An Efficient Spectrum Assignment Algorithm Based On Variable-grouping Mechanism For Flex-grid Optical Networks

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Motivation

- EONs employ dynamic RSA algorithms to support diverse services with **heterogeneous bit-rates**.
- Induces **spectrum fragments** when allocating spectrum to accommodate different service requests.
- Spectrum fragments may exhaust the available spectrum resources and degrade networking performances.
- Traffic disruption or extra components via resource **reoptimization**. Some grouping RSA algorithms pre-divides fixed spectrum groups.
- This study proposes a RSA algorithm based on variable-grouping mechanism, namely **Minimized Variable Grouping (MVG)** RSA algorithm, which efficiently restrain the generation of **spectrum fragments**, also improve the **blocking performance**.

Key Contributions

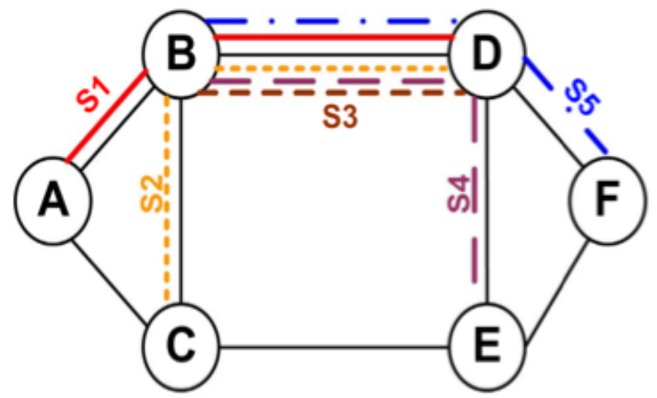
- The proposed algorithm sorts services according to their **bandwidth requirements** and then divides the spectrum resources into several variable groups according to the kinds of services.
- **Reduced Fragments:** The generation of the spectrum fragments is restricted in the spectrum intervals between two adjacent groups.
- **Reduced Blocking Probability**: The proposed algorithm can reduce the blocking probability by **minimizing the grouped spectrum resources** to maximize the remained vacant spectrum resources in the spectrum intervals between two adjacent groups for future service requests which helps improve the blocking performance.

Goodness of MVG RSA

1. Adopt **variable grouping** mechanism by specifying only the allocation starting FSs (Frequency slots) for each spectrum group and allowing the vacant FSs between two groups to be merged into either of the two groups if necessary. The variable grouping mechanism guarantees the flexibility in spectrum assignment.
2. Since the spectrum resources inside each spectrum group can always be reused by the services of the same kind, the generation of the spectrum fragments is restricted in the spectrum intervals between two groups.
3. MVG algorithm can reduce the blocking probability by **minimizing the grouped spectrum resources** so as to maximize the vacant spectrum resources in the spectrum intervals between two adjacent groups.

Variable grouping mechanism

- 1st service: 2 FSs
- 2nd service: 3 FSs
- Total 12 FSs on each link
- S(s, d, br) is employed to represent a service requests
- 6 Scenarios and 5 different service requests
- Since the link B-D is the only common link required by the five services, thus we focus the spectrum utilization illustration on link B-D.



(a)

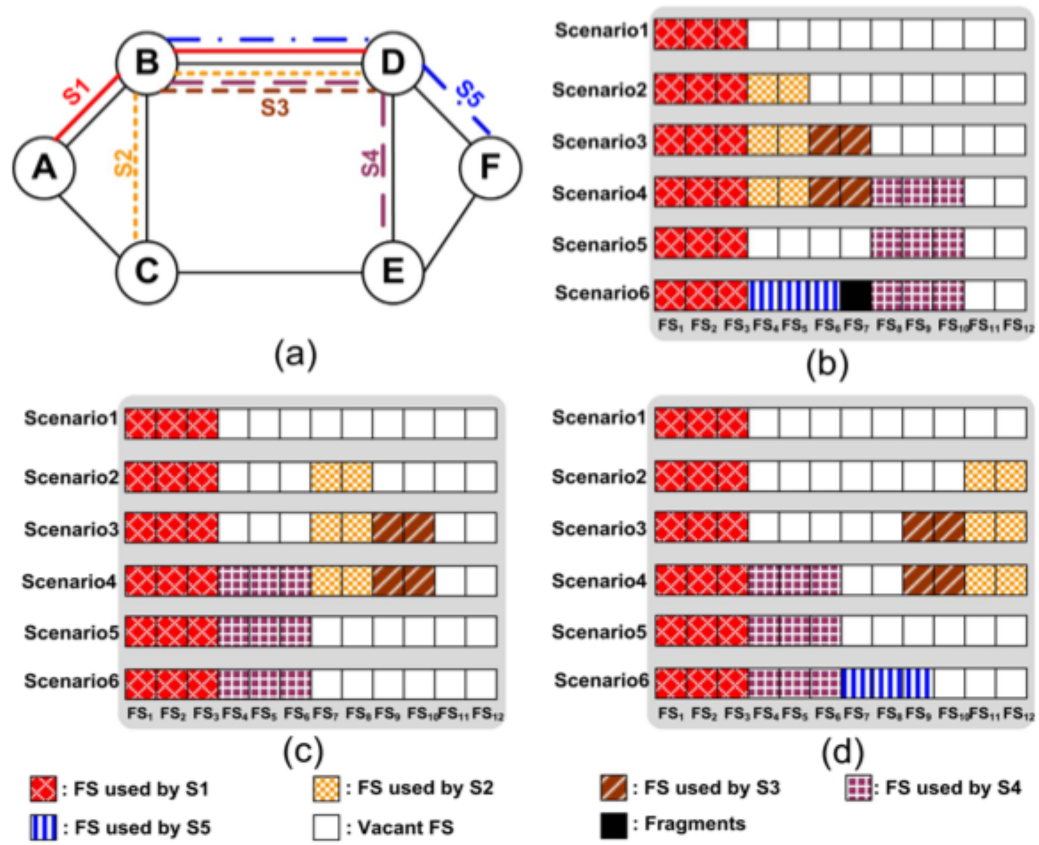


Fig. 1. An illustrative example for spectrum allocation employing different spectrum assignment algorithms in a 6-node network. (a) The network architecture and its accommodated service requests, (b) The spectrum allocation on link B-D in different scenarios when ungrouped spectrum assignment algorithm is adopted, (c) The spectrum allocation on link B-D in different scenarios when grouping spectrum assignment algorithm is adopted, (d) The spectrum allocation on link B-D in different scenarios when variable-group-based spectrum assignment algorithm is adopted..

Variable grouping mechanism

- The ungrouped algorithm always tries to assign the contiguous available FSs to services in a first-fit manner.
- In the grouping spectrum assignment algorithm, the twelve FSs are predivided into 2 constant groups: group#1 containing FS1-FS6 to accommodate the services requiring 3 FSs and group#2 containing FS7-FS12 to accommodate the services requiring 2 FSs.
- The variable-group-based algorithm divides the 12 FSs into 2 variable groups (e.g. FS1 being the allocation starting FS for the services requiring 3 FSs and FS12 being the allocation starting FS for the services requiring 2 FSs).

Minimized variable grouping RSA algorithm

- MVG RSA algorithm aims to minimize the grouped spectrum resources (both occupied FSs and the released or remained vacant FSs) in each variable group, and maximize the number of **available FSs** in the spectrum intervals between adjacent groups
- Group Size (GS), is defined to record the group size of a variable spectrum group on a selected routing path

$$GS_{gp} = \underset{e \in p}{Max}\left(\sum_{i \in F} (OF_{ie} + RF_{ie})\right)$$

GSgp represents the group size of variable group g on the selected routing path p
Max(·) is a function to return the maximum value
F represents the set of FSs on an edge in the network
OFie is a Boolean variable that equals 1 if FS #i on the edge *e* is occupied
RFie is a Boolean variable that equals 1 if FS #i on the edge *e* is a released or remained vacant FS inside the variable group

Minimized variable grouping RSA algorithm

- Released or remained vacant FSs at the border of a variable group should not be counted into *RFie*, since these FSs at the group borders are always merged into spectrum intervals between groups as vacant resources.
- By employing the index GS, we can always minimize the spectrum resources in variable groups via choosing the routing and spectrum allocation strategy which has the minimum GS.

MVG RSA Algorithm.

Algorithm 1
MVG RSA Algorithm.

1: Pre-compute K shortest paths for each s-d node pair
2: Sort the services into different kinds according to their bandwidth requirements and then divide the spectrum resources into several variable groups accordingly by specifying the allocation starting FS for each kind of service requests
3: while network is running do
4: When a request $S(s, d, b_r,)$ arrives, make an empty routing and spectrum assignment solution set L, and load the pre-computed paths set P for node pair s-d5: Then determine the variable group g and the allocation starting FS f_s for S
6: **for** each path p in P**do**
7: Find the nearest FS f_d from f_s that occupied by the other kind of services on all the edges along path p, and construct the slot set F_s from f_s to f_d
8: **for** each b_r FSs from f in the slot set F_s along p**do**
9: Check the availability of the b_r FSs
10: **if** all the b_r FSs from f are available **then**
11: Calculate the *group size* GS_{gp} of g on path p assuming the found b_r FSs from f on p are assigned to S 12: Add p, f and *group size* GS_{gp} to L as a possible solution l
13: **end if**
14: **end for**
15: **end for**
16: Check the solution set L
17: **If**L is non-empty **then**
18: Found the solution with the minimum *group size* GS_{gp} in L19: **If** there are multiple solutions with the same minimum *group size* GS_{gp}**then**20: Select the path and assignment the spectrum to S according to the first-found solution 21: **else**
22: Select the path and assignment the spectrum to S according to the found solution
23: Update the network and the variable group g
24: **else**
25: Block the request r
26: **end if**
27: **end while**

Simulation Setup

- Four typical kinds of service requests accommodated by the network, namely 40-Gb/s, 100-Gb/s, 400-Gb/s and 1 Tb/s
- 40-Gb/s and 100-Gb/s service requests, QPSK, 50 GHz, 4 FSs
- 400-Gb/s and 1 Tb/s service requests, 16-QAM and 32-QAM, 85-GHz & 150-GHz, 7 FSs & 12 FSs
- Service requests is set as 1:1:1:1
- 3 Groups
- Poisson traffic model with parameter λ and their respective duration satisfies negative exponential distribution with parameter μ.

Performance evaluation

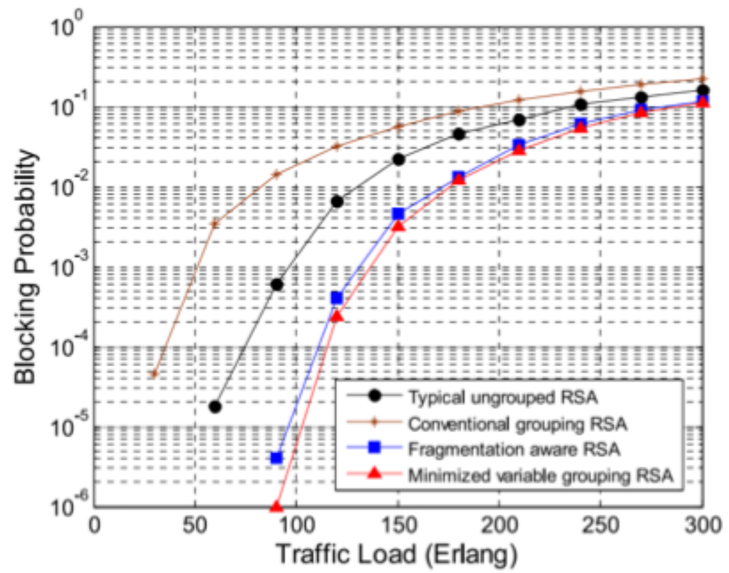


Fig. 4. Blocking probability vs. traffic load (NSFNET).

1. MVG RSA algorithm has lower blocking probability than typical ungrouped first-fit RSA algorithm, the conventional grouping RSA algorithm, and the fragmentation-aware RSA algorithm
2. Blocking performance differences between the proposed algorithm and the other algorithms decrease with the increase of traffic load, which implies the proposed algorithm can increase the blocking performance especially with a lower traffic load.

Performance evaluation

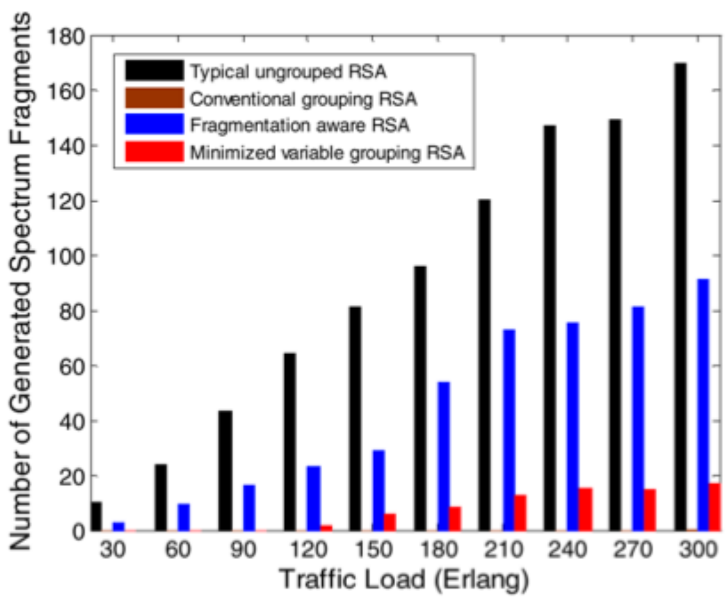


Fig. 5. Generated spectrum fragments vs. traffic load (NSFNET).

1. Proposed MVG RSA algorithm can reduce the number of spectrum fragments by about 87% compared with the typical ungrouped RSA algorithm, while the fragmentation-aware RSA algorithm can only reduce the number of spectrum fragments by about 45% compared to the typical ungrouped RSA algorithm

Performance evaluation

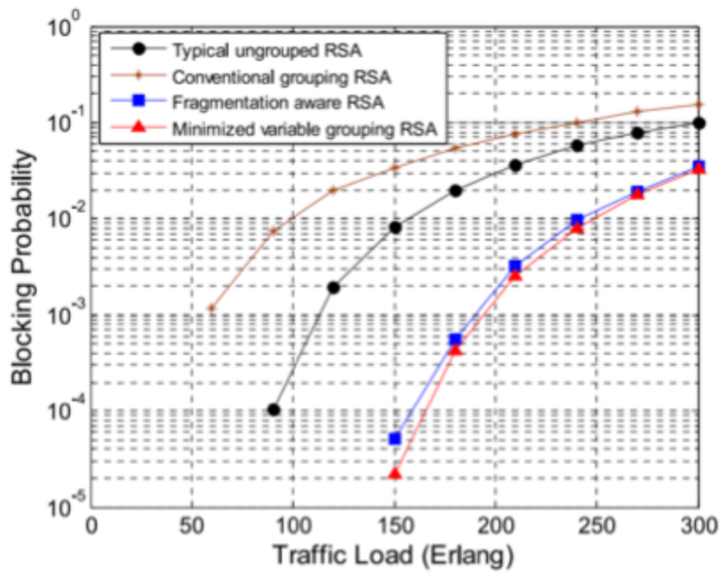


Fig. 6. Blocking probability vs. traffic load (USNET).

1. Blocking performances of the four RSA algorithms have all increased compared to those in Fig. 4, which may be mainly due to the larger network scale and more spectrum resources in the network.
2. When the traffic load is less than 120 Erlang, the proposed MVG RSA algorithm successfully reduces the blocking probability to zero. Although these performance differences decrease with the increase of traffic load, the proposed algorithm still has about 67%,78%, and 6% improvements in blocking performance compared with the typical ungrouped, the conventional grouping and the fragmentation-aware RSA algorithms, respectively, when the traffic load reaches as high as 300 Erlang.

Performance evaluation

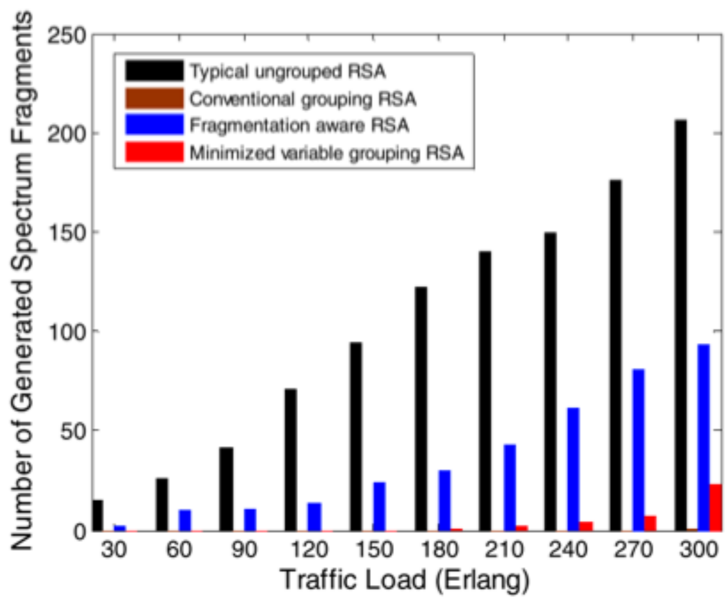


Fig. 7. Generated spectrum fragments vs. traffic load (USNET).

1. The proposed algorithm can successfully reduce the number of spectrum fragments to zero when the traffic load is less than 150 Erlang. For high traffic load (e.g.300 Erlang), the proposed MVG RSA algorithm can reduce the number of spectrum fragments by about 89% compared with the typical ungrouped RSA algorithm, while the fragmentation-aware RSA algorithm can only reduce the number of spectrum fragments by about 54%.

Conclusion

- Authors have proposed a variable-group-based RSA algorithm, MVG RSA algorithm, to reduce the generation of spectrum fragments as well as the blocking probability.
- Variable grouping mechanism, which helps restricting the generation of the spectrum fragments in the spectrum intervals between the groups.
- Additionally, by minimizing the grouped spectrum resources and maximizing the remained vacant spectrum resources in the spectrum intervals between two adjacent groups for future service requests, MVG RSA algorithm can remarkably reduce the blocking probability.