Fragmentation-aware routing and spectrum allocation algorithm in mixed-grid optical networks

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***Abstract*—The flex-grid technology is recognized as a promising solution to improve flexibility and scalability in optical networks. A gradual migrating process from the conventional fixed-grid to flex-grid networks is considered as a practical upgrading strategy, during which period the mixed-grid networks will emerge having both kinds of fixed/flex-grid nodes coexisting. Owing to different spectrum allocation constraints, conventional algorithms on fragmentation problem amelioration suited for pure flex-grid networks may not be feasible. In this work, a new fragmentation metric is proposed to ameliorate the fragmentation effects in mixed-grid networks and applied in a fragmentation-aware routing and spectrum allocation algorithm for spectrum efficiency improvement. Simulation on a representative network shows the bandwidth blocking ratio is reduced compared to the first fit policy in specific network scenarios.**

Keywords—mixed-grid, optical networks, fragmentation

I. Introduction

With the expansion of deployed optical network scale and rapid growth of high-rate traffic services, conventional dense wavelength-division multiplexing (DWDM) optical backbone networks based on fixed-grid technology are faced with the challenges of large capacity and flexibility. Flex-grid optical networks [1] are recognized as a promising technology to overcome the drawbacks of conventional networks, providing finer spectrum granularity and adaptive bandwidth super-channel to meet various traffic capacity demands.

Researches based on pure flex-grid networks have made much progress, while the large-scale deployed networks bring challenges on updating cost and technical maturity. The impact of network operation disruption should also be minimized. One-time green-field deployment is not an economical and practical option. On applying gradual migration towards flex-grid networks, starting the upgrade from the bottleneck nodes bearing heavy traffic load, the mixed-grid networks having both fixed and flexible nodes included are formed [2].

Prior works are mainly focused on migration strategies [2, 3], and resource optimization problems like routing and spectrum allocation (RSA) [4-6], while little on the fragmentation problem [7]. The mixed-grid networks are also suffering from the spectrum efficiency decreasing fragmentation effects, led by spectrum fragments that fail to meet the network spectrum allocation constraints. New constraints in mixed-grid networks may lead to poor performance or infeasibility of the conventional approaches for pure flex-grid networks. Besides the spectrum continuity and contiguity constraints [8], the range of a super-channel on a mixed-grid path shouldn't exceed the fixed-grid wavelength boundary [2]. Therefore, new optimization strategies in accordance with the mixed-grid characteristics should be worked out and validated.

Considering special allocation constraints, a mixed-grid fragmentation metric is proposed with a new approach to the traffic-carrying capacity measurement of free spectrum segments. Combined with such metric a fragmentation-aware routing and spectrum allocation algorithm is to be applied for spectrum utilization improvement and validated in various network scenarios for performance evaluation.

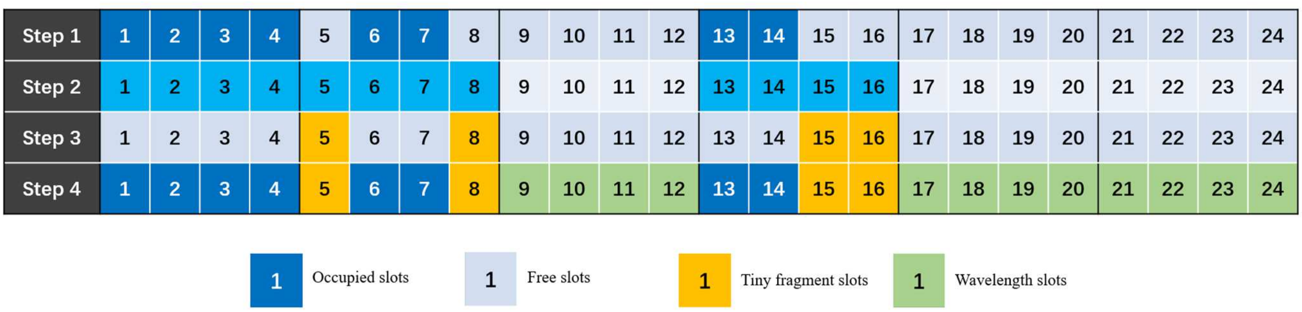
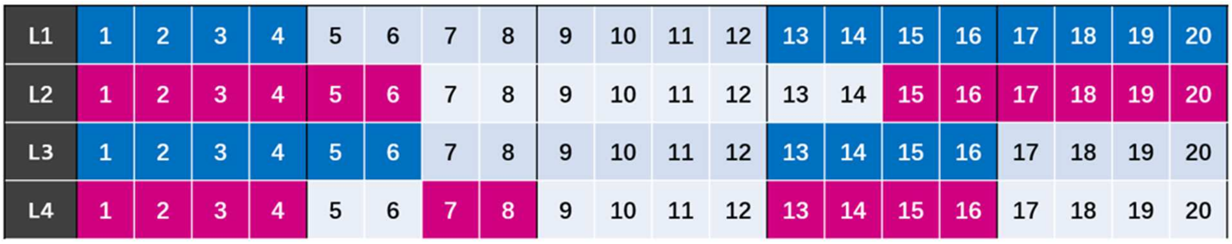


Fig. 1. Example of free segment repartition process.



$$F(L1) = \frac{12}{\sqrt{\frac{64}{1}}} = 1.5 \quad F(L2) = \frac{12}{\sqrt{\frac{4+16+4}{1}}} = 2.45 \quad F(L3) = \frac{10}{\sqrt{\frac{4+16+16}{2}}} = 2.36 \quad F(L4) = \frac{10}{\sqrt{\frac{4+16+16}{3}}} = 2.89$$

Fig. 2. Example of application of mixed-grid fragmentation metric.

II. Mixed-grid Fragmentation Metric

A. Regulated Free Spectrum Segments

Fragmentation metrics in flex-grid networks should take many factors into account like the size, the number of free spectrum segments, and super-channel granularity [9]. While in mixed-grid networks, the location of free segments is another factor having impact on their traffic-carrying capacity. Repartition of free segments on network links will gain a more accurate description of traffic-carrying capacity for further evaluation.

The free segments are divided along the wavelength boundary and sorted into two categories according to whether they can be composed into whole wavelengths. The segments that are not enough to cover a complete wavelength become tiny fragments. If the composed wavelengths are still adjacent to each other, they make up larger wavelength segments. Fig.1 shows the process of free segment repartition. A copy of the link spectrum profile is built while any occupied slot will mark the whole wavelength. Tiny fragments are got by bitwise-xor operation and the rest for wavelength segments.

B. Mixed-grid Fragmentation Metric

With the regulated free segments, the formula for the fragmentation metric and notation involved are given as follows:

$$\mathrm{F}(e) = \frac{S_m - \Sigma|a_{ei}|}{\sqrt{\frac{\Sigma|b_{ei}|^2}{|A_e|}}} \tag{1}$$

− $G(V, E)$: Network topology with V set of nodes and E set of links.

− $\mathrm{F}(e)$: The fragmentation metric of link e.

− S_m: Slots number on a link belonging to the network.

− A_e: Set of free segments on link e, where $a_{ei} \in A_e$.

− B_e: Set of regulated free segments on link e, where $b_{ei} \in B_e$.

This metric considers both traffic load intensity and fragmentation effects, reflecting the traffic-carrying capacity of the rest spectrum resources. A larger metric indicates fewer available resources and severer fragmentation effects. This metric cannot be calculated when $|A_e|$=0, while it only happens as all the spectrum slots are utilized and no resources would be available at this point.

Wavelength boundary aligning allocation and fewer fragments are encouraged by such metric. Fig. 2 shows examples of the metric application on independent 20-slot links. L1 and L2 both have a free segment of width 8 in the center, whose traffic-carrying capacity are approximately the same in flex-grid networks. While with a more regular segment, L1 can provide more spectrum slots when faced with fixed-grid services and gets a better grade than L2. Compared with L4, L3 has the same available slots of 10 but less fragments than L4 and is more potential to provide resources for flex-grid services.

III. Mixed-grid Fragmentation-aware RSA Algorithm

This work applies the proposed metric in fragmentation-aware routing and spectrum allocation algorithm for spectrum efficiency improvement. Fixed alternate routing is applied for routing and path-based fragmentation metric policy [10] for spectrum allocation, which approach applies the metric computing to the path spectrum profile constructed by links of each hop, having the advantage of paying more attentions on links with the heaviest traffic at low time complexity. The optimal allocation position on each alternative path having the lowest metric is preliminarily found, among which the final selected the allocation position along with the path is decided.

Algorithm 1. Mixed-grid fragmentation-aware RSA algorithm (MFA)

Input: Topology *G*(*V*,*E*), Service *s*(*src*, *dest*, *slotWidth*), *PathList*(*G, src, dest*) list of *K*-shortest paths

```
MinMetric ← Infinity
MinFragSeg ← null
for path in PathList do
    seg, fragMetric ← call Algorithm 2 (path, s)
    if seg /= null AND fragMetric < MinMetric then
        MinMetric ← fragMetric
        MinFragSeg ← seg
    end if
end for
if MinFragSeg = null
    service s gets blocked
end if
```

Output: the selected segment for service *s* allocation

Algorithm 2. Segment selection on single path

```
Input: Path p(G, src, dest), Service s(src, dest, slotWidth)
MinMetric ← Infinity
BestSegment ← null
Compute the path spectrum profile by bitwise-OR operation on links of each hop
for each valid segment in the path profile
    allocate the segment temporarily
    if F(path) < MinMetric then
        MinMetric ← F(path)
        BestSegment ← segment
    end if
end for
return BestSegment, MinMetric
```

IV. Simulation Results

The evaluation simulation is executed on NSFNET topology (shown in Fig. 3) which is modeled as an undirected graph. Each link in the network has a 4.4THz spectral capacity and provides 352 spectrum slots. Ten thousand dynamic services following Poisson distribution with the arrival rate of λ are generated on the given network with random sources and destinations. The duration of a service follows a negative exponential distribution with the rate of $1/\mu$. The relationship between traffic demand capacity and occupied spectrum resources is listed in Table 1 [2]. The traffic demanded capacity of a service follows the distribution series in Table 2.

Yen's algorithm is applied to compute 5 alternate routes for each service. The strategy of spectrum allocation applies the proposed algorithm and the first fit policy (FF) as a performance comparison. FF prefers to select the segments that have the lowest index. The performance is evaluated by bandwidth blocking ratio (BBR), the ratio of blocked bandwidth summation to the total bandwidth summation.

As the deployment of flex-grid nodes may have great impact on the algorithm performance. In the first scenario, 7 flex-grid nodes are deployed at east and west areas forming two flex-grid islands. In Fig. 4, for traffic profile 1 applying MFA, as the traffic load exceeded 189 Erlang, services gradually get blocked and BBR is growing exponentially due to insufficient spectrum resources. Compared with FF, MFA has achieved significant effects on blocking ratio decrease (about 56.1% at 210 Erlang, 57.4% at 215 Erlang). Profile 2 and 3 have similar tendency compared with profile 1 but faster increasement of BBR owing to heavier traffic. As reaching 1% BBR, all the three profiles have received a BBR drop of about 26%.

Another scenario introduces new flex-grid nodes deployed at node 10 and 11 as a simulation of gradual network updating. In Fig. 5, the tendency of BBR curves is similar to the previous scenario while the traffic load point of the first service get blocked has been advanced as applying MFA. The BBR reduction brought by MFA is not as significant as the before (range from 170 to 210 Erlang for profile 1).

Such decrease on algorithm performance may be led by the reduction of fixed-grid node number. MFA prefer to leave more available wavelengths for those services originating from fixed-grid nodes. However, as the network deployment progresses, the fewer remaining fixed-grid nodes may degrade the optimization performance. Even so, MFA can still play a Spectrum Occupation for Various Capacity significant role in

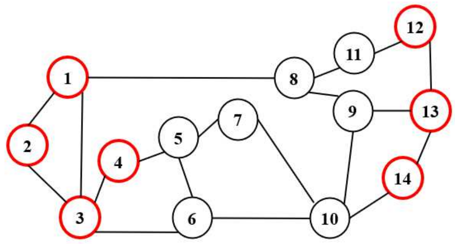


Fig. 3. 7 flex-grid node NSFNET topology

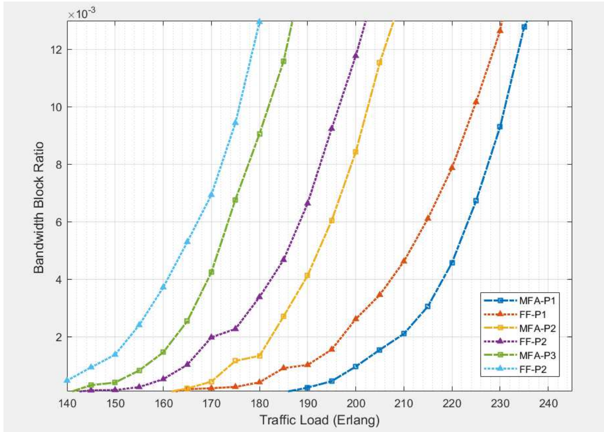


Fig. 4. BBR curves of 7 flex-grid nodes topology.

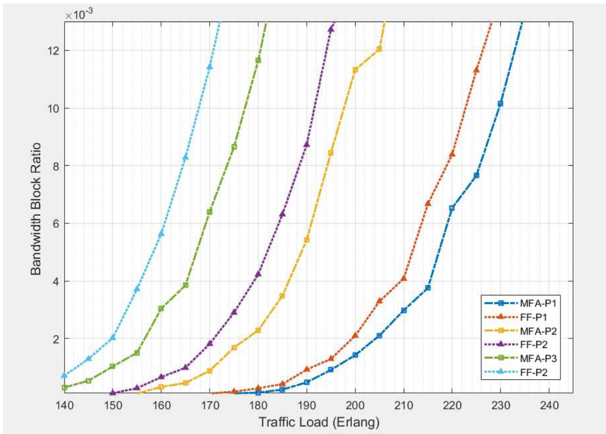


Fig. 5. BBR curves of 9 flex-grid nodes topology.

TABLE I. Spectrum Occupation for Various Capacity

Traffic Capacity	Spectrum Occupation			
	Fixed-Grid		*Flex-gird*	
	Bandwidth	***#Wavelengths***	***Bandwidth***	***#Slots***
40Gbps	50GHz	1	25GHz	2
100Gbps	50GHz	1	37.5GHz	3
200Gbps	100GHz	2	75GHz	6
400Gbps	200GHz	4	125GHz	10

TABLE II. Traffic Profiles

Traffic Capacity	Traffic Profies		
	Profile 1	***Profile 2***	***Profile 3***
40Gbps	40%	35%	20%
100Gbps	35%	35%	40%
200Gbps	10%	15%	20%
400Gbps	10%	15%	20%

spectrum utilization improvement of specific network scenarios as the simulation results showing.

V. Conclusion

A fragmentation metric dedicated for mixed-grid optical networks is proposed and applied in a fragmentation-aware RSA algorithm. Through simulation on NSFNET network with different flex-grid node deployments, it is proven to be effective in reducing blocking ratio and improving spectrum utilization in specific network scenarios.

Acknowledgment

This work was supported by grant from the Natural Science Foundation of NingXia, China (No. 2022AAC03618), and project of State Grid Ningxia Electric Power Co., LTD (SGNXDK00WLJS 2200163).

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