# Distributed Clustering Method for Large-Scaled Wavelength-Routed Networks

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# Background: Inter-Domain Wavelength-Routed Network

- Lightpaths are configured between domains
  - Route selection phase: Collect route information via routing protocols
  - Reservation phase: Reserve a wavelength along the route
- BGP is one of the candidates for inter-domain routing protocol
  - Optical BGP [7]


[7] M. J. Francisco, S. Simpson, L. Pezoulas, C.Huang, J. Lambadaris, and B. St. Arnaud, “Interdomain routing in optical networks,” in *Proceedings of Opticomm2001*, pp. 120-129, Aug. 2001.

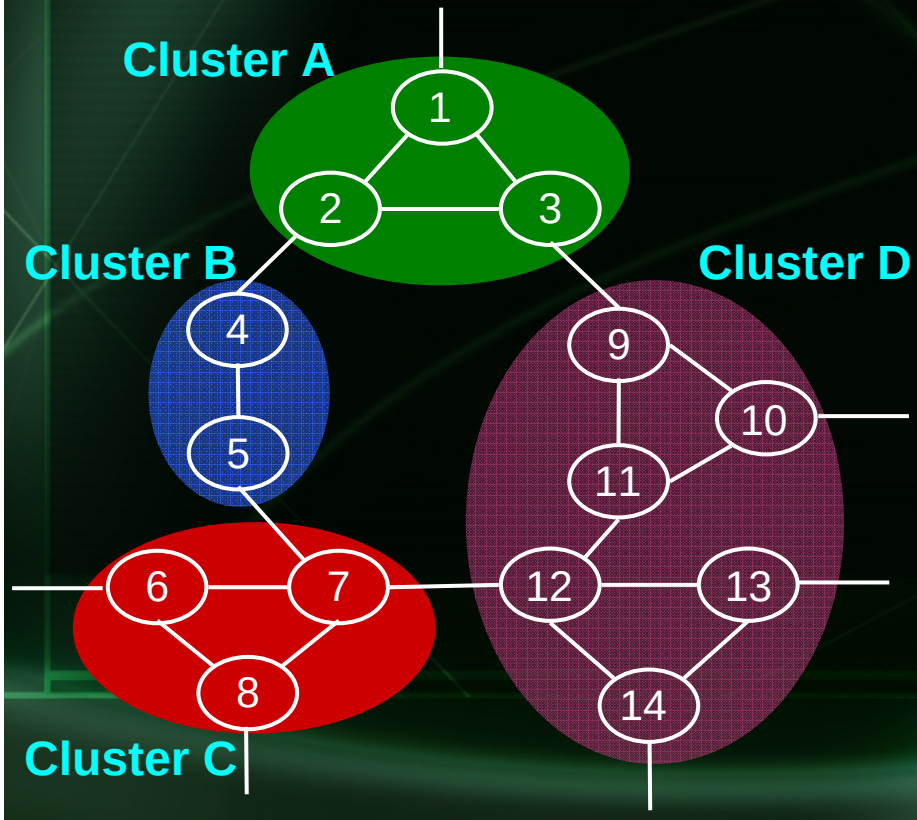
# Background: Problem in inter-domain routing protocol

- BGP lacks scalability of number of routes
  - BGP router's memory size limits the routing table size

➡ Aggregation of route information by hierarchical routing is necessary

# Background: Hierarchical Routing

- Route Information for nodes in the same cluster is aggregated into route information for a cluster
  - Table size is reduced




Routing table on node 1

Without hierarchical routing

| Dest.: | Route |
|---|---|
| Node 2: | 1,2 |
| Node 3: | 1,3 |
| Node 4: | 1,2,4 |
| Node 5: | 1,2,4,5 |
| Node 6: | 1,2,4,5,7,6 |
| Node 7: | 1,2,4,5,7 |
| Node 8: | 1,2,4,5,7,8 |
| Node 9: | 1,3,9 |
| Node 10: | 1,3,9,10 |
| Node 11: | 1,3,9,11 |
| Node 12: | 1,3,9,11,12 |
| Node 13: | 1,3,9,11,12,13 |
| Node 14: | 1,3,9,11,12,14 |

With hierarchical routing

Intra-cluster route

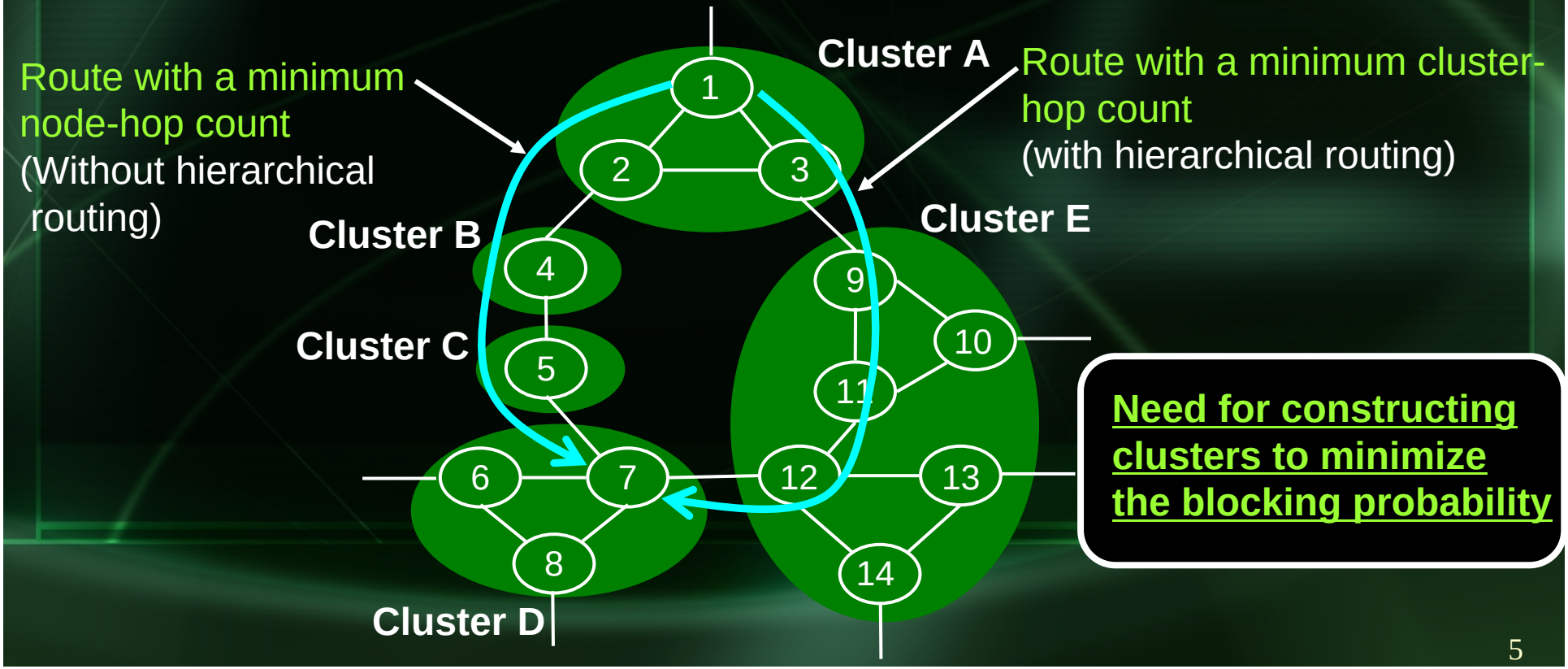
| Dest.: | Route |
|---|---|
| Node 2: | 1,2 |
| Node 3: | 1,3 |

Inter-cluster route

| Dest.: | Route |
|---|---|
| Cluster B: | A,B |
| Cluster C: | A,D,C |
| Cluster D: | A,D |

# Background: Problem in Hierarchical Routing

- Increase in blocking probability for lightpath requests
  - Increase in path length leads to decreasing the probability of finding wavelengths idle on the path



# Objective

**Need for constructing clusters to minimize the blocking probability**

Propose a distributed clustering method for hierarchical routing

- Improve the scalability of routing protocol
- Minimize the blocking probability for lightpaths requests

# Requirements for Clustering Method for Wavelength-Routed Networks

1) Keeping the size of routing table within a certain value
   ➡ Set upper bound on the number of nodes in a cluster

2) Minimizing blocking probability for lightpath requests
   ➡ Reduce blocking by increasing the number of lightpaths available between nodes

3) Constructing clusters without complete topological information
   ➡ Use local information for constructing clusters

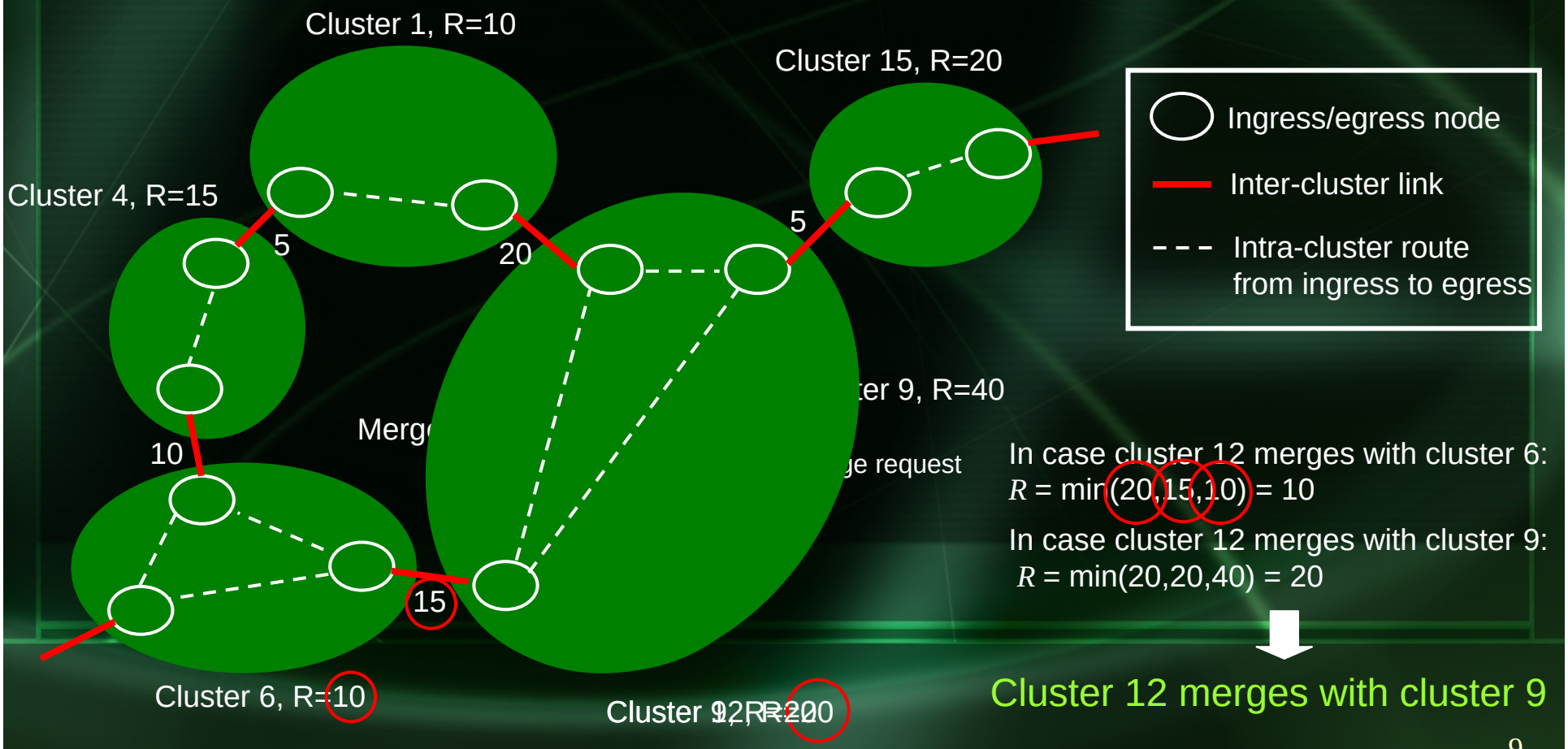
# Proposal of Distributed Clustering Method

- Objective
  - maximize the number of lightpaths available between nodes
- Distributed clustering method
  - Initial state
    - Cluster = Node
  - Each cluster repeatedly merges with one of its adjacent clusters
    - Determines the target cluster based on local information
  - Termination condition
    - Cluster size does not exceed the upper bound

# Illustrative Example of Proposed Method

- Each cluster tries to increase the minimum number of lightpaths available from ingress to egress in merged cluster (R)

Local information



# Simulation Model (1/2)

- Network model
  - Random networks generated with the Waxman algorithm
    - Number of nodes: 100, 200, 300, 400, 500
    - Number of fibers on a link: 1-30
    - Number of wavelengths: 32
  - Upper bound on cluster size: $\sqrt{N}$ ($N$ : Number of nodes)
    - Routing table size is minimized when the number of clusters is equal to the number of nodes in a cluster [10]

[10] L. Kleinrock and F. Kamoun, “Hierarchical routing for large networks,” *Computer Networks*, vol. 1, pp. 155-174, Jan. 1977.

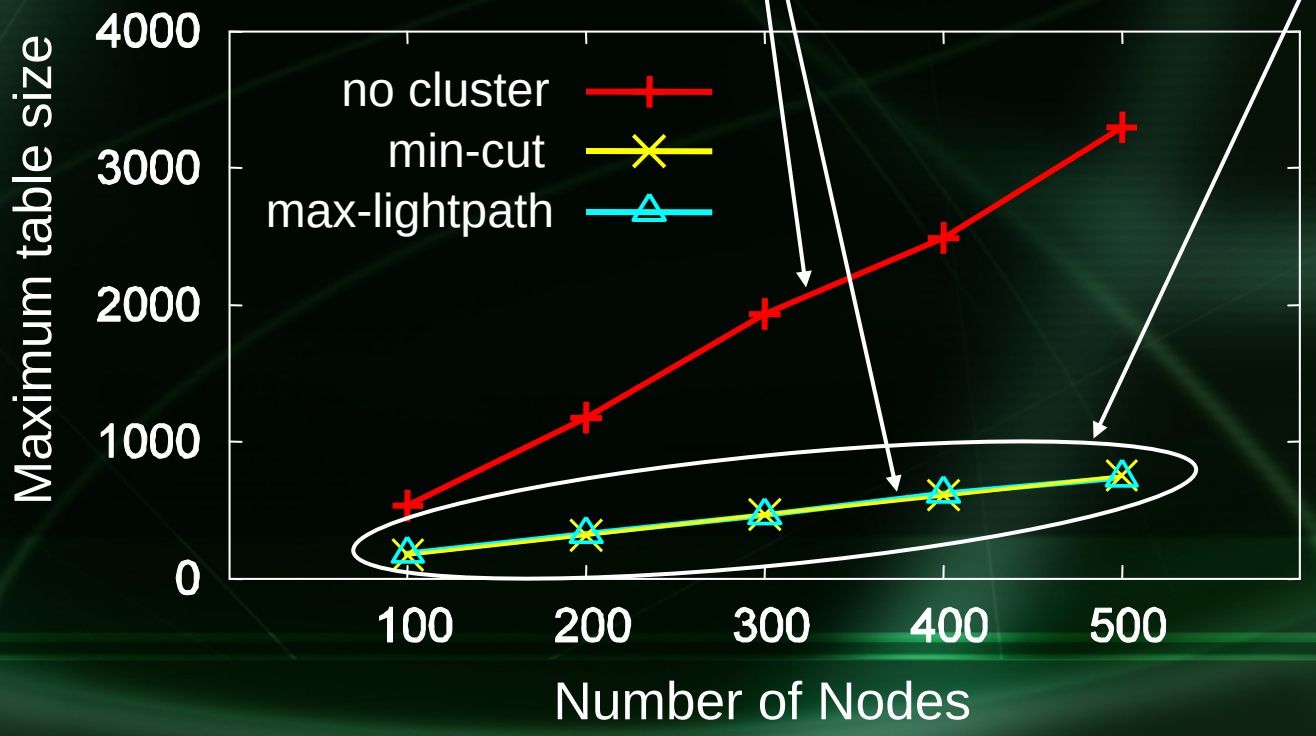
# Simulation Model (2/2)

- Request for lightpaths
  - Arrival rate: Poisson process at a rate of $\lambda$ (requests/s)
  - Holding time: Exponential distribution with an average of 60 [s]
- Clustering methods
  - Max-lightpath (proposed method)
    - Maximize the number of lightpaths available between nodes
  - Min-cut
    - Minimize the number of links between clusters
  - No cluster
    - No cluster is constructed

# Maximum Table Size

Max-lightpath: 22-33% of the table size without clusters
- Effect of aggregating route information increases as the number of nodes increases

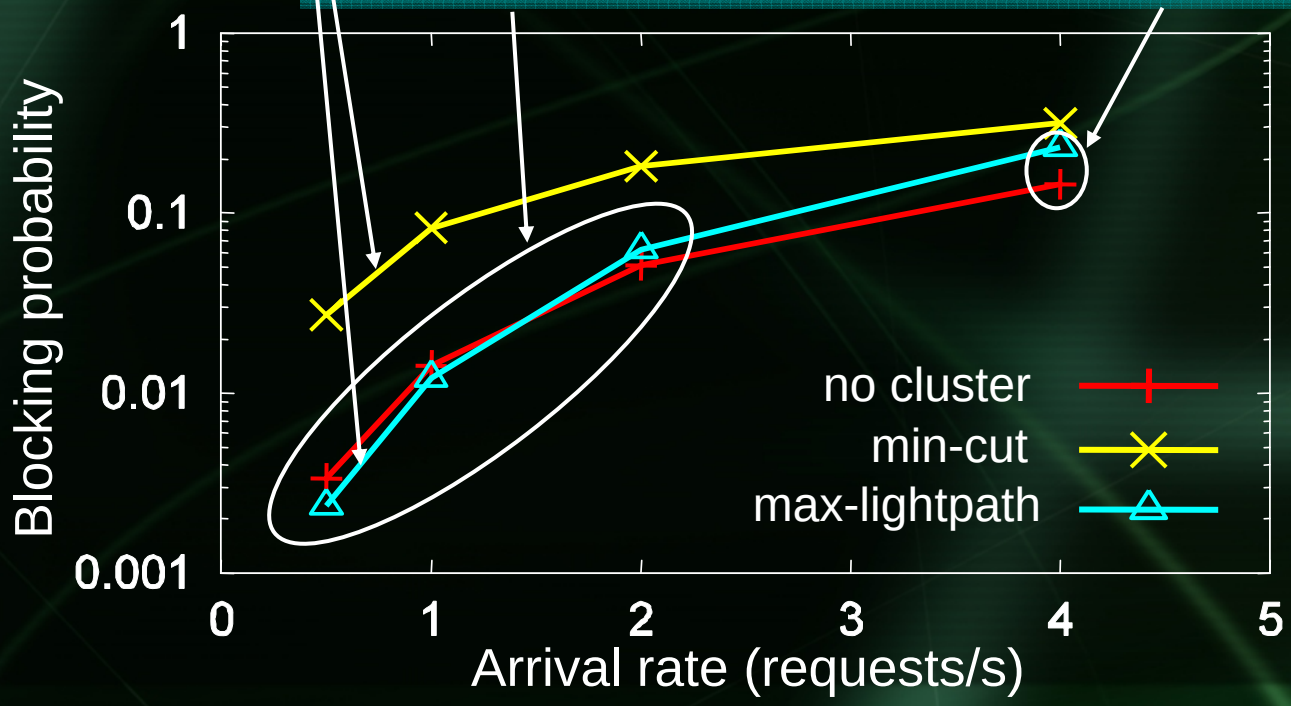
Table size of max-lightpath is almost the same as that of min-cut



# Blocking Probability for Lightpath Requests

Network without cluster outperforms max-lightpath
- Node-hop count of lightpaths with max-lightpath is larger than that without clusters
- More links are over-loaded with max-lightpath

Max-lightpath outperforms min-cut for all loads




Average number of lightpaths available between nodes

| No cluster | min-cut | max-lightpath |
|---|---|---|
| 307.8 | 262.6 | 337 |

# Conclusion and Future Work

- Conclusion
  - Proposed clustering method
    - Constructs clusters in a distributed way
      - Does not need complete topological information
    - Reduces blocking probability
  - Evaluated our proposed method by simulation
    - Table size with max-lightpath ranged between 22-33% of that without clusters
      - Effect of aggregating the route information increased as the number of nodes increased
    - Max-lightpath reduced the blocking probability as low as that without clusters
- Future work
  - Proposal of clustering method that reconstructs clusters when the network topology changes