Expected capacity guaranteed routing for Artificial Intelligence based Dynamic Failure Prediction of Links

Shu Sekigawa*, Eiji Oki †,
Satoru Okamoto*, Naoaki Yamanaka*

*Graduate School of Science and Technology, Keio University
†Graduate School of Informatics, Kyoto University

Outline

- Background
- Conventional approach
  - Dedicated path protection
  - Multi-path provisioning protection
- Proposed approach
  - Expected capacity guaranteed routing
- Simulation results
- Conclusion

Background

[1] J. Zhong, et al., "Study on network failure prediction based on alarm logs," in *2016 3rd MEC International Conference on Big Data and Smart City (ICBDSC)*, pp. 1-7, March 2016.

- In recent years, due to rapid popularization of the Internet, a high speed transfer capability is required for the backbone network.

  ⇨ To prevent a loss of large amount of data due to link failures, the backup paths are required for quick recovery.

- The prediction methods of network failure rate based on data mining and artificial intelligence are being studied[1].

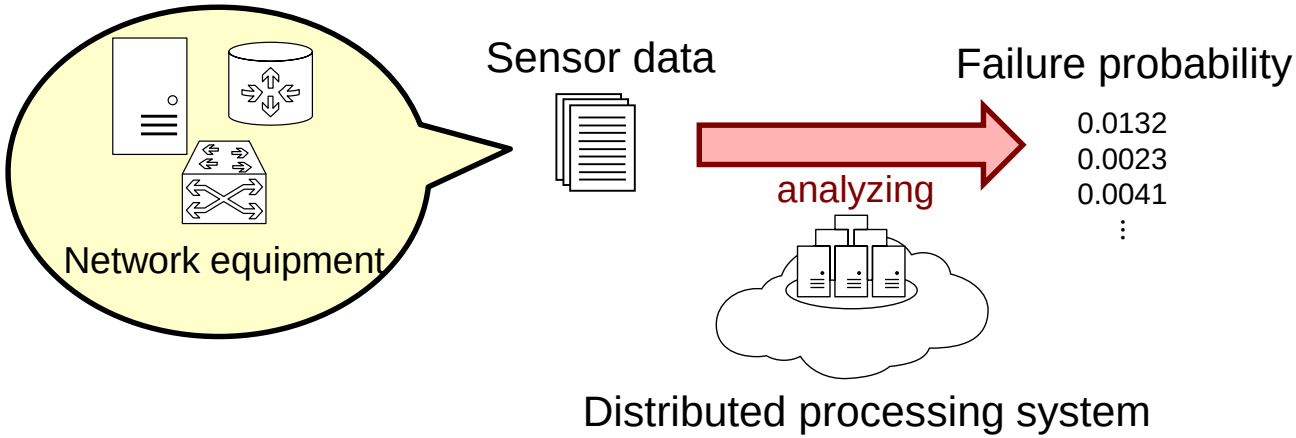


Fig. 1 Failure probability prediction based on big data

The number of connections can be accommodated in the network depends on the method of securing the backup path.

Conventional approach (1/2)

Dedicated-path protection(DPP)

- Reserve a backup path simultaneously with a working path.
- The working path and the backup path are link-disjoint.
- When the link fails, immediately switch to the backup path.

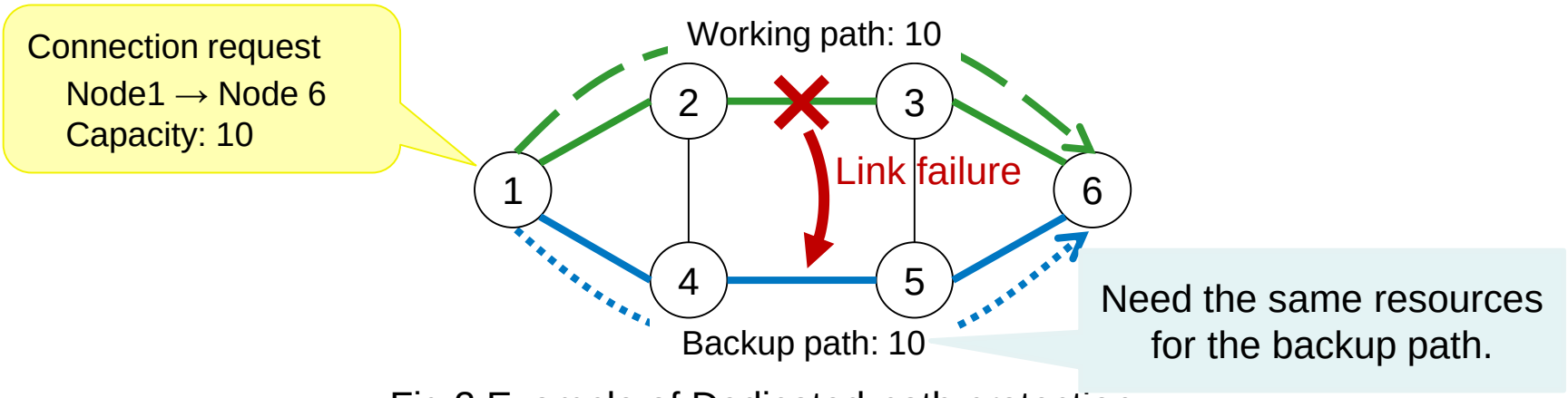


Fig.2 Example of Dedicated-path protection

✔ In case of single link failure, communication can be restored.
✗ The maximum number of connections can be accepted into the network are reduced by half.

Conventional approach (2/2)

[2] L. Ruan and Y. Zheng, "Dynamic survivable multipath routing and spectrum allocation in OFDM-based flexible optical networks," in *IEEE/OSA Journal of Optical Communications and Networking*, vol. 6, no. 1, pp. 77-85, Jan. 2014.

Multi-path provisioning (MPP) protection [2]

- Reserve N link-disjoint paths.
- Total allocated capacity on any group of N-1 paths exceeds requested capacity.

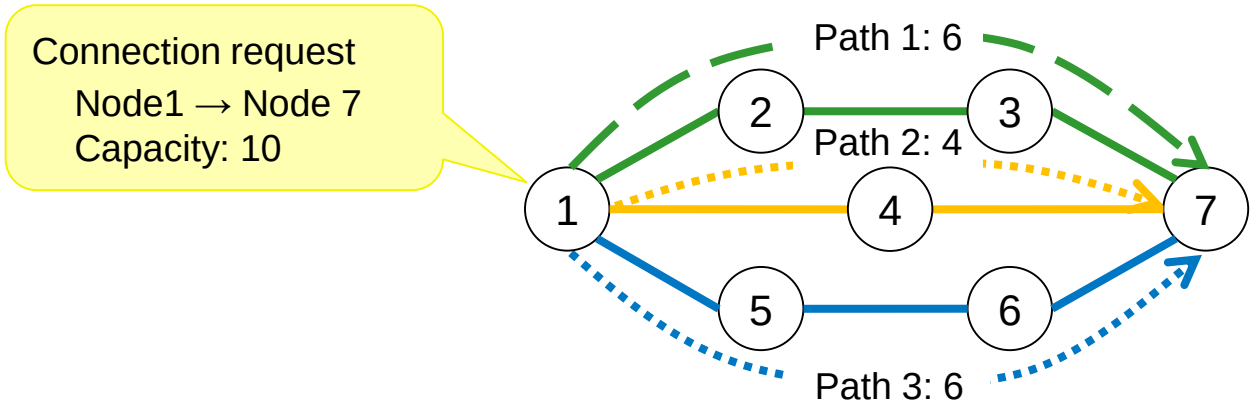


Fig.3 Example of Multi-path provisioning protection

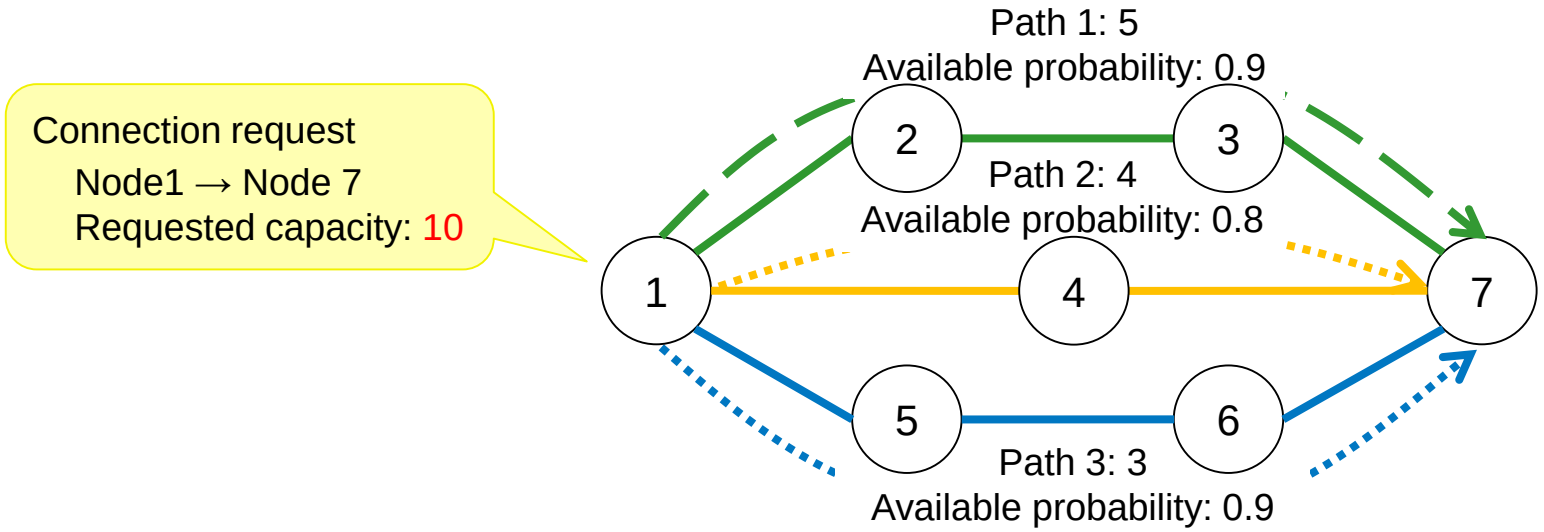
➡ The total allocated capacity can be reduced.

Conventional approaches do not consider the failure probability of each links.

Proposed approach: Expected capacity guaranteed routing Basic Concept

Expected capacity guaranteed routing (ECGR)

- Calculates the expected capacity on each of the allocated paths.
  Path Available probability×Allocated capacity
- Selects the multiple paths that the total expected capacity exceeds the requested capacity.



Total expected capacity: $5 \times 0.9 + 4 \times 0.8 + 3 \times 0.9 = 10.4 > 10$

Fig.4 Example of Expected capacity guaranteed routing

Proposed approach: Expected capacity guaranteed routing
Route allocation process

1. Connection request $r =< p, q, B_{req}, t >$ occurs.
   p: Source node, q: Destination node,
   B_{req}: Expected Capacity requirement, t: Connection holding time
2. Calculates the Link Available probability from Link failure rate.
3. Solves the Mixed-Integer Liner Programming (MILP) model and selects the optimal paths and allocated capacity.

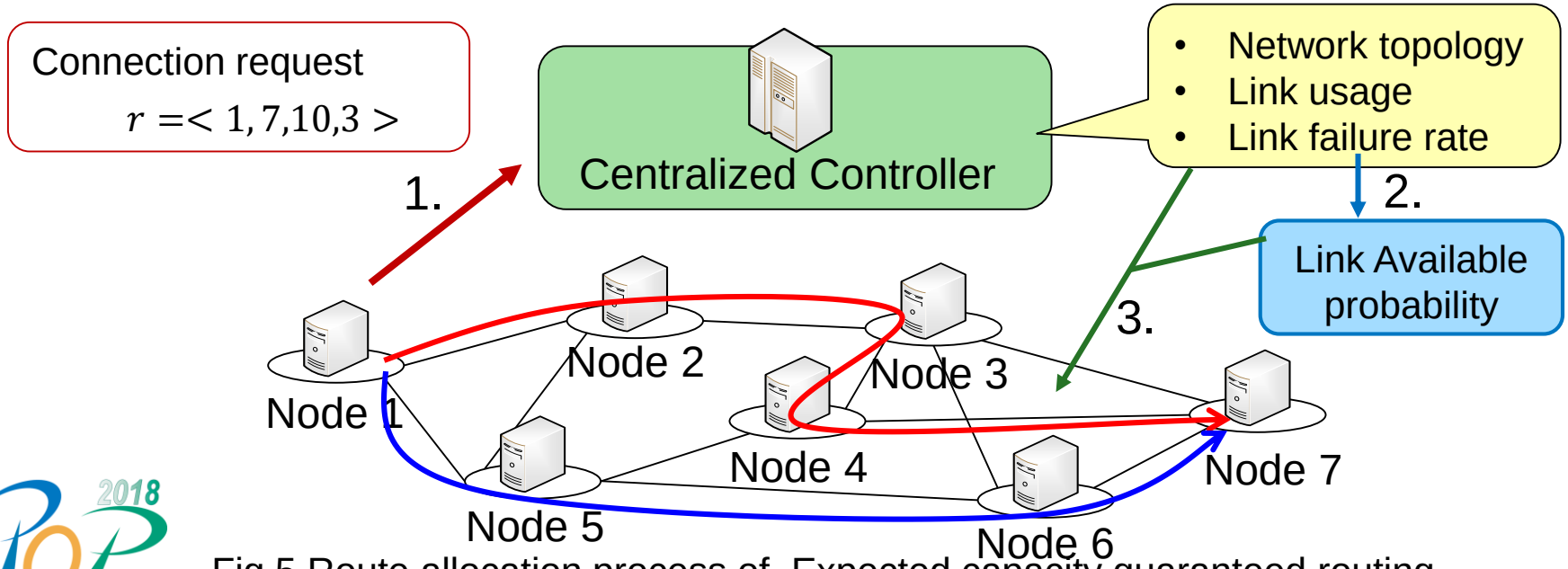


Fig.5 Route allocation process of Expected capacity guaranteed routing

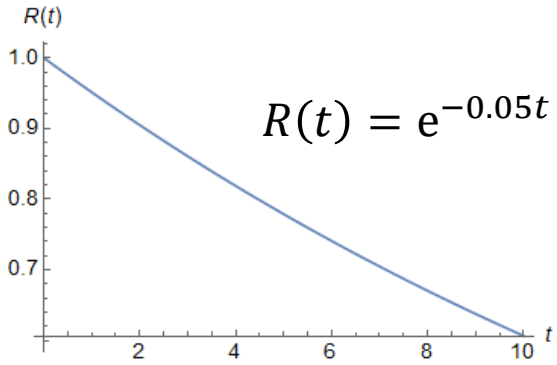
Proposed approach: Expected capacity guaranteed routing
Relationship between Failure rate and Reliability

- Link failure rate $\lambda_{ij}(t)$
  The probability that (i, j) fails next unit time
  when there is no failure before time t.
- Link reliability $R_{ij}(t)$
  The probability of no link failure at (i, j) before time t.

Relationship between Failure rate and Reliability:

$$R(t) = \exp\left\{-\int_0^t \lambda(x)dx\right\}$$

Failure rate $\lambda = 0.05$ (Random Failures)



$$R(t) = \mathrm{e}^{-0.05t}$$

Reliability decreases as time t increases.

Proposed approach: Expected capacity guaranteed routing
Path Available probability

- Link Available probability

  The probability that the link is available during communication.

  Assume that communication starts at T and ends at $T + \Delta t$.

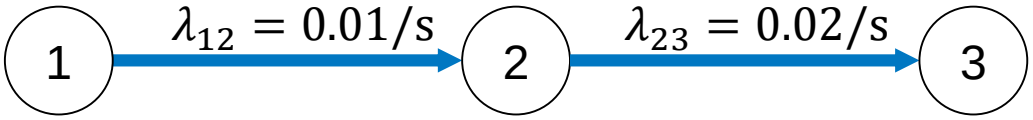
$$\text{Link Available probability } A_{ij}(T, \Delta t)$$
$$= P(\text{No failure before } t = T + \Delta t \mid \text{No failure before } t = T)$$
$$= \frac{R_{ij}(T + \Delta t)}{R_{ij}(T)}$$

- Path Available probability

  A path can be considered as serial system composed of links.

  ⇨ $\text{Path Available probability} = \prod^{\text{All links}} \text{Link Available probability}$

ex) Paths from node 1 to node 3, Connection holding time: $3s$



$$A_{1-2-3}(0,3) = \frac{R_{12}(3)}{R_{12}(0)} \times \frac{R_{23}(3)}{R_{23}(0)} = 0.97 \times 0.94 = 0.91$$

Proposed approach: Expected capacity guaranteed routing MILP Formulation (1/2)

- Objective

Allocated capacity on (i,j) of kth path

$$\text{minimize} \sum_{k \in K} \sum_{(i,j) \in E} y_{ij}^{k} \cdot d_{ij}$$

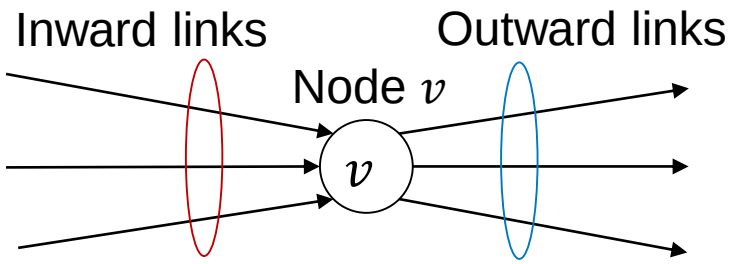
Length of (i,j)

⇒ Select the paths with minimum cost.

- Constraints
  - Flow conservation constraint

(i,j) is whether used by kth path (1) or not (0)

$$\sum_{j:(i,j) \in E} x_{ij}^{k} - \sum_{j:(j,i) \in E} x_{ji}^{k} = \begin{cases} 1 \ (\forall k \in K, i = p) \\ 0 \ (\forall k \in K, i \neq p, q \in V) \end{cases}$$



Count: 3 = Count: 3

Fig.5 Example of flow conservation constraint

Proposed approach: Expected capacity guaranteed routing MILP Formulation (2/2)

- Constraints
  - Link capacity constraint

(i,j) is whether used by kth path (1) or not (0)

Available capacity of (i,j)

$$0 \le \sum_{k \in K} x_{ij}^{k} \cdot b_k \le \min(c_{ij}, B_{req}) \quad (\forall (i,j) \in E)$$

Allocated capacity for kth path

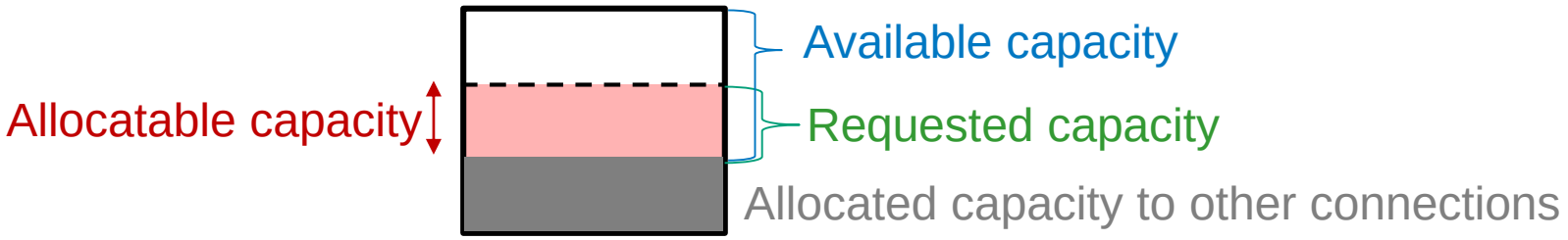


Fig.6 Example of Capacity allocation for (i,j)

  - Expected capacity requirement constraint

Available probability of kth path

$$\sum_{k \in K} b_k \cdot A_k(T, T+t) \ge B_{req}$$

Guarantees the total expected capacity exceeds the requested capacity.

According to the formulas, ECGR founds the optimal route and capacity allocation

Proposed approach: Expected capacity guaranteed routing Variable capacity allocation

Under high failure rate environment, ECGR allocates much larger capacity than that of connection request to guarantee the expected capacity.

⇒ This leads to increasing the blocking probability of connection request.

Variable capacity allocation (VCA)

Adjust the allocated link capacity and the connection holding time with maintaining the total traffic capacity.

ex) Requested capacity: 15MB/*s*, connection holding time: 4*s*

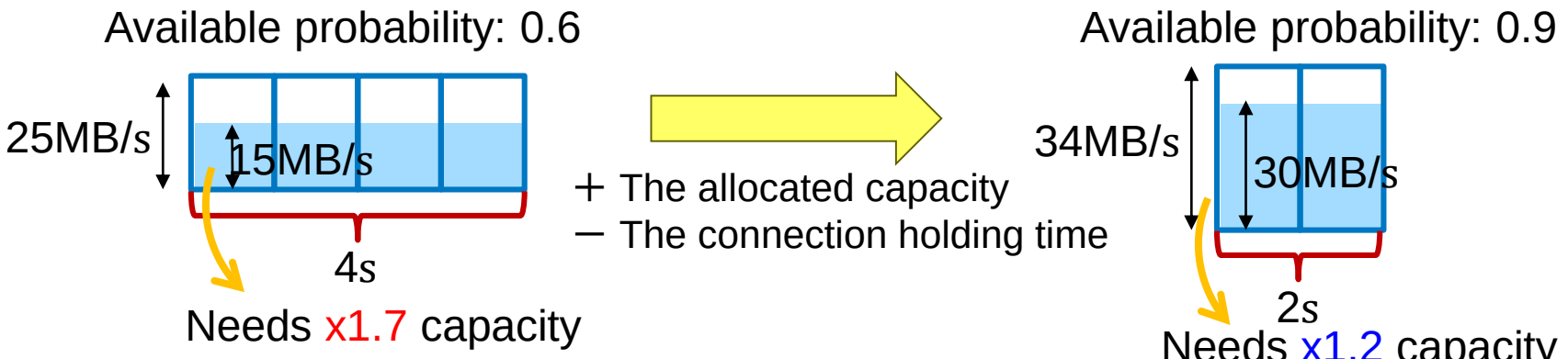


Fig.7 Example of Variable capacity allocation

With VCA, EDGR can reduce the block of connection requests

Numerical Evaluation (1/2)

Evaluated methods

- Minimum-cost flow problem (MCFP)
- Dedicated-path protection
- Expected capacity guaranteed routing (w/ VCA, w/o VCA)

Evaluated values

- Bandwidth blocking probability (BBP)

$$\mathrm{BBP} = \frac{\text{Total requested link capacity of blocked connections}}{\text{Total requested link capacity of all connections}}$$

- Traffic capacity achieved ratio(TCAR)

$$\mathrm{TCAR} = \frac{\text{\# of connections whose total traffic capacity exceeds the request}}{\text{\# of accepted connections}}$$

Numerical Evaluation (2/2)

Table.1 Parameters

Parameter	Value
Network topology	14-node 21-link NSFNET
Total number of connection requests	1000
Initial capacity of each links	100
Failure rate of each links	Weibull distribution with a shape parameter $\gamma = 5$ and a scale parameter $\eta = \{10, 20\}$
Recovery time of each links	Geometrically distributed with a mean of 5 second
Maximum number of paths	3
Arrival time of connection requests	Poisson distribution with a mean of λ
Connection holding time	Geometrically distributed with a mean of 4 second
Requested Capacity B_{req}	Randomly chosen from $\{2,4,8,16\}$
Source and destination nodes	Random

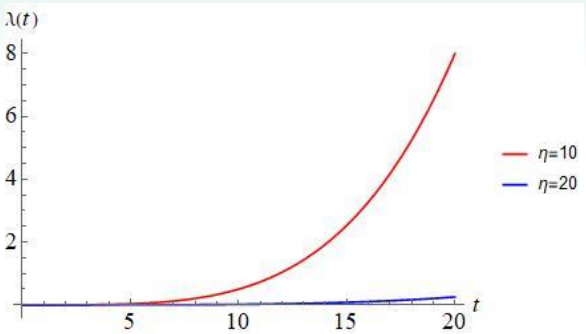


Fig.8 Weibull failure rate

Simulation results (1/2)

Scale parameter $\eta = 20$ (Low failure rate)

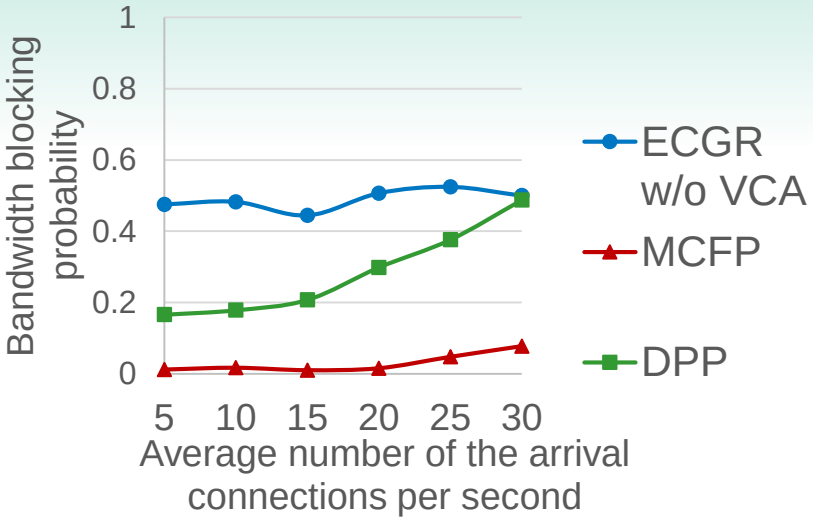


Fig.9 Bandwidth blocking probability with $\eta = 20$

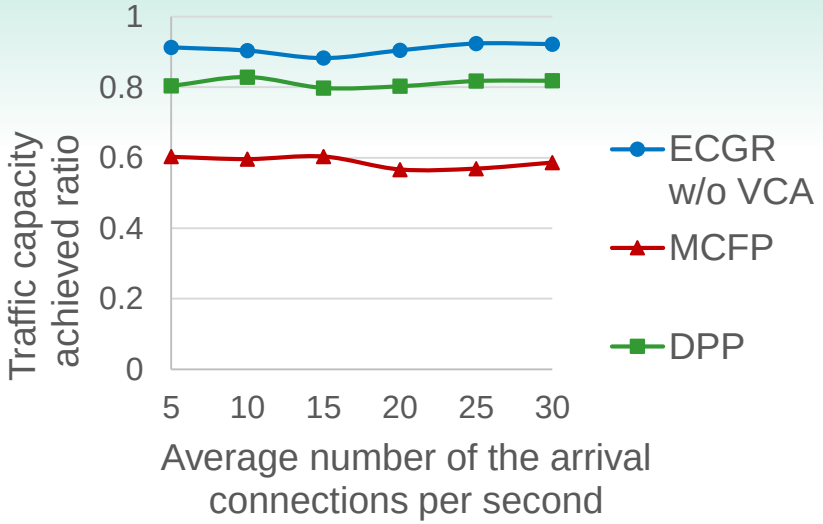


Fig.10 Traffic capacity achieved ratio with $\eta = 20$

- Traffic capacity achieved ratio of ECGR is 90% and 10% higher than that of DPP on average.
- Bandwidth blocking probability of ECGR is higher than that of the conventional methods.

Simulation results (2/2)

Scale parameter $\eta = 10$ (High failure rate)

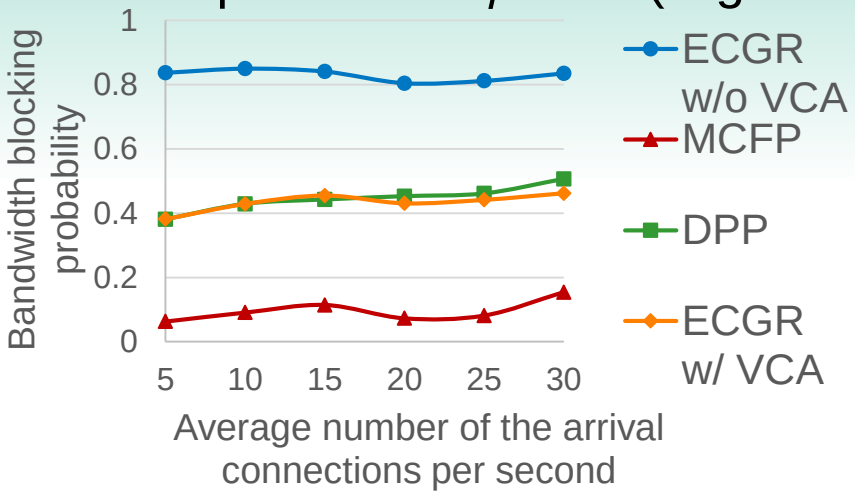


Fig.11 Bandwidth blocking probability with $\eta = 10$

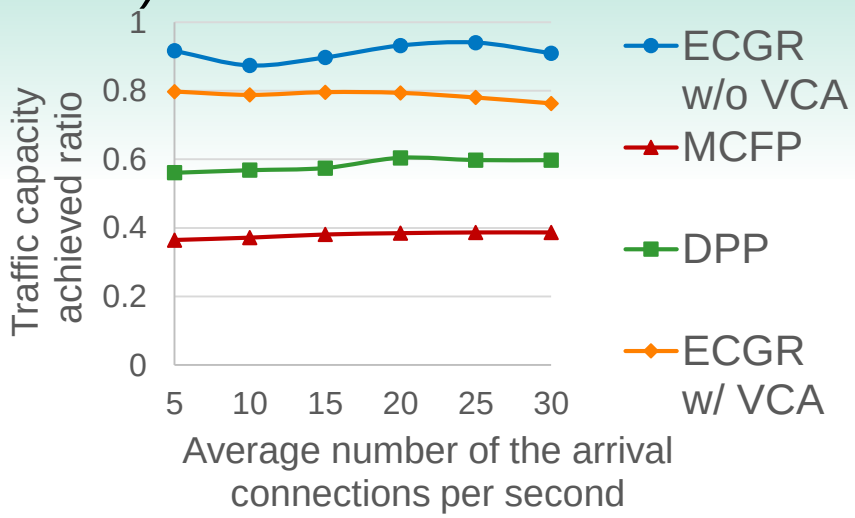


Fig.12 Traffic capacity achieved ratio with $\eta = 10$

- ECGR w/o VCA maintains 90% traffic capacity achieved ratio under high failure rate environment.
- Traffic capacity achieved ratio of ECGR w/ VCA is 20% higher than that of DPP.
- Bandwidth blocking probability of ECGR w/ VCA is approximately equal that of DPP

Conclusion

Background

- In high speed backbone network, the backup paths are required for quick recovery to prevent a loss of data.
- The conventional protection approach do not consider the failure probability of network.

Proposed approach

- Routing and capacity allocation method that guarantees the expected value of allocated capacity based on failure rate of links.

Simulation results

- ECGR without VCA achieves 90% traffic capacity achieved ratio regardless of the failure rate of links.
- ECGR with VCA shows the equal bandwidth blocking probability compared to DPP and 20% higher traffic capacity achieved ratio than that of DPP under the high failure rate environment.