Abstract. With the explosive growth of network services, the reasonable traffic scheduling and efficient configuration of network resources have an important significance to increase the efficiency of the network. In this paper, an adaptive traffic scheduling policy based on the priority and time window is proposed and the performance of this algorithm is evaluated in terms of scheduling ratio. The routing and spectrum allocation are achieved by using the Floyd shortest path algorithm and establishing a node spectrum resource allocation model based on greedy algorithm, which is proposed by us. The fairness index is introduced to improve the capability of spectrum configuration. The results show that the designed traffic scheduling strategy can be applied to networks with multicast and broadcast functionalities, and makes them get real-time and efficient response. The scheme of node spectrum configuration improves the frequency resource utilization and gives play to the efficiency of the network.

1. Introduction

In recent years, with the rapid development of broadband and high rate services, such as big data, cloud computing, high definition video on demand and Internet of Things, optical networks need to be able to deal with the enormous carrier pressure brought by these large capacity services. Nowadays, the fixed-grid rigid-bandwidth WDM network is widely used to allocate resources. This fixed-grid WDM optical network allocates the same spectrum resources for spectrum requirements of different services at various rate and different bandwidth, which will lead to excessive resource waste when the services need only low-rate and low-bandwidth requirements. Moreover, the waste of resources will show deteriorating trend with the expansion of networks. Therefore, the novel spectrum-sliced elastic optical path (SLICE) network [1, 2] based on programmable devices has been proposed. However, the flexible grid network is also facing new issues, such as traffic scheduling scheme [3] and the effective allocation of network resources, to be addressed. Therefore, an adaptive traffic scheduling policy based on the priority and time window is proposed in this paper. The performance of this algorithm is evaluated in terms of scheduling ratio. Moreover, the routing and spectrum allocation are achieved by using the Floyd shortest path algorithm and establishing a node spectrum resource allocation model based on greedy algorithm. The fairness index (FI) [4] is introduced to improve the capability of spectrum configuration.
2. Adaptive scheduling algorithm

The priority is defined considering bandwidth and duration of a service request, assuming that bandwidths are proportional to data-rates. The model that determines the scheduling order is abstractly expressed as $T(s,d,p,dt,w)$, where $s$ and $d$ are the source node and the destination node, respectively, and $p$ is the traffic priority. $dt$ is the expected starting time of scheduling and $w$ represents time window. Figure 1 denotes the time-window model of scheduling. If the actual scheduled starting moment $S_i$ can move within time window following $dt$, i.e., $dt + w \geq S_i$, the traffic is scheduled, which stops at $E_i$. Otherwise, the scheduling fails. When $dt$ is the same, the scheduled starting moment is movable within the individual time window.

Table 1 represents priorities and time-window setting. The traffic with high-priority should be scheduled earlier, while the time efficiency of scheduling should also be considered at the same time. The shorter time window of traffic, i.e., the earlier deadline $dt + w$, can save more idle time for scheduling more traffic. Therefore, scheduling efficiency of each service request consists of priority efficiency and time efficiency. The priority efficiency is expressed as $a_i = p_i$. The time efficiency is expressed as $b_i = e^{(0.1(dt + w - S_i) + (E_i - S_i))}$, $i = 1,2,\ldots$. The overall efficiency of a scheduled traffic is $G_i = a_i + b_i$, which is exploited to measure the performance of the scheduling algorithm. Obviously, this algorithm reflects a better performance with a greater scheduling efficiency. The goal of this algorithm is

$$\sum_{i=1}^{N} G_i = \max \quad (1)$$

$$s.t. \quad S_i \geq dt \quad (2)$$

$$w > 0 \quad (3)$$

Table 1. Priorities and Time-window Setting.

| Requests                     | Priority | Time Window(ms) |
|------------------------------|----------|-----------------|
| High-bandwidth, Short-duration | 4        | 50              |
| High-bandwidth, Long-duration  | 3        | 30              |
| Low-bandwidth, Short-duration  | 2        | 20              |
| Low-bandwidth, Long-duration  | 1        | 10              |

The adaptive scheduling algorithm with time window will have a range and sort criteria to adjust to the actual scheduling order when a large number of service requests arrive synchronously. The method is depicted in Algorithm 1. The core of this scheduling policy is the sorting a large number of service requests based on three different criteria, which are the priority rule (PR), the deadline rule (DR), and the priority-deadline rule (PDR). The performance of this algorithm is evaluated in terms of scheduling ratio.

Figure 1. Time-window model of scheduling.
Algorithm 1
Adaptive Scheduling Algorithm

1: Initialize idle time
2: Read the requests belonging to a scheduling period
3: Sort the requests by priority or deadline
4: Take the sorted requests in order
5: while requests queue is not empty, do
6: for idle time meet the $dt$ and $w$ do
7: (a) A request join executive matrix.
8: (b) Waiting for allocation of spectrum resources.
9: (c) Update starting point of idle time.
10: end for
11: (a) Request added to delay matrix.
12: (b) Update requests to the next scheduling period
13: end while
14: Scheduling finished

3. Routing and node spectrum configuration
Scheduling and resource allocation model in Figure 2 shows that the traffic successfully added to the execution queue will wait for corresponding routing and spectrum allocation according to the source node and destination node.

The shortest path between any two nodes is calculated by using Floyd algorithm [5] in this paper. The spectrum resource distribution of node output links is altered on a regular basis, taking into account the network spectrum consistency and continuity in the perspective of network node spectrum resource reconfiguration. Assume that each node has the capability of center frequency conversion [6]. As shown in Figure 3, the spectrum resource is allocated for the traffic to access the respective links through node $i$. An appropriate spectrum allocation policy can groom traffic as much as possible, and save spectrum resources substantially, while ensuring the quality of service.

In order to make the output links of node $i$ get equitable distribution of spectrum resources and reduce traffic blocking probability, a node spectrum allocation scheme based on greedy algorithm is proposed. The steps of this algorithm are presented below.

1) Set a certain time period. Calculate the average value of maximum and minimum bandwidth among traffic requests through each link in the set time interval. This average bandwidth $B_i$ is defined as the initial solution of bandwidth for link $i$.

2) Set an appropriate frequency slot period. Select several links randomly and make them share a same frequency-slot period, and accumulate each $B_i$ of these selected links. If the sum of $B_i$ is less than the frequency slots period, replace each $B_i$ with a larger bandwidth $B'_i$ in the traffic requests queue. If the sum is still lower than the frequency slots period, do the same operation until it is closest to the period.

3) Move central frequencies of traffic to the corresponding spectrum.

4) Use the first-fit spectrum assignment approach to allocate spectrum resources for traffic leading to different links through the node.

![Figure 2. Scheduling and resource allocation model.](image-url)
The effectiveness of the proposed algorithm in terms of better quality of service is modified by assigning broadband for each output links of the node. The fairness index (FI) can be defined as below to measure the equity of spectrum allocation scheme

\[
FI = \frac{\sum_{i=1}^{N} (B_i / A_i)^2}{N \sum_{i=1}^{N} (B_i / A_i)^2}, i = 1, 2, \ldots, N
\]  

(4)

where \( N \) is the total number of node output links. \( A_i \) and \( B_i \) are respectively the request spectrum bandwidth and the actual assigned bandwidth for link \( i \). Visibly, FI is a value between 0 and 1. The FI closer to 1 indicates a better fairness between the links and a lower blocking probability. When FI is lower than the threshold, the node spectrum for links is reconfigured.

4. Results and discussions

4.1. Performance of scheduling policy

To verify the performance of the adaptive scheduling algorithm based on priority and time window, the number of priorities is increased by adding the number of bandwidth threshold of request. Six priorities and 50ms scheduling interval are set in the simulation. The scheduling ratio with different priorities is taken as a evaluation index. The result shows scheduling performance comparison curve of three criteria, as shown in Figure 4.

![Figure 4. Scheduling ratio vs. priority under three criteria](image-url)
Figure 4 shows that scheduling ratio of PR and PDR increases linearly with the growth of priority. The scheduling ratio of DR has the similar trend with the former two criteria when the priority is low, while presenting a downtrend with higher priorities. In this case, scheduling ratio of DR depends primarily on the deadline of traffic requirement. Therefore, different scheduling rules exhibit their own advantages in different requirements. The PDR or DR should be selected to avoid low-priority traffic not to be treated for a long time. The PR presents better scheduling ratio when the priority is high. Therefore, an appropriate sort rule should be chosen to meet the user's multi-media service requests with different granularities. This scheduling scheme is also applicable among multiple networks. The appropriate adjustments for priority or time window of service request can improve the probability of a timely response for the network with real-time requirements.

4.2. Performance of routing and node spectrum allocation

The performance of routing algorithm is verified through a 6-node test network presented in Figure 5. As seen from the weighted graph, Floyd algorithm can accurately calculate the shortest path between any two nodes in the network.

The objective of spectrum allocation is to meet service requirements while reducing the spectral fragmentation. Assume that each node has the capability of center frequency conversion. The traffic passes node \( i \) to different destinations through respective output links. Seven output links are set to verify the fairness of node spectrum allocation in the simulation. 50 spectrum slices are set to a frequency slot period (FS) and allocated to partial links randomly. When the spectral occupancy of one FS reaches the upper limit, another FS is assigned to remaining links. Figure 6 (a) shows the status of node spectrum. The white and blue histograms, respectively, represent idle spectrum and request spectrum of links, while the red histogram presents the occupied spectrum within FS. Figure 6 (b) reports the spectrum allocation of output links. Clearly, links 6, 4, 2, 1 share the same FS and links 5, 3 share the second FS, while link 7 is configured in another FS. Result of simulation shows that the node spectrum configuration scheme greatly reduces spectrum fragmentation and improves the utilization of spectrum resources.

The throughput of the node is set to 110 Erlang in the node spectrum allocation simulation based on greedy algorithm. The bandwidth is assigned to each link to satisfy traffic transmission. Fairness Index (FI) varies with variance between the links under node spectrum allocation as shown in Figure 7. When the bandwidth of each link request is similar, the FI is closer to 1, namely, the fairness of allocated spectrum between links is better. If FI is less than a set threshold, reset the combination of links sharing the same FS or shorten FS to reduce the link variance. In this case, less allocated spectrum for one link that affects the quality of service and increases blocking probability is avoided.

![Figure 6](image_url)
Figure 7. Fairness vs. variance between the links under node spectrum allocation.

5. Conclusion
In this paper, an adaptive traffic scheduling algorithm based on priority and time window is presented. Routing and spectrum allocation for scheduled traffic are achieved with the flexible and reconfigurable network node. The designed traffic scheduling strategy can be applied to the networks with multicast and broadcast, and makes them get real-time and efficient response, which lays the foundation for the scheduling investigation of multimedia services with different granularity in the future network. The scheme of node spectrum configuration improves the frequency resource utilization and gives play to the efficiency of the network, while the fairness of spectrum assignments for services through links leading to different destination nodes, is ensured.

Acknowledgment
This work was supported in part by the National Natural Science Foundation of China (NSFC) under Grants 61071123 and The First HAEPC Science and Technology Project in 2015 under Grant 5217Q014006V.

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