Network Topology Design Considering Detour Traffic Caused by Link Failure

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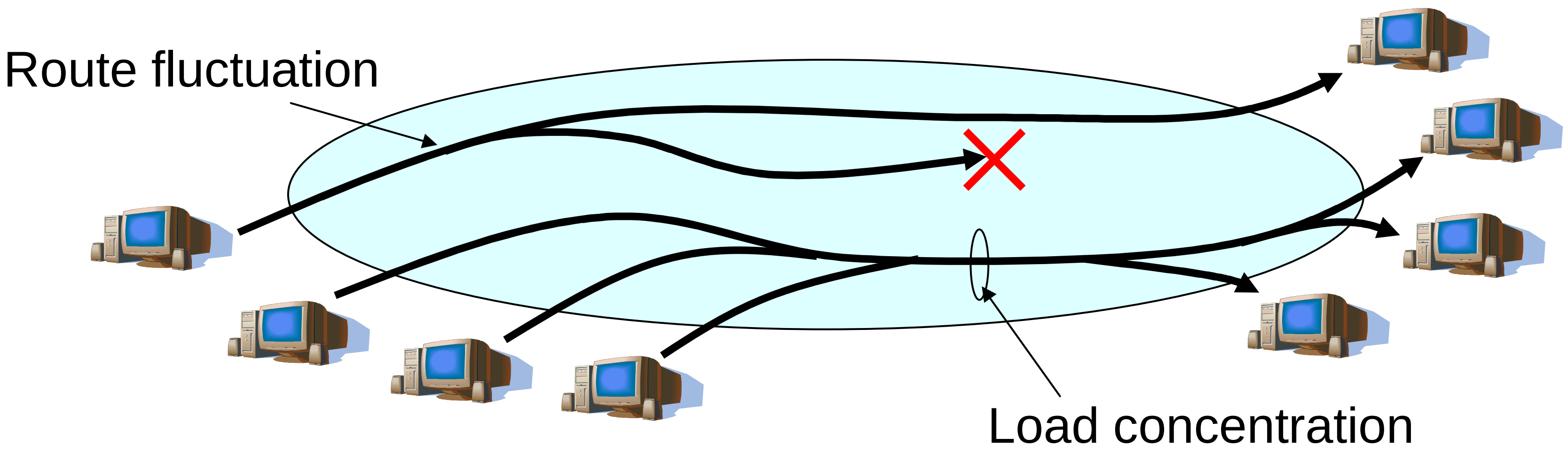
Principal Task for ISP

- Link congestion is unavoidable in Internet.
  - Without admission control
  - Hosts autonomously set packet transmission rate.
  - Packet routes constantly change because of failures.



- One principal task for ISPs is to maintain desirable QoS.
  - Manages network to keep link utilization below desired level

Traffic Engineering (TE)

- Dynamically balances link load by flexibly controlling routes and effectively utilizing links with low utilization

- Link utilization depends not only on demand matrix and routes but also on network topology and link capacities.
- TE methods assume both network topology and link capacities are fixedly given.

- Topology and link capacities affect cost and qualities.
- It is important for ISPs to design topology and link capacities suitably to maintain desirable quality at limited cost.

Existing Design Method of Topology

- Integer linear programming (ILP)
  - Minimizes total cost
  - Heuristic algorithms
  - Without considering failures or with considering just connectivity after failures

- No existing ILP approaches consider detour traffic caused by failures.

Purpose of This Presentation

- Propose method of designing network topology and link capacities
  - Assumes that node locations and traffic matrix are given
  - Minimizes total link cost under constraint that utilization of all links is kept below given threshold considering detour traffic at link failures
- Analyze topologies designed by proposed method for backbone network in USA
  - Investigate structural properties of links on which excess capacities are provided

Overview of Proposed Design Method

- Assume OSPF minimum-cost routes with fixed link costs
- Given information
  - Node positions and d_{ij}, distance between nodes
  - Traffic matrix **D**
- Link cost model: DWDM links
  - x_{ij}: number of wavelengths designed on link e_{ij}
  - Consider costs of optical fibers, (de)multiplexers, optical amplifiers, and repeaters
  - Define $c_{ij}(d_{ij}, x_{ij})$, cost function of e_{ij}, depending on d_{ij} and x_{ij}
- Design x_{ij} minimizing total link cost with constraint of keeping utilization of any link below given threshold γ

Design Policy

- Need to consider detour traffic caused by failures
  - Normally see failures of various links in Internet
  - About 70% failures originate from single link failure.
- Keep link utilization below γ at single failures of any link
- Huge excess capacity will be required if we consider detour traffic caused by single failures of any link.
- Consider single failures just for k links
  - k = floor(εL), L is link count and ε is design parameter ($0 \leq \varepsilon \leq 1$).
  - Select k links with largest traffic at normal operation
  - Also consider satisfying connectivity between all pairs of nodes at single failures of remaining L - k links

Definition of ILP

- Objective: Minimize $C = \sum_{i,j:\, e_{ij} \in \mathbf{E}} c_{ij}(d_{ij}, x_{ij})$
- Subject to: $\dfrac{t_{ij}^{k,max}}{x_{ij}B} \leq \gamma$, for any $e_{ij} \in \mathbf{E}$

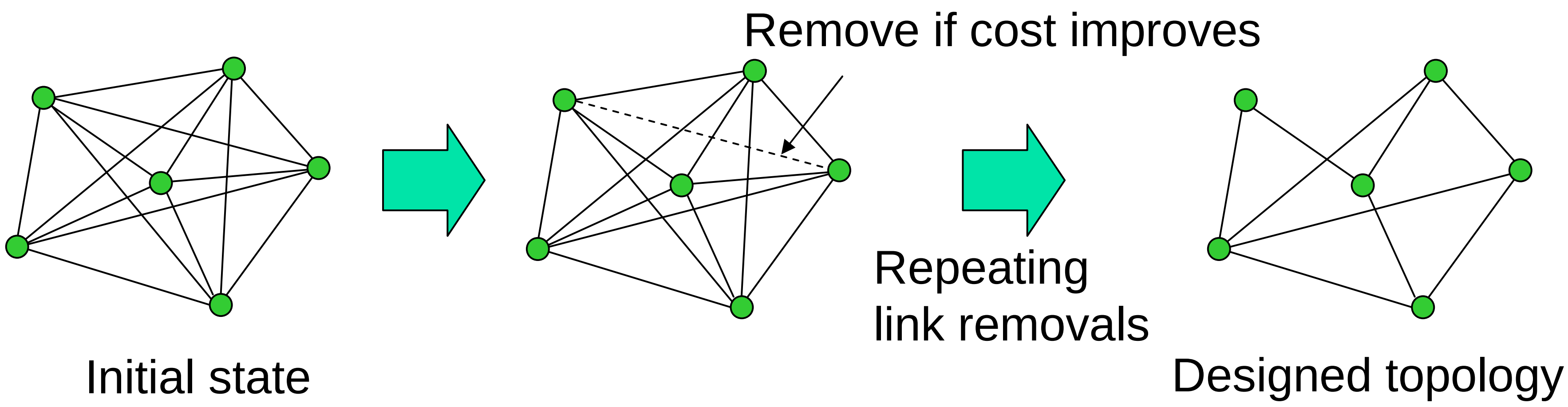
  $w_{sd}^{(-e_{i'j'})} < \infty$, for any s, d, and $e_{i'j'} \in \mathbf{E}^{(L-k)}$

- $t_{ij}^{k,max}$: maximum traffic on link e_{ij} considering detour traffic at single failures of k links
- B: transmission capacity of wavelength
- **E**: link set
- **E**(L-k): link set after removing k links
- $w_{sd}^{(-e_{i'j'})}$: sum of link weights from node s to d on topology from which k links are removed

Greedy Algorithm

- Start from full-mesh topology
- Remove one link with higher link cost and less traffic, i.e., maximum value of $c_{ij}(d_{ij},x_{ij})/t_{ij}^{(n)}$

  ($t_{ij}^{(n)}$: traffic volume on e_{ij} at normal operation)
- Repeat link removal as far as cost improves

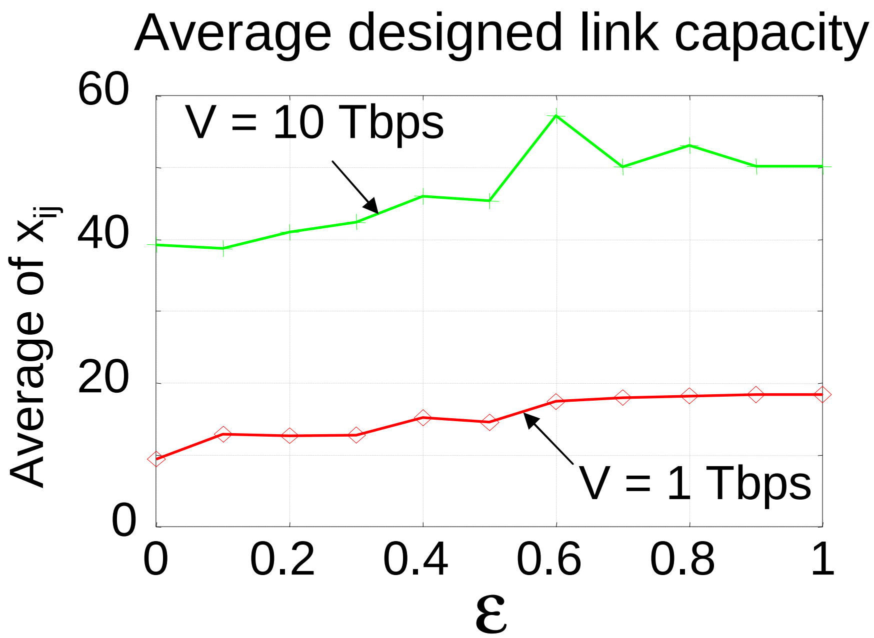


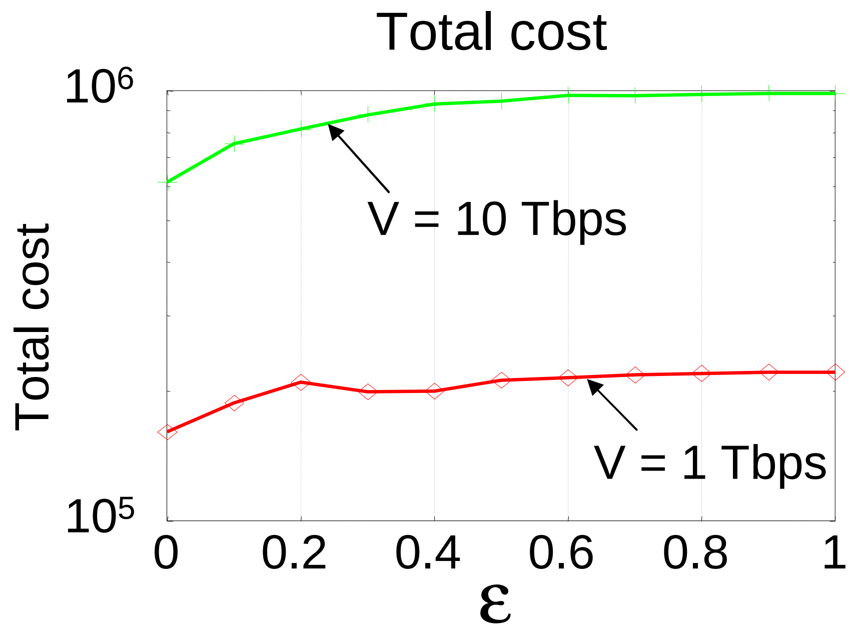
Evaluation Condition

- Upper limit of link utilization: $\gamma = 0.7$
- Maximum number of wavelengths on fiber: W = 60
- Transmission capacity of wavelength: B = 10 Gbps

- Node location: Abilene network
  - Backbone network in USA
  - 11 nodes
  - Set traffic demand matrix proportional to actual value
  - Total amount of traffic: V = 1 Tbps or 10 Tbps

Influence of Parameter ε (1)



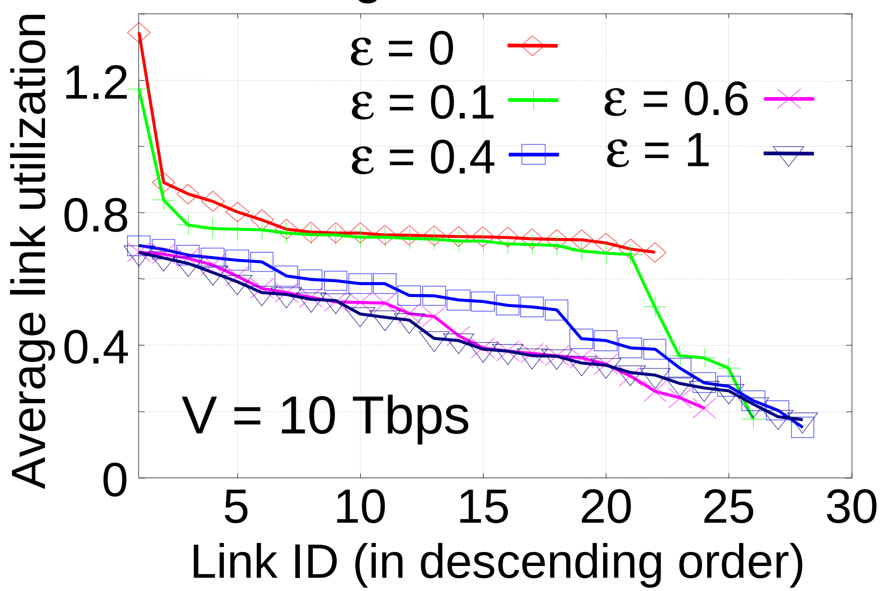


- When ε was greater than about 0.5, designed link capacity was almost constant independently of ε.

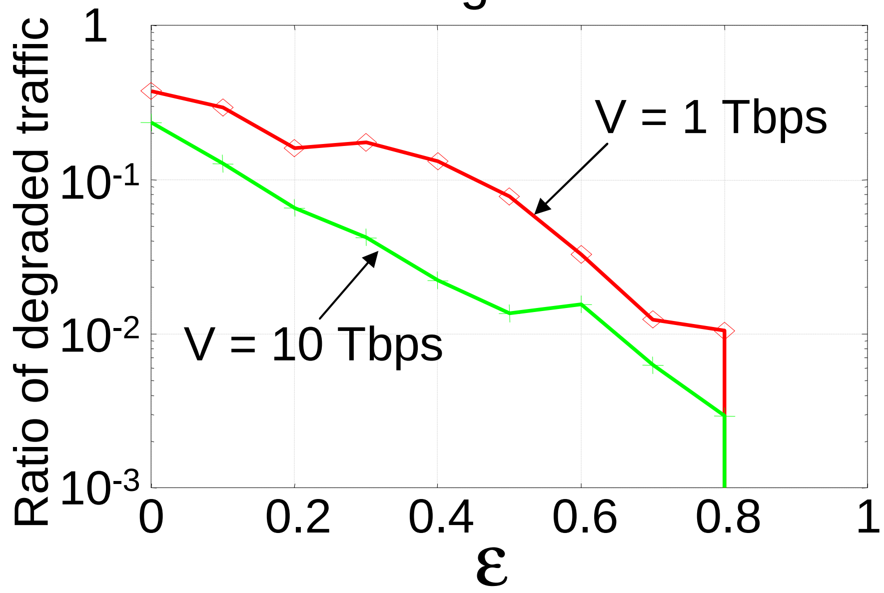
  ⇒ Network designed with considering single failures of half links can accommodate detour traffic at failures of remaining links.
- Total network cost was almost constant when ε was greater than 0.5.

Influence of Parameter ε (2)

Average link utilization at single link failures



Ratio of traffic taking congested links at single link failures



- When ε ≤ 0.1, utilization of many links exceeded γ (0.7) because of detour traffic caused by failures in links that were not considered.
- As ε increased, amount of traffic taking congested links decreased exponentially.

Desirable Value of ε

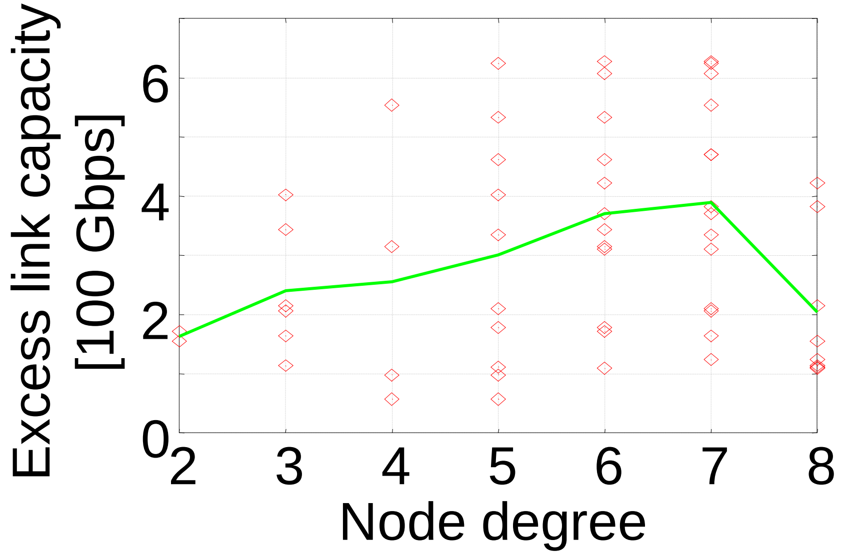
- When ε was smaller than about 0.5, large portion of traffic took congested links.

  $\Rightarrow$ We should set ε greater than about 0.5.

- Total cost was almost constant when $\varepsilon > 0.5$.

- We should set $\varepsilon = 1.0$.

Property of Designed Topologies



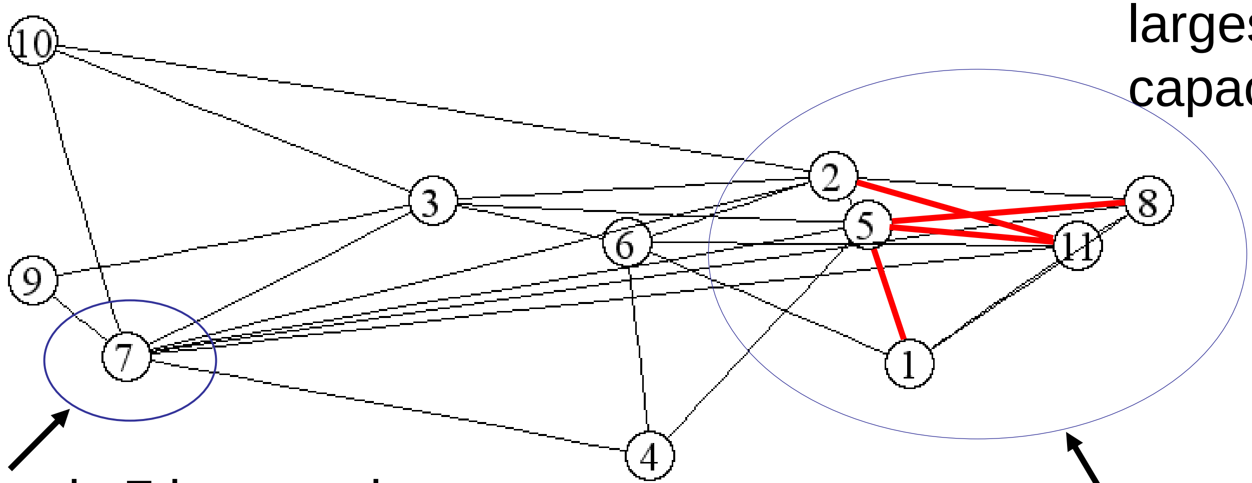
V = 10 Tbps, ε = 1

- Large excess capacities tended to be designed on links connected with high-degree nodes.

Example of Links with Large Excess Capacity

V = 10 Tbps, ε = 1

Top 4 links with largest excess capacity



Although node 7 has maximum node degree, traffic demand in western area is small.
⇒ Excess capacities on links connected with node 7 are small.

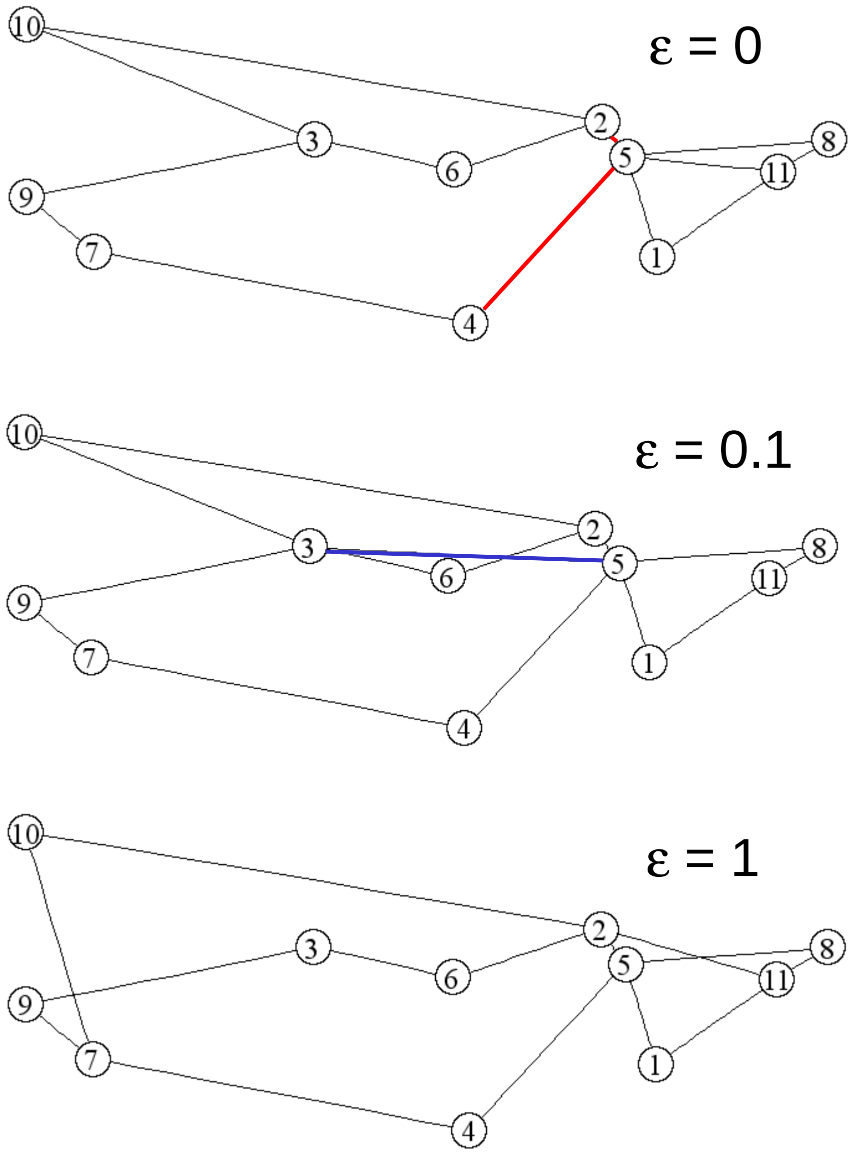
Top-3 s-d node pairs with largest traffic demand were in eastern area of USA.

- Links connected with high-degree nodes in areas with large traffic demand have large excess capacity.

Conclusion

- Proposed method of designing network topology and link capacities to minimize total cost, with constraint of keeping utilization of all links below given level considering detour traffic at single-link failures
- Desirable to consider single failures of all links
- Links connected with high-degree nodes in area with large traffic demand tend to have large excess capacities.

パラメタεの影響: 設計例(1)

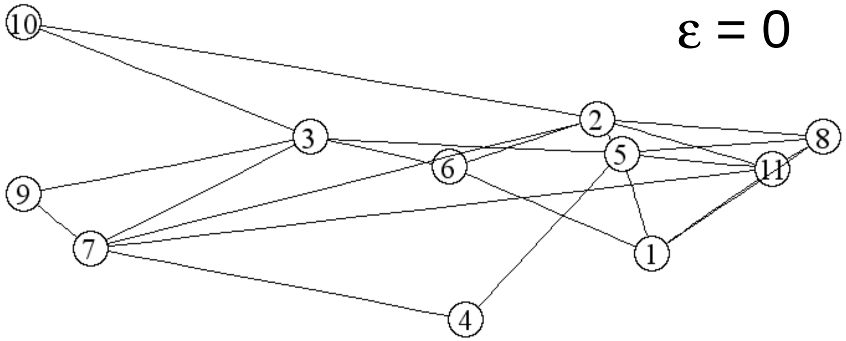


Abilene, V = 1Tbps

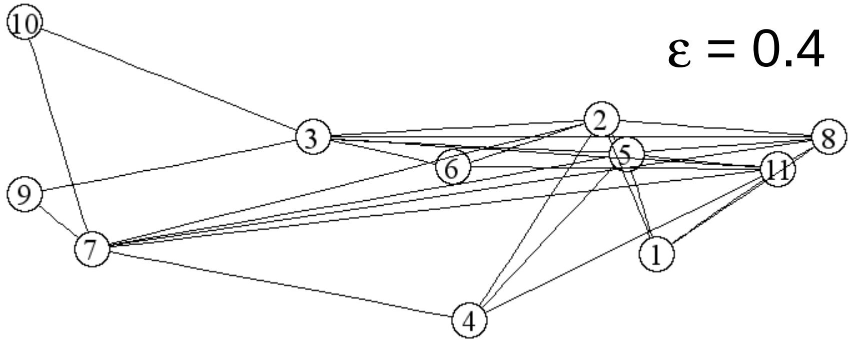
- ε = 0のとき，$t_{ij}^{(n)}$の大きいリンクは大ループの一部を構成
- ε = 0.1のとき，これらリンクの障害時の迂回トラヒックを効率的に運ぶリンク(3,5)を追加
- ε = 1のとき，多数の発着ノード間の迂回トラヒックを共通のリンクで効率よく収容できるループを組合わせたトポロジが良好

パラメタεの影響: 設計例(2)

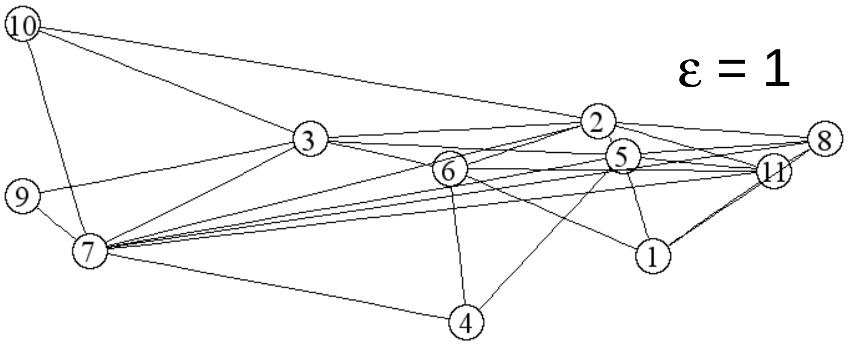
Abilene, V = 10Tbps



ε = 0



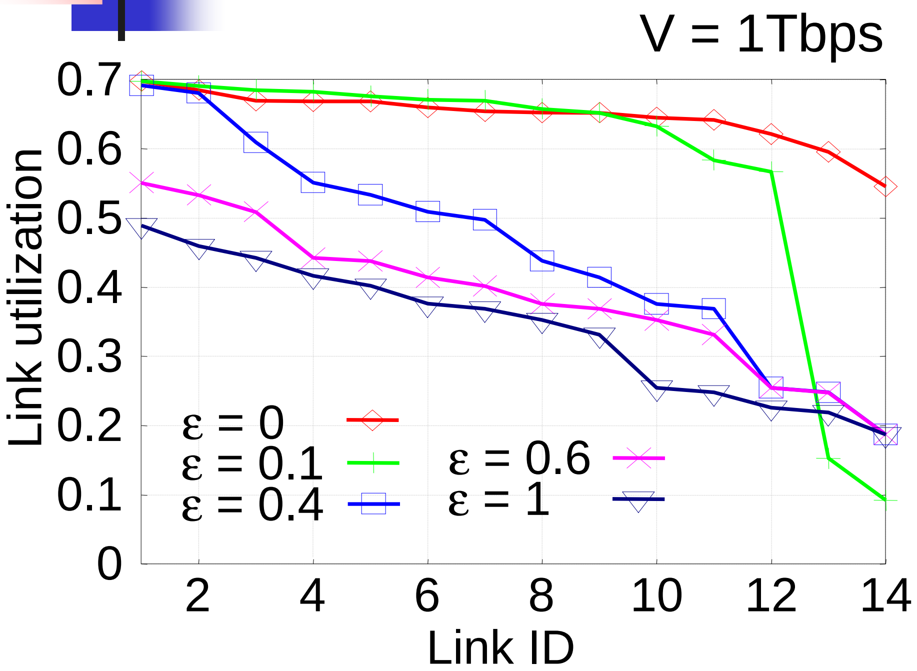
ε = 0.4

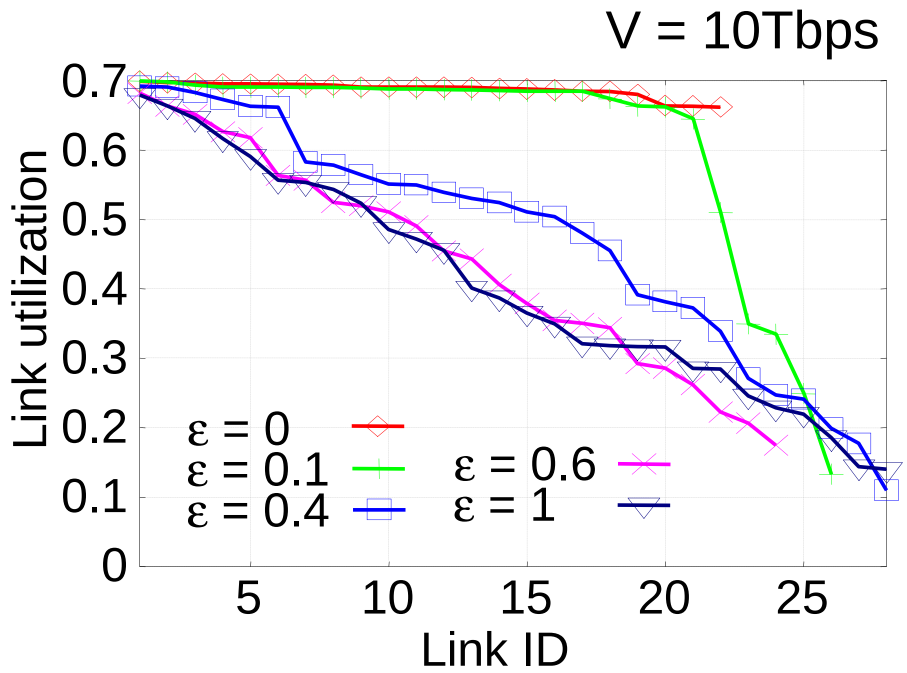


ε = 1

- 交流トラヒックが大きい場合，多数の対地にダイレクトリンクを設置

パラメタεの影響: 正常時のリンク使用率





- ε=0のとき，全リンクの使用率が
  規定上限γに近い．
- ε=0.1のとき，少数のリンクの
  使用率が大きく低下(過剰設計)
- εが0.4程度より大きい場合，