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弹性光网络中基于效用的公平性感知动态频谱分配方案

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摘　要：针对弹性光网络中不同粒度业务之间的服务公平性问题，提出了公平性感知的动态频谱分配算法. 通过引入一个新的效用函数，使得进行频谱分配时不仅考虑不同粒度业务间的服务公平性，而且还兼顾网络整体的频谱资源利用率，从而大大缓解了网络整体阻塞性能损伤. 仿真结果表明，在动态网络环境下，该方案可以极大地提高弹性光网络中不同粒度业务之间的服务公平性，并且没有明显的阻塞性能恶化.

关键词：弹性光网络；路由频谱分配；服务公平性；带宽阻塞比
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A Utility-based Fairness Aware Dynamic Spectrum Allocation Scheme in Elastic Optical Networks

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Abstract: In order to address the service fairness issue of traffic with different granularities in elastic optical networks, a fairness aware dynamic spectrum allocation scheme was proposed. A novel utility function was introduced to take into consideration the spectrum utilization together with the service unfairness during spectrum allocation process, thus greatly migitating the overall blocking performance deterioration. Simulation results reveal that the proposed scheme migitaes service unfairness problem remarkably without significant blocking performance deterioration.

Key words: Elastic optical networks; Routing and spectrum allocation; Service fairness; Bandwidth blocking ratio
OCIS Codes: 060.4251; 060.4256; 060.4264

0 Introduction

Due to the rise of services with varying bandwidth requirement, the flexibility of optical networks is becoming a growing concern. To address this problem, elastic optical networks, such as SLICE[1] which introduces finer granular spectrum unit called Frequency Slot (FS) instead of following rigid ITU-T WDM grid, have been proposed. Based on optical orthogonal frequency division multiplexing technology[2], elastic optical networks can slice spectrum resource to FSs, with the ability to wisely

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and dynamically allocate spectrum resources to incoming traffic demands. Unfortunately, the high spectrum efficiency and improved flexibility do not come for free and the service fairness problem follows. Similar to the Routing and Wavelength Assignment (RWA) in WDM networks, Routing and Spectrum Assignment (RSA) also plays a critical role in flexible bandwidth elastic optical networks. Although higher spectrum efficiency is achieved, it should be noted that, if special RSA measures not taken, traffic requests with more bandwidth requirement are bound to experience higher blocking probability because of the spectrum assignment constraints (i. e., spectrum continuity and contiguity constraints). Moreover, as the gap of bandwidth requirements of traffic becomes larger, this diversity of blocking performance will be more pronounced. However, the network service is supposed to be fair and not have any inherent bias against a particular subset of users/requests.

In WDM networks, there′ re several works reported focusing on the fairness among classes with different hop counts or connections with different capacities[3-7]. Ref.[3-4] proposed traffic classification and reservation based fairness schemes. Although they can solve the problem in some scenarios, they were not suitable for use in networks with dynamic traffic load[5-6]. gave a call admission control scheme based on Markov Decision Process (MDP) for fairness management, but the scheme was overly complicated and thus cannot be used in real networks. In Ref. [7], an admission control algorithm was proposed. Simple as it is, it penalizes the overall blocking performance and bring about new unfairness among different connections in the same class, i. e., the blocking probability of traffic belong to a certain class might be different over time. In elastic optical networks, previous works on spectrum assignment issue are mostly focused on improving spectrum utilization and seeking better overall blocking performance and there is hardly any discussion about this granularity oriented service fairness issue[8-12].

In Ref. [13], we once proposed a fairness-aware spectrum allocation scheme used in elastic optical networks, i. e., Progressive Allocation and Dynamic Reallocation (PADR), which can improve the service fairness greatly. However, the fairness is not good enough and the total blocking performance is severely undermined.

In this paper we proposed an improved fairness aware spectrum allocation scheme to address this problem. Simulation results indicate that the proposed approach can further improve service fairness with much smaller cost of network blocking performance deterioration.

1 Granularity oriented fairness evaluation model

In optical network with dynamic traffic, the spectrum will become exhausted and fragmented because of frequent lightpath setup and teardown throughout the network. Also, with the knowledge that that spectrum fragmentation reduces the possibility of finding available allocation of contiguous FSs for traffic requiring larger bandwidth, traffic with larger bandwidth requirement will experience more blocking. Therefore, we classify the traffic into different classes according to the number of FSs they required. Note that Wavelength Conversion (WC) is not considered here.

In this paper, we continue follow the definition of Normalized Blocking Probability (NBP) and Fairness Index (FI) given in ref.[13].

1.1 Normalized blocking probability

When service fairness is achieved, the blocking performance of a request of size n should be equal to that of n requests of size 1 [14], i. e.,

$$1-(1-p_1)^n=p_n \tag{1}$$

where p_i is the Blocking Probability (BP) of traffic with size i. Therefore, we denote NBP of class n as

$$\tilde{p}_n=1-\sqrt[n]{1-p_n} \tag{2}$$

1.2 Fairness index

Based on the definition of NBP above and FI given in Ref. [15], the FI can be redefined as below to measure the service fairness degree of the spectrum allocation scheme,

$$\mathrm{FI}=\frac{(\sum_{i=1}^{N}\tilde{p}_i)^2}{N(\sum_{i=1}^{N}\tilde{p}_i^2)},i=1,2,\cdots,N \tag{3}$$

where N is the total number of classes and $\tilde{p}_i$ is the NBP of class i. Note that FI is a number between 0 and 1 and the closer to 1, the better the service fairness is. Complete fairness is achieved when the NBP value of all classes are equal.

2 Fairness aware spectrum allocation schemes

In this section, we focus on the previously mentioned granularity oriented service fairness issue in flexible bandwidth elastic optical networks. We start with the definition of a utility function and based on it we present the description of the fairness-aware scheme. The basic idea is to divide the whole spectrum resource into equal Spectrum Blocks (SBs) with the same number of FSs and dynamically perform SB allocation based on the utility function with spectrum utilization and service fairness considered.

2.1 Utility function

In the PADR scheme we proposed in Ref. [13], a threshold concerning the ratio of NBP between different classes is introduced to trigger the SB reallocation. Provided that the threshold is met, we mechanically transfer the dedication of one SB from the class with least NBP to the class with the largest. Although the service unfairness problem is mitigated to some extent, the fairness achieved is not good enough and the total blocking performance is severely deteriorated. Therefore, in this paper we introduce a utility function, which takes into consideration the spectrum utilization together with the service unfairness among different classes, to further improve performance of the spectrum allocation scheme.

The definition of utility function is given as follows

$$\text{utility}(i)=\text{up}(i)*\text{NBP}(i) \tag{4}$$

where up(i) is the number of usable FSs when a SB is dedicated to class i and NBP (i) is the current normalized blocking probability of class i. For instance, if one SB is composed of 20 FSs, then up(3) and up(8) is 18 and 16 respectively rather than 20. The utility function will pay more attention to spectrum utilization when the service unfairness problem is not severe and focus more on service fairness otherwise.

2.2 Utility based PADR scheme

Based on the definition of utility function, we developed an improved PADR scheme, i. e., Utility Based Progressive Allocation and Dynamic Reallocation (UBPADR) scheme, as is described below, to address the fairness issue.

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UBPADR Scheme:
Divide the whole spectrum into $C$ equal SBs.
When a request belonging to class $i$ arrives
    for $j=1 \cdots C$ do
        if SB $j$ is dedicated to the class $i$ then
            Search for available allocation in SB $j$
        end if
    end for
    if available allocations are found then
        Select one among the allocations according to the predefined selection policy (in this paper we choose the first one)
    else if there exist SBs not dedicated to any class then
        Assign one SB to class $i$
    else
        Request is blocked
    end if
    Obtain NBP according to accumulated BP of all classes
    Calculate the utility of a SB when assigning to different classes
    Search for the classes with the largest utility and the least.
    if the gap between the least utility (corresponding to class $m$) and the largest utility (corresponding to class $n$) is larger than a given threshold $thr$, then
        Reallocate one SB, which is currently dedicated to class $m$, to class $n$
    end if
```

3 Performance evaluation

To evaluate the performance of our proposed scheme, simulation experiments have been conducted on the 14-node NSFNet topology in terms of Bandwidth Blocking Ratio (BBR) and service FI.

3.1 Simulation setup

The simulation setup is described as follows:

1) Each link of the network has a pool of 500 FSs;

2) Each connection request is generated with the source and destination nodes uniformly chosen;

3) The traffic arrivals are Poisson distributed and the call-holding time obeys negative exponential distribution;

4) The bandwidth demand for each request ranges from 1 FS to 10 FSs and the total bandwidth demand of each class of traffic is equal;

5) Fixed shortest path routing is adopted.

3.2 Simulation results & discussion

Fig. 1 shows the service fairness performance under UBPADR compared with first fit as well as PADR we proposed in Ref. [13]. It can be observed that both PADR and UBPADR can improve service fairness remarkably compared with First Fit under each load, and UBPADR achieves the best fairness which is pretty much to be 1. Meanwhile, the First Fit gets better service fairness with the increase of load. This is because the classes with small bandwidth requirement hardly experience any blocking when the load is low while those with large bandwidth requirement are more likely to be blocked due to spectrum fragmentation and

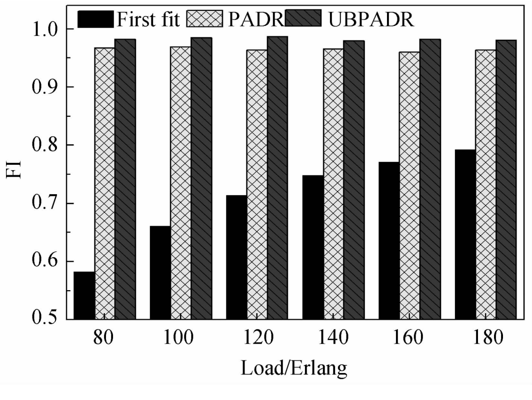

Fig. 1 FI vs. traffic load under different schemes

spectrum continuity constraints.

Fig. 2 illustrates the blocking performance of the three schemes. In combination with Fig. 1, it can be seen that the UBPADR achieves better service fairness performance at much smaller cost of blocking performance deterioration.

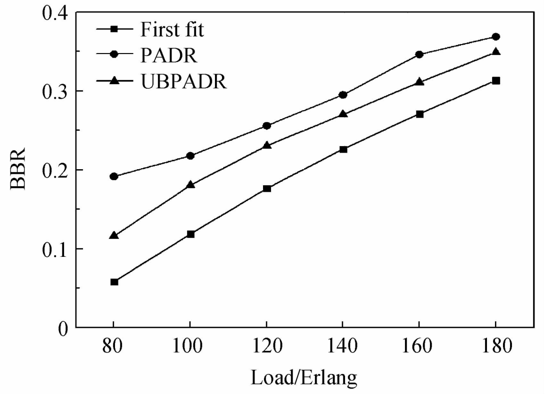

Fig. 2 BBR vs. traffic load under different schemes

In order to evaluate the influence on UBPADR scheme of different threshold value, i. e. , thr, we also conduct further simulations and the results are shown in Fig. 3 and Fig. 4. They clearly show that smaller threshold value means better service fairness performance but worse bandwidth blocking probability. This is because spectrum block transfer is triggered more frequently when threshold is smaller, which leaves the spectrum more fragmented and exhausted , thus increasing total bandwidth blocking probability while improving service fairness. As a consequence, comprehensive consideration should be taken into before selecting the threshold value.

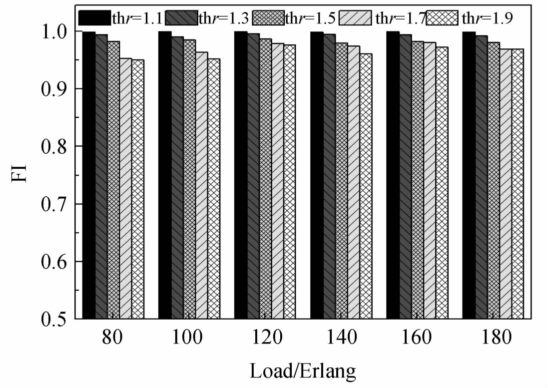

Fig. 3 FI vs. traffic load with different threshold value

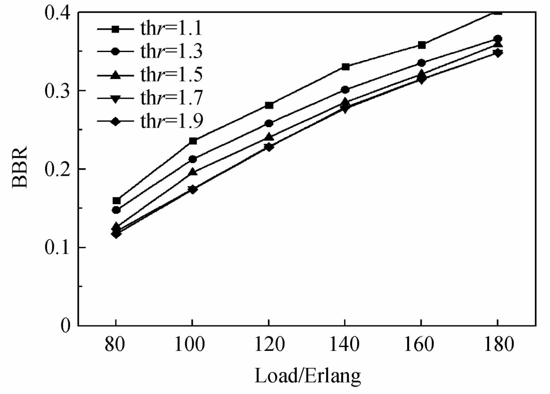

Fig. 4 BBR vs. traffic load with different threshold value

Also, it should be noted that the blocking performance deterioration can be further mitigated by combining with other schemes. As is given in Ref. [13], better blocking performance can be achieved while remains good service fairness when combined with partial shared first-fit scheme.

4 Conclusion

In this paper, we investigate the granularity oriented fairness issue in elastic optical networks under dynamic traffic load. Based on the introduced utility function and the PADR scheme we previously presented, we propose an improved fairness-aware dynamic spectrum allocation scheme, i. e. , UBPADR scheme. The fairness and blocking performance of UBPADR is compared with PADR and traditional Fist Fit via simulations. Results show that both PADR and UBPADR can improve service fairness remarkably compared with First Fit under each load, and UBPADR scheme can further mitigate the service fairness problem at much smaller cost of blocking performance deterioration compared with PADR. Moreover, smaller threshold value means better service fairness performance but worse bandwidth blocking probability.

References

[1] JINNO M, TAKARA H, KOZICKI B, *et al*. Spectrum-efficient and scalable elastic optical path network: architecture, benefits and enabling technologies[J]. *IEEE Communications Magazine*, 2009, **47**(11): 66-73.

[2] LIU Wu, YANG Qi. Carrier phase recovery without pilot subcarriers in coherent optical OFDM transmission systems [J]. *Acta Photonica Sinica*, 2011, **40**(12): 1893-1898.

[3] LI Y, FRANCISCO M J, LAMBADARIS I, *et al*. Traffic classification and service in wavelength routed all-optical networks [C]. IEEE International Conference on Communications. IEEE, 2003, 2: 1375-1380.

[4] PRAMOD S R, MOUFTAH H T. Traffic classification and fairness in wavelength routed optical networks [C]. International Conference on Parallel Processing Workshops, 2004: 422-426.

[5] MOSHARAF K, TALIM J, LAMBADARIS I. A call admission control for service differentiation and fairness management in WDM grooming networks[C]. the First International Conference on Broadband Networks, 2004: 162-169.

[6] MOSHARAF K, LAMBADARIS I, TALIM J. A call admission control for service differentiation and fairness management in WDM grooming networks [J]. *Optical Switching and Networking*, 2005, **2**(2): 113-126.

[7] THAIGARAN S, SOMANI A. Capacity fairness of WDM networks with grooming capabilities [J]. *SPIE Optical Networks Magazine*, 2001, **2**: 24-31.

[8] MUNOZ R, CASELLAS R, MARTINEZ R. Dynamic

distributed spectrum allocation in GMPLS controlled elastic optical networks[C]. European Conference and Exhibition on Optical Communication, 2011: Tu. 5. K. 4.

[9] JU Wei-guo, HUANG Shan-guo, XU Zhen-zhen, *et al*. Spectrum fusion oriented routing and spectrum allocation algorithm and spectrum defragmentation algorithm[J]. *Acta Photonica Sinica*, 2013, **42**(8): 929-935.

[10] ZHU Zu-qing, LU Wei, ZHANG Liang, *et al*. Dynamic service provisioning in elastic optical networks with hybrid single-/multi-path routing[J]. *IEEE Journal of Lightwave Technology*, 2013, **31**(1): 15-22.

[11] SAMBO N, CASTOLDI P, CUGINI F, *et al*. Toward high-rate and flexible optical networks[J]. *IEEE Communications Magazine*, 2012, **50**(5): 66-72.

[12] WANG Yang, CAO Xiao-jun, HU Qian, *et al*. Towards elastic and fine-granular bandwidth allocation in spectrum-sliced optical networks[J]. *IEEE Journal of Optical Communications and Networking*, 2012, **4**(11): 906-917.

[13] MA Song-wei, WANG Yan, GUO Bing-li, *et al*. A fairness-aware dynamic spectrum allocation scheme in elastic optical networks[C]. The OptoElectronics and Communication Conference, 2013: TuPQ-6.

[14] THIAGARAJAN S, SOMANI A K. Capacity fairness of WDM networks with grooming capabilities[J]. *Optical Network Magazine*, 2001, **2**(3): 24-32.

[15] POINTURIER Y, BRANDT-PEARCE M, DENG T, *et al*. Fair QoS-aware adaptive routing and wavelength assignment in all-optical networks[C]. IEEE International Conference on Communications, 2006, 6: 2433-2438.