag{1}$$

where b_{edge} denotes the aggregated bit rate for the traffic directed to a particular buffer, S_0 is the threshold of the buffer, ρ_{buffer} is the load of the buffer. The formation of the function f is decided by the type of the arrival traffic, in the case of Poisson processes:

$$f(S_0, b_{edge}, \rho_{buffer}) = S_0/(b_{edge} \cdot \rho_{buffer}), \tag{2}$$

where t_{begin_proc} is the initial time of the control node making DWR and reserving wavelength resource at corresponding core nodes. We can get

$$t_{begin\_proc} = t_{ask\_wave} + t_{head\_trans}, \tag{3}$$

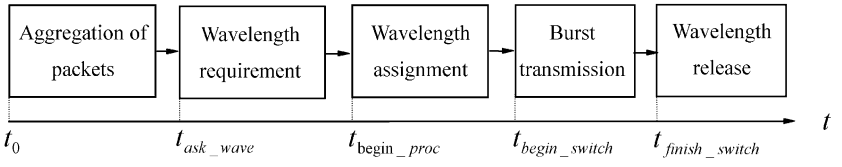

Fig. 2. Burst transmission processes.

where $t_{\text{head\_trans}}$ is the propagation delay for the wavelength requirement sent by the edge node. At $t_{\text{begin\_switch}}$ the edge node begins to send out the burst into the core network.

$$t_{\text{begin\_switch}} = t_{\text{begin\_proc}} + t_{\text{proc}} + t_{\text{ack\_return}}, \tag{4}$$

where t_{proc} is the total delay that the control node makes the DWR and allocates the wavelength for the core nodes along the path. $t_{\text{ack\_return}}$ is the propagation delay for the reservation acknowledge returned by the control node.

$t_{\text{finish\_switch}}$ is the time of the burst reaching the destination edge node. We can have

$$t_{\text{finish\_switch}} = t_{\text{begin\_switch}} + l_{\text{OBS}}/b_{\text{core}} + n \cdot \bar{t}_{\text{switch}} + \sum_{i=1}^{n-1} t_{\text{hop\_}i}, \tag{5}$$

where n is the number of the core nodes along the path; l_{OBS} is the length of the burst; b_{core} denotes the bit rate of the core DWR-OBS network; $\bar{t}_{\text{switch}}$ is the average delay spent by the core node to switch the burst; $t_{\text{hop\_}i}$ denotes the propagation delay for the burst between the ith core node and the $(i+1)$th core node along the path.

3. Efficient QoS guarantee in the DWR-OBS network

The QoS guarantee in the DWR-OBS network will be discussed from two aspects: one is the latency of packet transmission and the other is the blocking probability. Denote N_{QoS} as the number of QoS priority and we use subscript i to distinguish different priority.

3.1. Control of the transmission latency in the DWR-OBS network

The transmission latency of the traffic belonging to priority i $(1 \leqslant i \leqslant N_{\text{QoS}})$ is given as

$$\begin{aligned} t_{\text{delay\_}i} &= t_{\text{finish\_switch}} - t_0 \\ &= f(S_{0\_i}, b_{\text{edge}}, \rho_{\text{buffer\_}i}) + t_{\text{head\_trans}} + t_{\text{proc}} + t_{\text{ack\_return}} + \frac{l_{\text{OBS}}}{b_{\text{core}}} + n \cdot \bar{t}_{\text{switch}} + \sum_{j=1}^{n-1} t_{\text{hop\_}j}. \end{aligned} \tag{6}$$

In Eq. (6) $t_{\text{head\_trans}}$, t_{proc}, $t_{\text{hop\_}j}$, $\bar{t}_{\text{switch}}$ are decided by the hardware of the network and their value will not change with the bursts' priority and t_{unchange} denotes the sum of them. The only parts in this equation changed with the traffic priority are l_{OBS} (the length of the burst), $\rho_{\text{buffer\_}i}$ (the load of the buffer sending out the burst) and S_{0_i} (the threshold size of the buffer). We have

$$t_{\text{unchange}} = t_{\text{head\_trans}} + t_{\text{proc}} + t_{\text{ack\_return}} + n \cdot \bar{t}_{\text{switch}} + \sum_{j=1}^{n-1} t_{\text{hop\_}j}, \tag{7}$$

$$S_{0\_i} = S_i - b_{\text{edge}} \cdot (t_{\text{head\_trans}} + t_{\text{proc}} + t_{\text{ack\_return}}), \tag{8}$$

where S_i denotes the size of the edge node buffer pertaining to priority i and S_{0_i} l_{OBS} and S_i satisfy the following relationship:

$$S_{0\_i} \leqslant l_{\text{OBS}} \leqslant S_i. \tag{9}$$

From Eqs. (6)–(9) we get:

$$t_{\text{delay\_}i} = f(S_{0\_i}, b_{\text{edge}}, \rho_{\text{buffer\_}i}) + t_{\text{unchange}} + \frac{l_{\text{OBS}}}{b_{\text{core}}} \leqslant f(S_{0\_i}, b_{\text{edge}}, \rho_{\text{buffer\_}i}) + t_{\text{unchange}} + \frac{S_i}{b_{\text{core}}},$$
$$S_{0\_i} = S_i - b_{\text{edge}} \cdot (t_{\text{head\_trans}} + t_{\text{proc}} + t_{\text{ack\_return}}). \tag{10}$$

In the case of Poisson processes Eq. (10) becomes

$$t_{\text{delay\_}i} = f(S_{0\_i}, b_{\text{edge}}, \rho_{\text{buffer\_}i}) + t_{\text{unchange}} + \frac{l_{\text{OBS}}}{b_{\text{core}}} \leqslant \frac{S_{0\_i}}{b_{\text{edge}} \cdot \rho_{\text{buffer\_}i}} + t_{\text{unchange}} + \frac{S_i}{b_{\text{core}}},$$
$$S_{0\_j} = S_i - b_{\text{edge}} \cdot (t_{\text{head\_trans}} + t_{\text{proc}} + t_{\text{ack\_return}}). \tag{11}$$

Eq. (10) indicates the relationship between $t_{\text{delay\_}i}$ and S_i. Particularly in the case of Poisson processes, this relationship is approximately linear. Therefore, it becomes very easy to satisfy the latency requirement through modifying S_i according to Eq. (11), which is important for time-critical traffic.

3.2. Control of the blocking probability in the DWR-OBS network

3.2.1. Dynamic preferred wavelength sets wavelength reservation method

The basic idea of the dynamic preferred wavelength sets (D-PWS) is that the wavelength requests are treated differently according to their QoS requirements. The wavelength requests with higher QoS requirements, such as real-time video or voice, should have higher priority and, hence, should incur lower blocking probability. Besides QoS requirement the D-PWS reservation method also considers the following factors: (1) The load of traffic belonging to different priorities is also a very important aspect we should take into account. (2) A floor level of wavelength resource reserved is assumed for the low priority traffic because excessively high blocking probability of low priority will affect the integer performance of the network. (3) Reserve the wavelengths dynamically and the preferred wavelength sets are not specified, which means that a wavelength can be assigned to the wavelength request of any priority and the control node only control a pre-set wavelength quota for each priority class.

Assume that the network contains W wavelengths and W_i is the wavelength quota assigned to priority i $(1 \leqslant i \leqslant N_{\text{QoS}})$. The constraints on the quota are stated as follows:

$$W_{i\_\min} \leqslant W \leqslant W_{i\_\max}, \tag{12}$$

where $W_{i\_\min}$ is the floor level of the wavelength quota assigned to priority i and $W_{i\_\max}$ denotes the ceiling level.

With the floor level of $W_{i\_\min}$, the influence from the QoS requirement and the load of different priorities should be taken into account. Denote $w_{i\_\min}$ as the floor level of the reservation rate belonging to priority i. We have

$$w_{i\_\min} = \frac{\min(W_i)}{W} = \frac{W_{i\_\min}}{W} \tag{13}$$

and

$$w_{i\_\min} = a\frac{\rho_i}{\sum_i \rho_i} + b\frac{Q_i}{\sum_i Q_i}, \ \sum_i w_{i\_\min} = \psi \leqslant 1, \tag{14}$$

where ρ_i is the load of traffic belonging to priority i and $\rho_i = (n_e - 1) \cdot n_e \cdot \rho_{\text{buffer\_}j}$. Q_i is the coefficient of QoS requirement and is proportional to i (the priority of the traffic). a and b are two constants and we will use them to balance the weightiness of the QoS requirement and the load of different priorities in the wavelength reservation. ψ denotes the fix-assignment-rate of the whole wavelength resource.

For the ceiling level of the wavelength quota assigned to priority i, we pay more attention to the QoS requirement. When the traffic of priority i has occupied its ceiling level, the priority 1–$(i-1)$ will have to be

assigned to the floor level and the traffic of priority $(i+1)$–m can be reserved for the average level. So we assume $W_{i\_\max}$ as

$$W_{i\_\max} = \max(W_i) = W - \sum_{i=1}^{i-1} \min(W_i) - \sum_{i=1+1}^{m} \frac{\max(W_i) + \min(W_i)}{2}. \tag{15}$$

Here, for example, assume that the system has three priorities and the bandwidth contains 16 wavelengths ($W = 16$). We suppose that the QoS priority and the load of different priorities have the same weightiness, so $a{:}b = 1{:}1$. We also assume that $\psi = 0.5$ and the load of different priorities has the following relationship: $\rho_1{:}\rho_2{:}\rho_3 = 3{:}3{:}2$. Based on above assumptions and Eqs. (12)–(15), we can get the following wavelength reservation scheme:

$$2 \leqslant W_1 \leqslant 4, \quad 3 \leqslant W_2 \leqslant 7, \quad 4 \leqslant W_3 \leqslant 11.$$

3.2.2. Entire-candidate path sets wavelength assignment based on D-PWS method

The entire-candidate path sets (E-CPS) wavelength assignment consists of two components: one is to determine a node path along which the connection can be established; the other is to assign wavelengths to the selected path. In the DWR-OBS network every core node can only make limited wavelength conversion (WC) and the conversion range is 0–C_{range}.

Take the weighted graph $G(V,E)$ to denote the topology of a optical network, where V is the set of nodes and E is the set of links. $|V|$ is the number of the node in the set V. $e_{jk} \in E$ $(1 \leqslant j,k \leqslant |V|)$ denotes the link between the adjacent nodes j and k. When there are available wavelengths for assignment, $e_{jk} = 1$; otherwise $e_{jk} = \infty$.

A burst belonging to priority i sends a request to the control node to assign wavelengths from node s to d. The control node receives the requirement and makes the wavelength assignment based on E-CPS with the following steps:

(1) The control node modifies the weighted graph $G(V,E)$ according to the wavelengths available in the network. At the every link e_{jk}, if $\sum_{i=1}^{N_{\text{QoS}}} W_{i\_jk} < W$) and $W_{i\_jk} < W_{i\_\max}$, $e_{jk} = 1$; otherwise $e_{jk} = \infty$. W_{i_jk} denotes the number of the wavelengths which have been assign to priority i at the link e_{jk}.

(2) With the new weighted graph $G(V,E)$, the control node searches all the paths between node s and d to form the ECPS P using the depth first search (DFS) algorithm and the paths in the set P should be sorted by the number of the hops. If no path is found, the burst will be dropped and the wavelength assignment is over.

(3) The control node judges the wavelength conversion feasibility of the paths in the set P in turn. Once a path P_s can satisfy the WC limit, the control node assigns the corresponding wavelength along the path P_s and returns the wavelength reservation acknowledge back to the edge node. At the same time the situation of the wavelength occupied at every link e_{jk} along the path P_s should make the following amendment: $W_{i\_jk} = W_{i\_jk} + 1$; If no path in the set P can satisfy the WC limit, the wavelength assignment will fail and the burst will be dropped.

(4) Once the burst reaches the destination edge node, the wavelength used along the path P_s will be released. Every link e_{jk} at the path P_s should be modified as following: $W_{i\_jk} = W_{i\_jk} - 1$.

4. Simulation results and analysis

4.1. The topology of the network and assumptions

As shown in Fig. 3, we take a network with topology like the Chinese Education and Research Network (CERNET) as the example to present the simulation based on our dynamic optical resource model. This

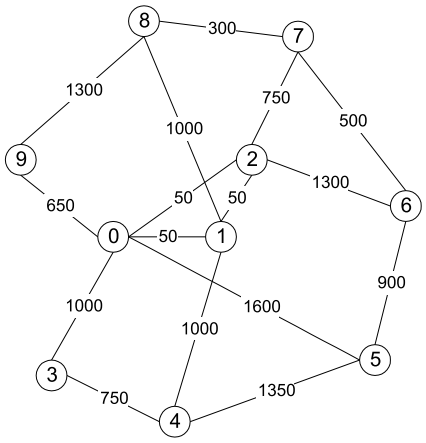

Fig. 3. The CERNET-like network.

network consists of 10 nodes and 16 edges, where the numbers on the edges denote the inter-node distances (in km). There are three priority levels in the simulated network and 16 wavelength channels in each link. Nodes 0–3 are assumed to be the edge nodes and the other nodes are core nodes.

We make the simulation basing on the following assumptions: (1) The packets reach the source edge node according to Poisson process. (2) Every core node has the same switching ability. (3) The source-destination node pairs follow the uniform distribution. (4) There are three different traffic priorities and the load of them has the following relationship: $\rho_{\text{buffer\_1}}:\rho_{\text{buffer\_2}}:\rho_{\text{buffer\_3}} = 3{:}3{:}2$ ($\rho_{\text{buffer\_}i}$ denotes the load of every buffer belonging to priority) and $b_{\text{edge}} = 1$ Gb/s, $b_{\text{core}} = 10$ Gb/s.

4.2. Wavelength reservation scheme of the D-PWS method

In the simulation we consider that the QoS priority and the load of different priority have the same weightiness, so $a{:}b = 1{:}1$. At the same time we assume that $\psi = 0.5$. Based on the D-PWS method and above assumptions we can get the following wavelength reservation scheme:

$$2 \leqslant W_1 \leqslant 4, \quad 3 \leqslant W_2 \leqslant 7, \quad 4 \leqslant W_3 \leqslant 11. \tag{16}$$

4.3. Comparison of the D-PWS method and S-PWS method

4.3.1. S-PWS wavelength reservation method [6]

For comparison, here we introduce the static preferred wavelength sets (S-PWS) method briefly. S-PWS method pre-defines a preferred wavelength set for each priority. Let V_i be the preferred wavelength set for a priority class i. The S-PWS method chooses an available wavelength for a wavelength request of a priority from its own preferred wavelength set. The constraints on the preferred wavelength sets are listed as follows:

(1) $i < j \Rightarrow V_i \subset V_j$. The preferred wavelength set belonging to priority i contains all the preferred sets whose priorities are lower than i.
(2) $V_{N_{\text{QoS}}} = \{\lambda_i | i = 1, \ldots, W\}$. $V_{N_{\text{QoS}}}$ is the preferred wavelength set of the highest priority which contains all the wavelengths in the network.

From the above analysis, we find the S-PWS method can satisfy the QoS requirement of the high priority very well but with following disadvantages:

(1) In the S-PWS method the QoS requirement of the low priority traffic cannot be guaranteed efficiently. Though the S-PWS method has pre-defined a preferred wavelength set for every low priority, all of the wavelengths in the set can often be occupied by other higher priorities because of the constraint (1). However in the D-PWS method, because a floor level of wavelength is assigned to each priority, the blocking probability of the low priority can be controlled in an expecting range.

(2) The S-PWS method pre-defines the preferred wavelength sets and chooses wavelengths from these sets according to the priorities which will declines the network resource using rate. Otherwise in the D-PWS method, the preferred wavelength sets are not specified and only the number of wavelengths assigned to the priority is controlled. A wavelength can be assigned to any priority.

4.3.2. The comparison of blocking probabilities

The performances of blocking probability Bp for the two methods are illustrated in Fig. 4, from which we can induce that: The two methods almost can give the same guarantee to the high priority traffic. But when we compare the average blocking probability of the two methods, we will find that the D-PWS has manifest superiority. In the S-PWS method, guaranteeing the low Bp of the high priority will cost the low priority too many blocks. But in the D-PWS method blocking probability of the low priority can be controlled in our expecting range because of the floor level of the wavelengths assigned to it.

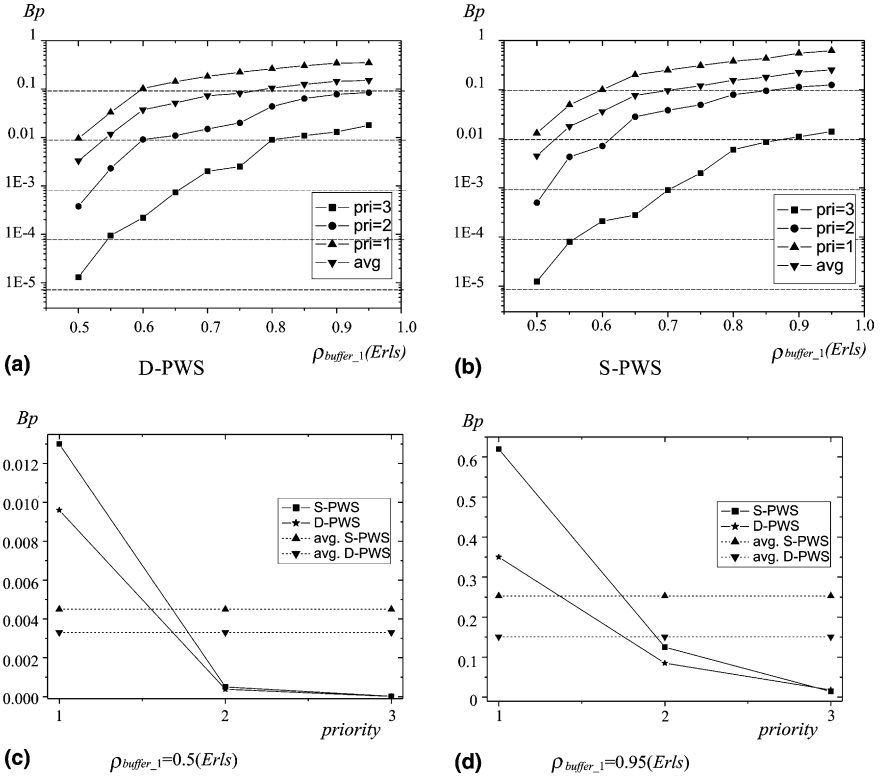

Fig. 4. Blocking probability in the CERNET-like network with 16 wavelengths and three priority levels: $C_{\text{range}} = 3$, $S_i = 32$ M$(i = 1$–$3)$.

4.3.3. The comparison of wavelength resource using rates

The wavelength resource using rates are defined as

$$\bar{U} = \sum_{i=1}^{3} \bar{W}_i / W, \tag{17}$$

where $\bar{W}_i$ denotes the average number of wavelengths occupied by priority i over every link.

The performances of two methods are shown in Fig. 5. When the load of the traffic is small both methods have low wavelength using rates. With the increase of the load, the D-PWS embodies its advantage because it assigns the wavelength dynamically according to the wavelengths left in the network while the S-PWS must choose the available wavelength from the pre-defined preferred wavelength sets.

4.4. The influence of wavelength conversion range on the blocking probability using D-PWS method

We have simulated the influence of WC on the DWR-OBS network by using D-PWS. The relationship between WC range and blocking probability is illustrated in Fig. 6, with which we can induce: (1) When the WC range varies from 0 to 1, the blocking probability of priority 2 and 3 decreases, while that of the priority 1 increases appreciably. During the transition for the network from without WC to with limited-range WC, because the wavelengths reserved for priority 1 by D-PWS method is relatively small, priority 1 could get little benefit from this transition. At the same time the blocking rates of the other two high priorities reduce greatly and the increase of their occupation rate of network resources are rather dramatic, which causes the blocking probability of priority 1 increases under this condition. (2) Limited-range WC improves the Bp performance effectively but with the increase of the WC range its influence over the network blocking probability becomes smaller and smaller. There are nearly the same average Bp when $C_{\text{range}} = 2$ and $C_{\text{range}} = 3$ for the CERNET-like network, which shows that the limited-range WC can make almost the same improvement over blocking probability with the entire-range WC.

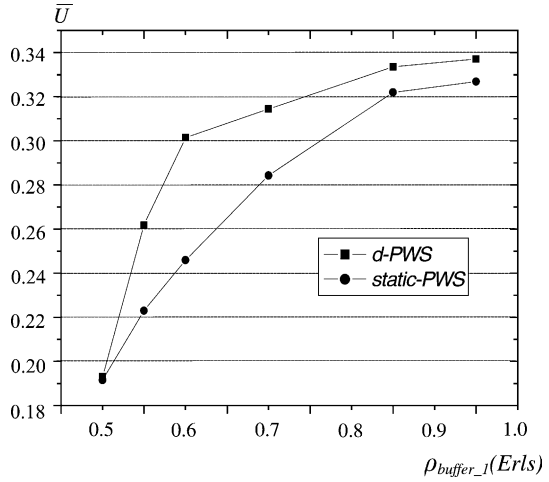

Fig. 5. The comparison of the wavelength resource using rates, $W = 16$, $N_{\text{QoS}} = 3$, $C_{\text{range}} = 3$, $S_i = 32$ M$(i = 1$–$3)$.

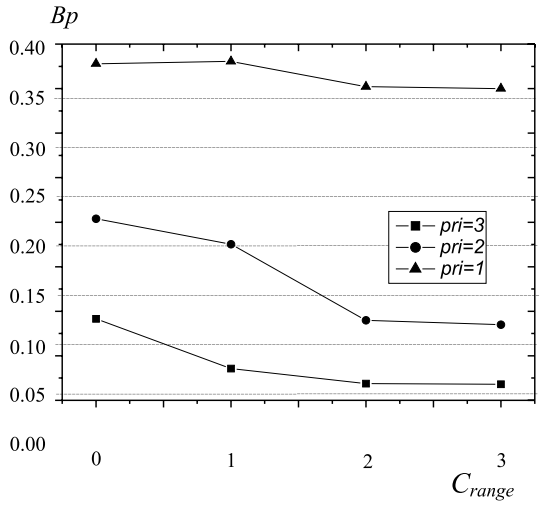

Fig. 6. The relationship between WC and B_P, $W = 16$, $N_{\mathrm{QoS}} = 3$, $S_i = 32$ M($i = 1$–3), $\rho_{\mathrm{buffer\_1}} = 0.98$ (Erls).

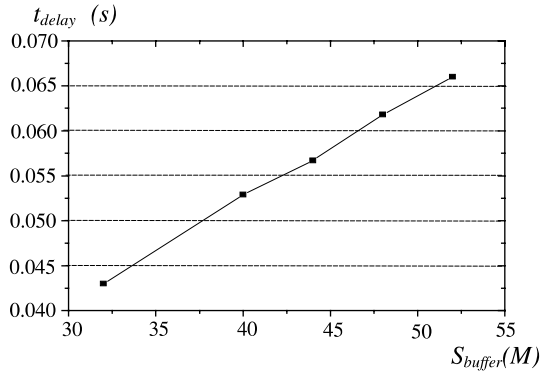

Fig. 7. The effect of the buffer size on the transmission latency, $W = 16$, $N_{\mathrm{Qos}} = 3$, $C_{\mathrm{range}} = 3$, $\rho_{\mathrm{buffer\_1}} = 0.95$.

4.5. The relationship between the buffer size and the latency

The relationship between the size of buffer and the latency is shown in Fig. 7. We find that they approximately have a linear relationship, which satisfied the Eq. (11) very well.

5. Conclusion

In this paper we mainly discuss the guaranteeing QoS in the DWR-OBS network. An equation about the size of the edge node buffer and the latency is given and through simulation we verified its correctness. We propose the D-PWS wavelength reservation method to control the blocking probability of different priorities and make a comparison with the S-PWS method. The results of analysis and simulation show that the DWR-OBS network using D-PWS method can guarantee QoS effectively.

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