# Route Partitioning Scheme for Elastic Optical Networks With Hitless Defragmentation[1]

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[1] S. Ba, B. Chatterjee, S. Okamoto, N. Yamanaka, A. Fumagalli, and E. Oki, “Route Partitioning Scheme for Elastic Optical Networks With Hitless Defragmentation,” *IEEE/OSA Journal of Optical Communications and Networking*, vol. 8, no.6, pp. 356-370, Jun. 2016.

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# Outline

1. Background
2. Spectrum Defragmentation
3. Route partitioning(RP) scheme
4. Performance evaluation
5. Conclusions

# Background

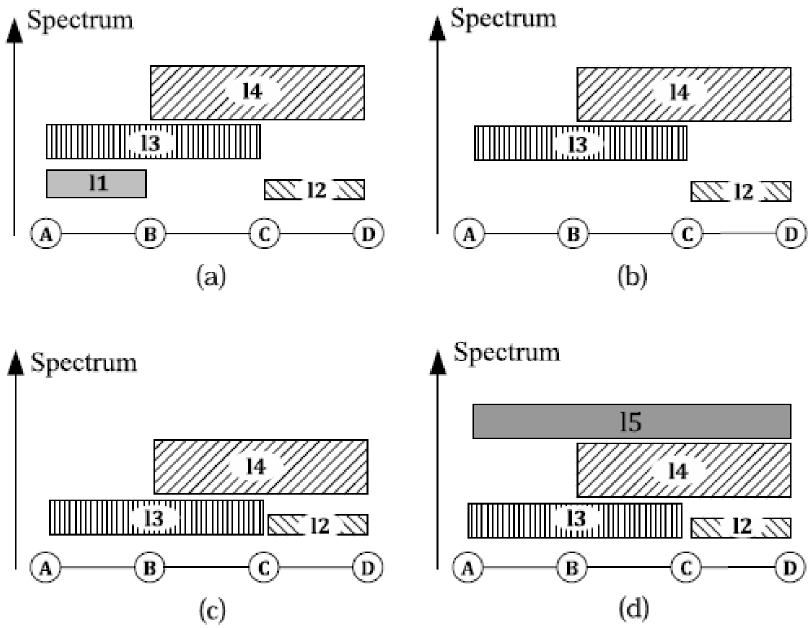
- The traffic volume in communication networks witness continuous growth due to the increasing number of connection demands and higher capacity requirements
- Due to its flexibility, the elastic optical network (EON) offers an efficient use of the network spectrum resources for the future network
- The routing and spectrum allocation (RSA) problem is one of the key functionalities in EONs
- The resources previously utilized by terminated connections need to be reallocated to new requests
- As the requests are of varying sizes, the operation leads to small-sized spectrum slot blocks and to dispersed slot blocks that are not available through contiguous links, which is refer to as *spectrum fragmentation*
- To overcome the issue of spectrum fragmentation in EONs, serval *defragmentation* approaches have been presented.

# Spectrum defragmentation

- Non-hitless defragmentation scheme
  - Advantage: most of them can be deployed without additional equipment
  - Disadvantage: lead to traffic disruptions
- Hitless defragmentation scheme
  - Works contiguously without service disruption
  - Advocate retuning the spectrum of the already established lightpaths after a connection is terminated to fill in the gap left behind
  - Two Retuning approaches
    - Hop retuning
    - Push-pull retuning

# Spectrum defragmentation

- Example
  - The horizontal axis indicates the routing paths
  - The vertical axis indicates the spectrum
  - $l1$ (200 Gbps between A–B),
  - $l2$ (100 Gbps between C–D),
  - $l3$ (100 Gbps between A–C),
  - $l4$ (400 Gbps between B–D)
  - $l5$ (200 Gbps between A–D).
  - 1. signals $l1$ to $l4$ are active
  - 2. $l1$ is terminated
  - 3. Hitless defragmentation is applied to move down $l3$ and $l4$
  - 4. $l5$ is added



# Spectrum defragmentation

- Hop retuning
  - Allow the retuning of a lightpath to any available spectrum slot regardless of whether it is contiguous or not
  - Use fast tunable lasers at the transmitter and burst-mode coherent receivers with fast wavelength tracking at the receiver.
  - The fast auto-tracking technique involves an athermal arrayed waveguide grating (AWG) with a detector array sensing a change in the transmission wavelength
  - Hop-retuning technology is not easy to deploy in the case of a fine granular grid
    - With each fast-tuning laser/coherent receiver couple covering only the range of a spectrum slot, the number of photodetectors needed is equal to the number of spectrum slots
    - In a 12.5 GHz grid, a 400 port AWG and 400 photodetectors are required; this increases the system complexity

# Spectrum defragmentation

- Push–Pull retuning
  - A push and pull approach is used for all spectrum grid ranges.
  - A dynamic and flexible network node architecture using modulation flexible universal transceivers.
  - The retuning is executed gradually, and the spectrum change cannot be jumped.
  - It is performed by all involved devices in a coordinated manner under a distributed control environment or a centralized network controller.
  - This process is executed without rerouting and therefore does not require any traffic interruption

# Spectrum defragmentation

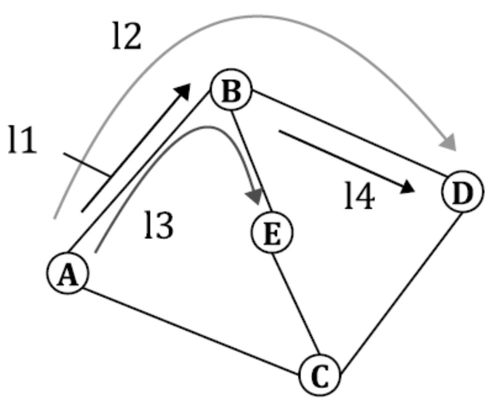
- Summaries of different defragment approaches
  - Hop retuning is difficult to deploy for a fine granular spectrum
  - push–pull retuning is used for all spectrum granularity and offers significant request blocking reduction
  - In this paper, they consider a proactive hitless defragmentation scheme using push–pull retuning to offer a defragmentation of the spectrum

TABLE I
SUMMARIES OF DIFFERENT DEFRAGMENTATION APPROACHES

| Approaches | | Non-hitless Defragmentation | | Hitless Defragmentation | |
|---|---|---|---|---|---|
| | | Alignment | Consecutiveness | Hop Retuning | Push–Pull Retuning |
| Proactive | Rerouting | M. Zang [8]<br>M. Zang [9] | | | |
| | No rerouting | | R. Wang [18] | R. Proietti [12]<br>M. Zhang [14] | M. Sekiya [10]<br>Y. Aoki [13]<br>X. Wang [23]<br>R. Wang [15] |
| Reactive | Rerouting | W. Shi [7], Y. Yin [16]<br>X. Chen [21], W. Fadini [19]<br>M. Zang [9] | | M. Zang [9] | |
| | No rerouting | | | | R. Wang [15] |

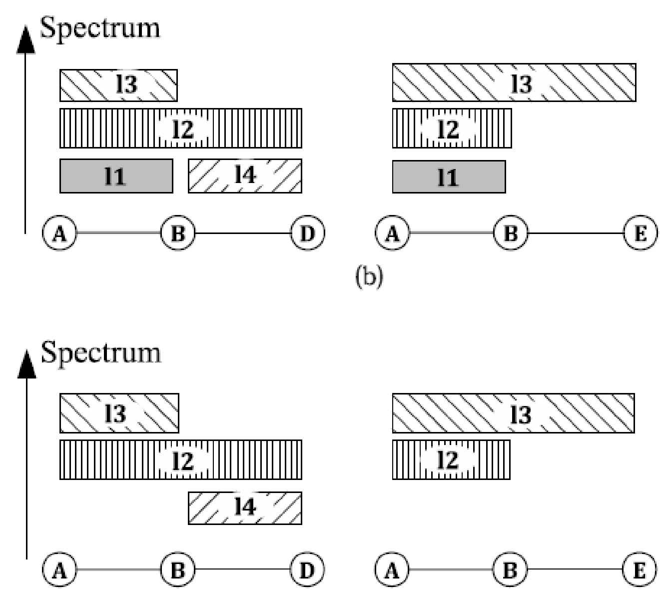
# Spectrum defragmentation

- End-of-line in hitless defragmentation
  - A lightpath cannot be retuned to fill in a gap left by an expired connection due to the interference of another lightpath preventing it from being moved further
  - When an end-of-line situation occurs, the retuning of a lightpath, if started, is stopped




(a)

Can not jump




(b)

(c)

# Route partitioning(RP) scheme

- Retuning time
  - The speed at which the retuning is executed impacts the performance of hitless defragmentation
  - The time needed to retune a lightpath from an initial wavelength to a new wavelength is considered as a combination of two limitation factors
    - Physical, as the speed limit at which the equipment can perform the retuning ($\alpha$)
    - Operational, for operations such as synchronization ($\beta$)

$$t_{\text{ret}} = \alpha \times s + \beta$$

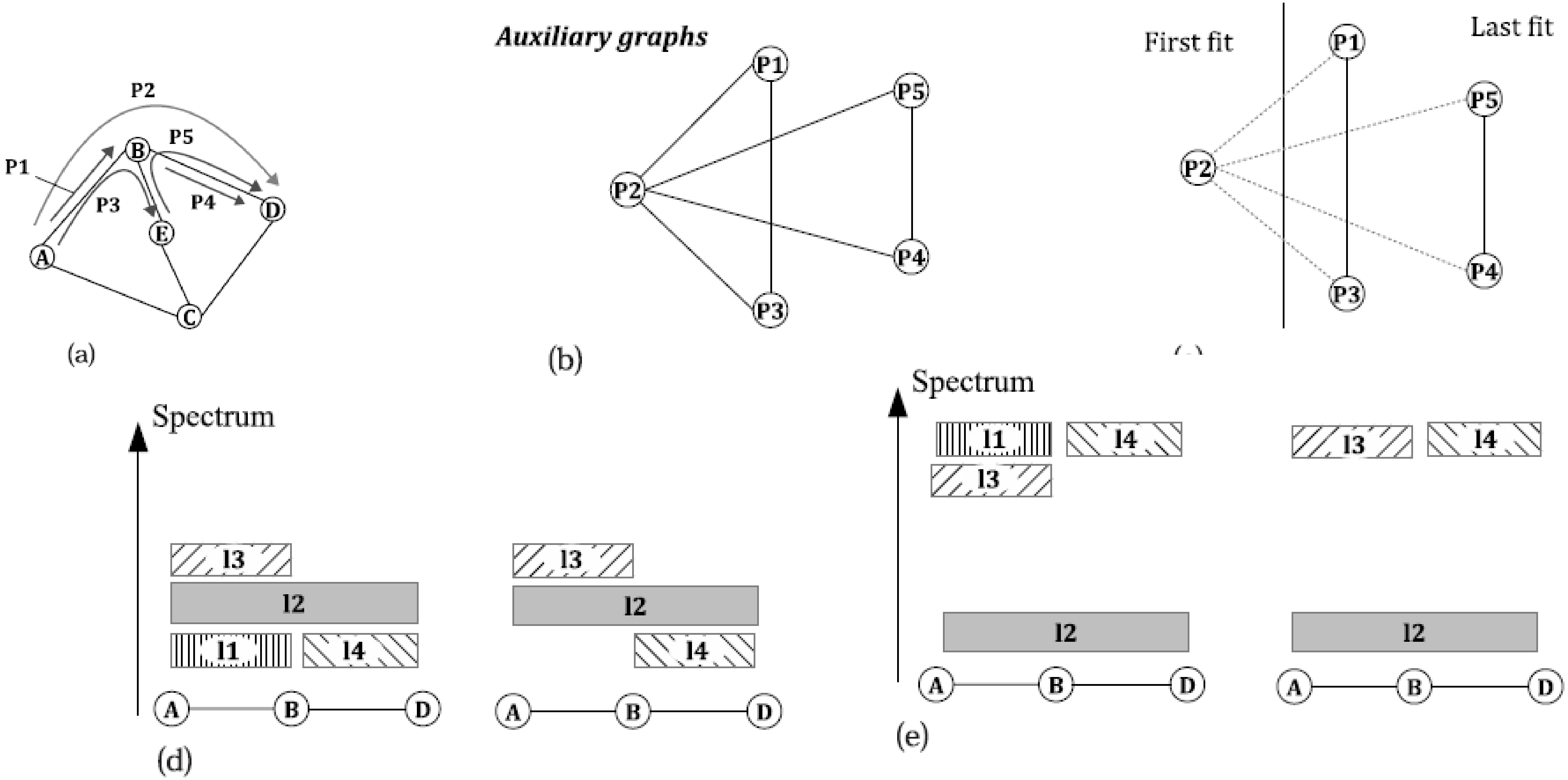
    - S is the distance between the spectrum index of the initial wavelength and the spectrum index of the new wavelength
- First-last fit allocation policy
  - Reduces the retuning distances due to the reduced number of lightpaths that need to be retuned in one direction or the other

# Route partitioning(RP) scheme

- Route partitioning (RP)
  - Use *an auxiliary graph* where the routing paths are considered as nodes and the routes that share a link are connected by an edge
  - The partitions are set by seeking *a cut* to take advantage of the separation offered by the first-last fit allocation
  - The cut is defined by the set of edges that have their two edge endpoints in different sets
  - lightpaths with a routing path in one partition set are allocated using first fit and the other lightpaths using the last-fit allocation

# Route partitioning(RP) scheme

- Route Partitioning (RP)



# ILP model

- Equations

Minimize the total interference among nodes sharing partitions

$$\min \sum_{1\le p<q\le |P|} w_{pq} \times k_{pq}, \quad (3a)$$

the traffic flow constraint

$$\text{Subject to } \sum_{j\in V:(i,j)\in E} x_{ij}^p - \sum_{j\in V:(j,i)\in E} x_{ji}^p = 1 \quad \forall\, p=(s,d)\in P, i\in V, i=s, \quad (3b)$$

$$\sum_{j\in V:(i,j)\in E} x_{ij}^p - \sum_{j\in V:(j,i)\in E} x_{ji}^p = 0 \quad \forall\, p=(s,d)\in P, i\in V, i\ne s,d, \quad (3c)$$

triangle inequalities

$$d_{pq}+d_{pk}+d_{qk}\le 2 \quad \forall\, 1\le p<q<k\le |P|, \quad (3d)$$

$$d_{pq}-d_{pk}-d_{qk}\le 0 \quad \forall\, 1\le p<q\le |P|, k\ne p,q, \quad (3e)$$

$$x_{ij}^p + x_{ij}^q - 1 \le y_{pq} \quad \forall\, (i,j)\in E, p,q\in P, \quad (3f)$$

defines the auxiliary graph from the routing paths

$$k_{pq}\le y_{pq} \quad \forall\, p,q\in P, \quad (3g)$$

$$k_{pq}\le 1-d_{pq} \quad \forall\, p,q\in P, \quad (3h)$$

$$k_{pq}\ge y_{pq}-d_{pq} \quad \forall\, p,q\in P, \quad (3i)$$

$$x_{ij}^p=\{0,1\} \quad \forall\, (i,j)\in E, p\in P, \quad (3j)$$

define the remaining edges after the cut

$$y_{pq}, d_{pq}, k_{pq}=\{0,1\} \quad \forall\, p,q\in P. \quad (3k)$$

TABLE II
LIST OF NOTATIONS

| | |
|---|---|
| $G(V,E)$: | Directed graph, where $V$ is a set of nodes and $E$ is a set of links. |
| $P$: | Set of routes, $p\in P$. |
| $w_{pq}$: | Edge cost on auxiliary graph. |
| $y_{pq}$: | Binary variable, 1 if routes $p$ and $q$ share at least a link, and 0 otherwise. |
| $d_{pq}$: | Binary variable, 1 if routes $p$ and $q$ are on different sides of the cut, and 0 otherwise. |
| $x_{ij}^p$: | Binary variable, 1 if route $p$ uses link $(i,j)$, and 0 otherwise. |
| $k_{pq}$: | Binary variable, 1 if routes $p$ and $q$ share a link and are on the same side of the cut, and 0 otherwise. |

# Heuristic algorithm

- Step1
  - Determine all the routing paths by using load-balanced routing in order to minimize the number of routes sharing the same link
  - Formulate the load balanced routing as an ILP model
  - For the large considered network
    - All the source/destination pairs are randomly sorted and routed through the first found minimum-hop path
    - For each pair considered, an alternative minimum-hop path substitutes the one previously assigned if and only if the number of channels (congestion) of the most loaded link in the alternative path is lower than the congestion of the most loaded link in the previously assigned path. This process is repeated for all node pairs.
    - Repeat step ii until no more substitution is possible.

# Heuristic algorithm

- Step2
  - Draw an auxiliary graph from the defined routing paths
  - A node of the auxiliary graph expresses a route
  - An edge of the auxiliary graph expresses that the two nodes connected by it [redacted]

**Algorithm 1.** LBR-MC Heuristic Algorithm

**Input**: Network, set of routes
**Output**: Routing and partitions

1. **Step 1**: Determine routing paths with LBR
2. **Step 2**: Draw auxiliary graph from routes
3. **Step 3**: Define partitions
4.     **3.1**: Find maximum cut
5.     **3.2**: Set partition for maximum cut

[redacted]

S. Sahni and T. Gonzalez, “P-complete approximation problems,” J. Assoc. Comput. Mach., vol. 23, no. 3, pp. 555–565, 1976.



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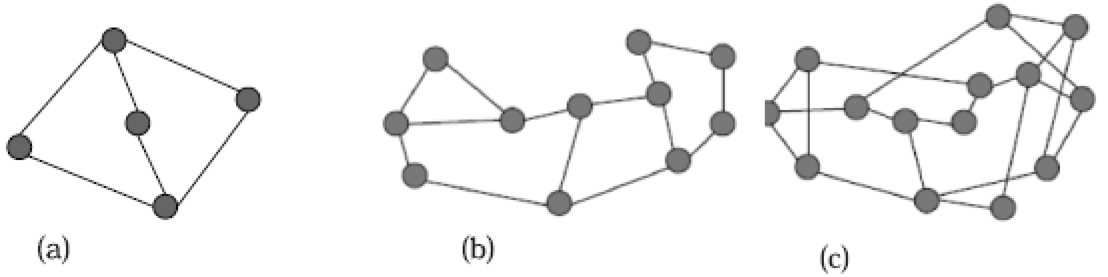
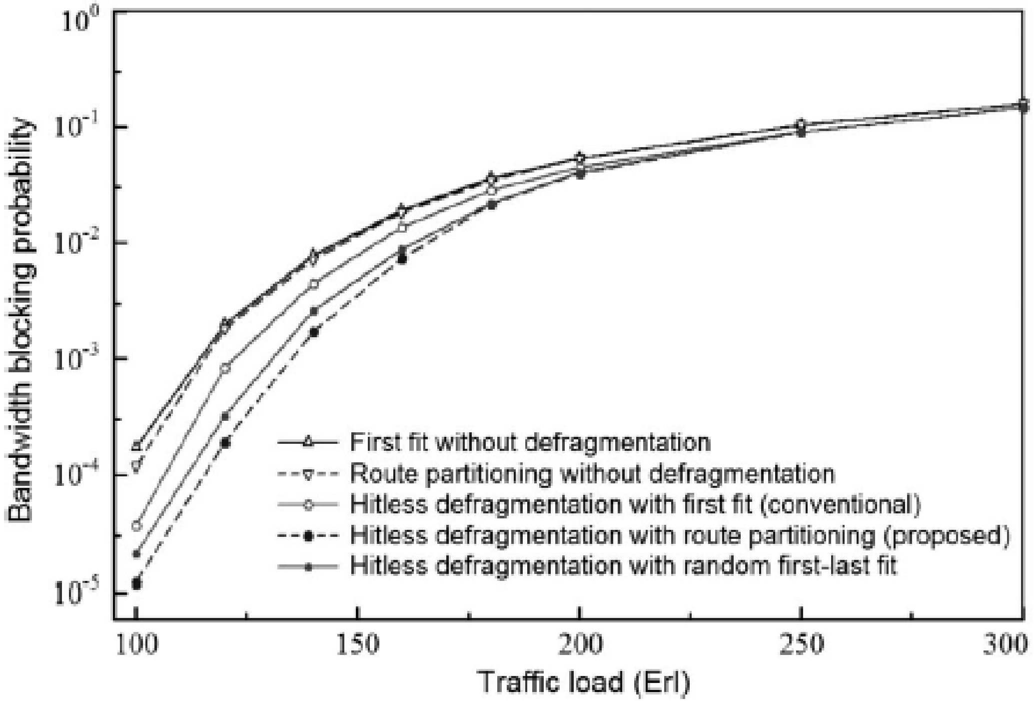
# Performance evaluation

- Simulation conditions
  - The channel spacing : 12.5 GHz, Slot number: 400
  - The connection requests are generated randomly based on a Poisson distribution process ($\lambda$)
  - The holding time of connection requests follows an exponential distribution ($H = 1 / \mu$)
  - The number of requested lightpaths is uniformly distributed from 1 to 16
  - Run the simulation for 200 different seeds, with each of which 10,000 lightpath connection requests are generated
  - The interval of confidence of the reported results is 95%
  - Test networks:



# Performance evaluation

- Bandwidth blocking probabilities




network 1 (ILP )
an α set to 0.05 ms

- **It shows that the proposed scheme reduces considerably the bandwidth blocking probability and that it outperforms the conventional push–pull retuning**

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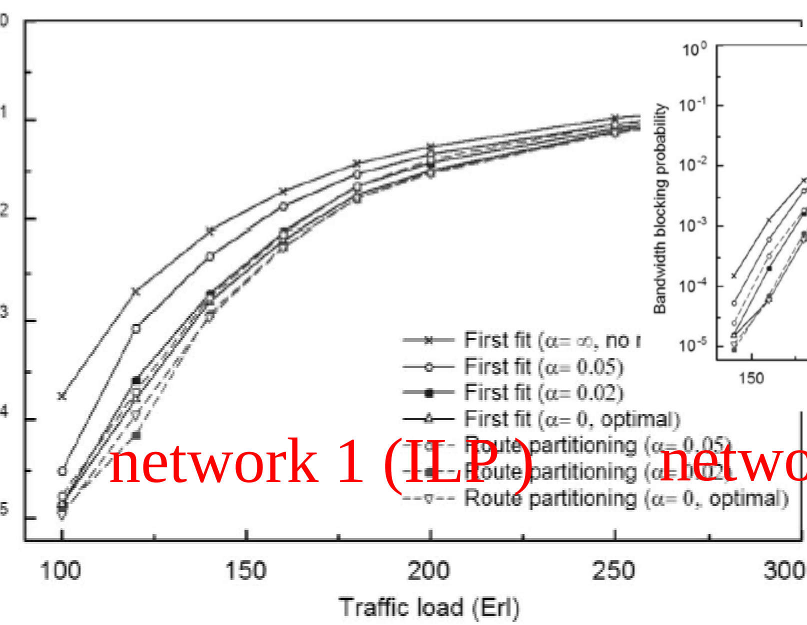
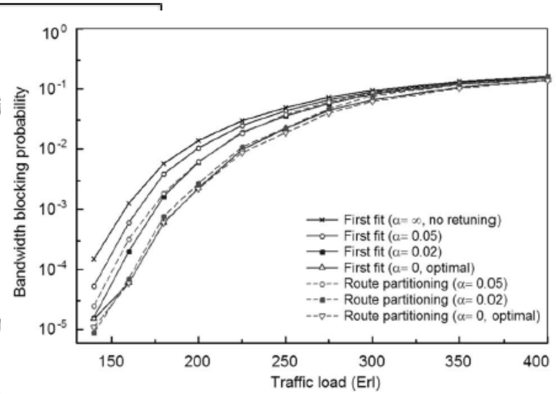
# Performance evaluation

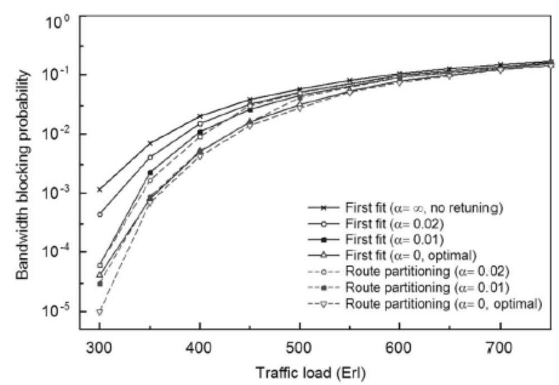
- Bandwidth blocking probabilities
  - the bandwidth blocking probabilities of both the route partitioning and the first fit are improved by increasing the retuning speed (decreasing α)
  - the performances of the route partitioning improve at a higher rate than those of the first fit
  - For bandwidth blocking probabilities less than 0.01, the route partitioning offers up to 10% additional traffic compared to the conventional first fit.




network 1 (ILP)




network 2 (LBR-MC)




network 3 (LBR-MC)

# Conclusion

- This paper proposed a *route partitioning scheme* for hitless defragmentation using *first-last fit allocation* in order to increase the allowable traffic in EONs.
- The proposed scheme increases the possibilities of lightpath retuning by avoiding the retuning interference among lightpaths.
- The use of the first-last fit reduces the number of needed retuning operations and the retuning time
- Formulated an ILP model and presented a heuristic algorithm LBR-MC
- The numerical results showed that the proposed scheme offers reduced bandwidth blocking probability with limited retuning speed.
- Furthermore, the proposed scheme allows up to *10%* more traffic compared to the conventional hitless defragmentation.

# Thank you for your attention!

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$$\min M, \tag{8a}$$

$$\text{Subject to} \sum_{p \in P} x_{ij}^{p} \leq M \quad \forall\ (i,j) \in E, \tag{8b}$$

$$\sum_{j \in V:(i,j) \in E} x_{ij}^{p} - \sum_{j \in V:(j,i) \in E} x_{ji}^{p} = 1 \quad \forall\ p = (s,d) \in P, i \in V, i = s, \tag{8c}$$

$$\sum_{j \in V:(i,j) \in E} x_{ij}^{p} - \sum_{j \in V:(j,i) \in E} x_{ji}^{p} = 0 \quad \forall\ p = (s,d) \in P, i \in V, i \neq s,d, \tag{8d}$$

$$x_{ij}^{p} = \{0,1\} \quad \forall\ (i,j) \in E, p \in P. \tag{8e}$$