Differentiated Traffic Engineering for Providing QoS in networks

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Outline

- Bandwidth management vs. Bandwidth over-provisioning
- Differentiated Traffic Engineering (DTE): Selective over-provisioning
- DTE two stage Structure
    - Path to Class Assignment
    - Load Distribution
- DTE Challenge: Non-convexity
- Simulated Annealing for path to class assignment
- Gradient Projection for Load Distribution
- Simulation Results & Discussion
- Summary and Future Work

Bandwidth management v.s. Over-provisioning for QoS

Bandwidth Management:

- *Allocate and control the serving rate of each class of traffic by means of classification, shaping, policing, scheduling, …*

Advantages:

- *BW efficient.*
- *Predictable performance.*
- *Flexible.*

Problems:

- *Operational and management complexity and cost.*
- *Hard to monitor and troubleshoot.*
- *Functional complexity in routers.*

Bandwidth Over-provisioning:

- *Operate the networks at low utilization and increase the network capacity when needed to avoid congestion*

Advantages:

- *Relatively simple to operate, manage and trouble shoot.*

Problems:

- *BW Inefficiency.*
- *Unpredictable performance.*
- *Sensitive to network planning assumptions.*

Objectives of (Differentiated) Traffic Engineering

- Common Objectives for Traffic Engineering:
  - To avoid congestion points and route traffic around them.
  - To provide alternative paths once the primary path is faced with failure.
- Additional Objective for the Differentiated Traffic Engineering:

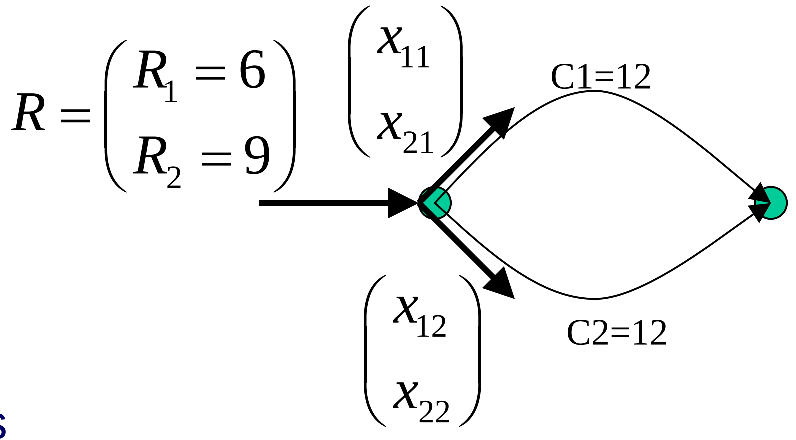
To provide differentiated paths for different classes of service, in order to selectively over-provision the paths and links in the network.

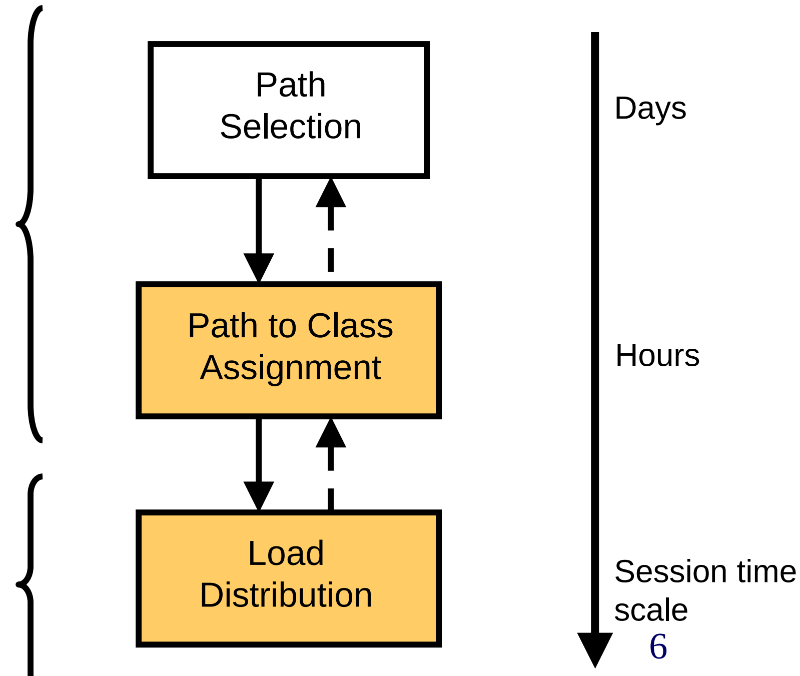
Differentiated Traffic Engineering

- Highlights:
  - Classification and policing of the traffic only at the edge for routing.
  - No sophisticated per-packet QoS enforcing operation in the core such as scheduling and shaping (simple FIFO queues).
  - Requires only link utilization monitoring.
  - It requires multi-path source based routing (MPLS, ATM, Overlay).

Differentiated Traffic Engineering Structure

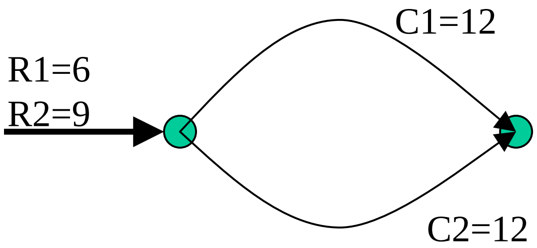
- **Assumptions:**
  - Class 1 and 2 traffic demands are given.
  - A group of path between every source-destination (S-D) pair is given.
  - Utilization of the links carrying class 1 traffic below 0.5 and other links below 1.
- **Two Stage Approach**
  - Path to class assignment unit: specifies the paths that will carry class 1 traffic.
  - Load Distribution unit: specifies how traffic load is distributed among paths.





DTE Characterization

➢ The DTE optimization problem is inherently non-convex: Example:

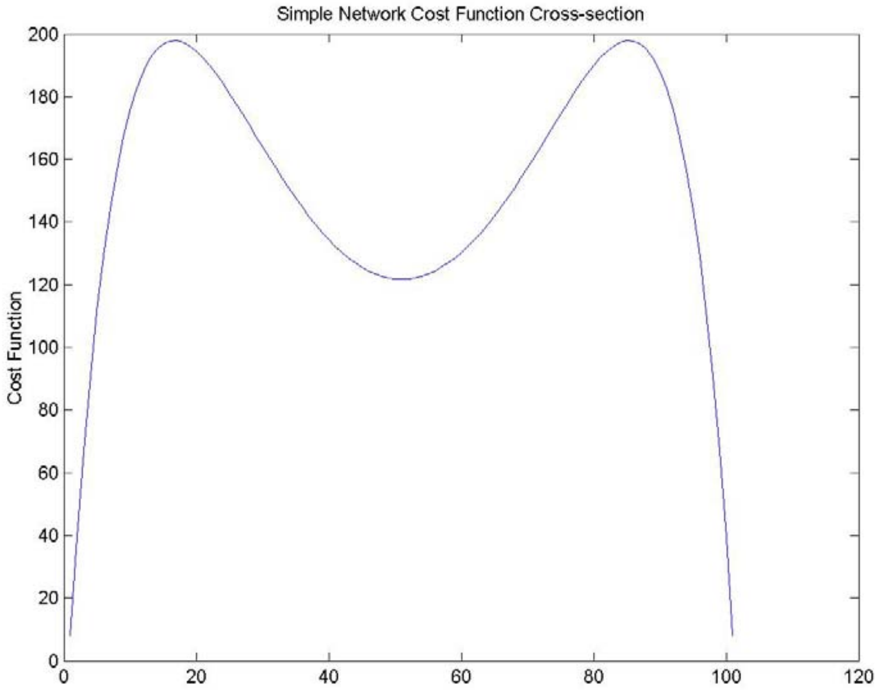


$$X^1 = \begin{pmatrix} 6 & 0 \\ 0 & 9 \end{pmatrix}, \text{ and } X^2 = \begin{pmatrix} 0 & 6 \\ 9 & 0 \end{pmatrix}$$

are both optimum solution, and due to symmetry the

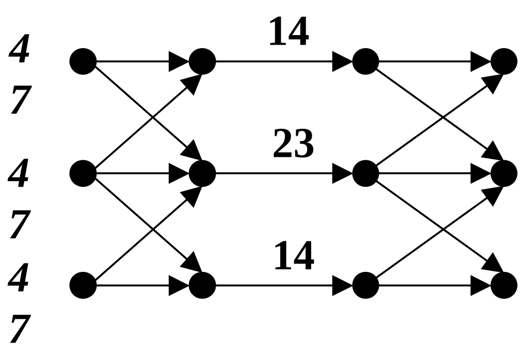
mid-point $X^3 = \begin{pmatrix} 3 & 3 \\ 4.5 & 4.5 \end{pmatrix}$

is also an extreme point



Two Stage Approach

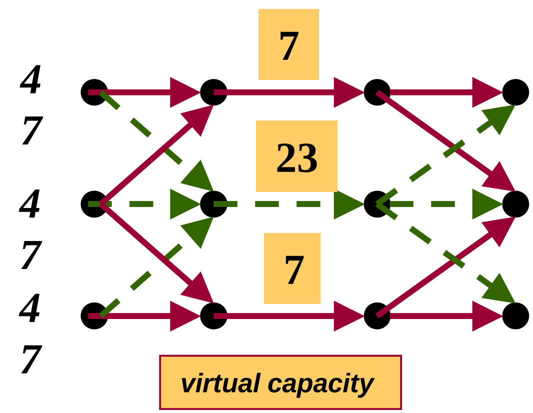
- At each iteration:
  1. Path to class assignment unit uses Simulated-Annealing optimization algorithm to specify the paths that are used for class 1 traffic.



Path to class Assignment

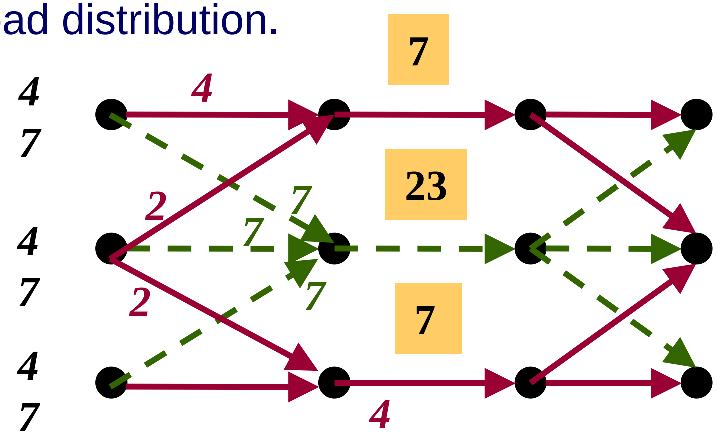
$$S = (1\ 0\ 1\ 0\ 1\ 0\ 1)$$

Specifies virtual capacity of the links



  2. Load Distribution unit uses the Gradient-Projection method to determine the optimum load distribution.

Load Distribution



$$X = \begin{pmatrix} 4\ 0\ 2\ 0\ 2\ 0\ 4 \\ 0\ 7\ 0\ 7\ 0\ 7\ 0 \end{pmatrix},$$

$$COST(X)$$

Gradient Projection for Load Distribution

- Path assignment specifies the *virtual capacity* of the links:

$$\tilde{c}_l = \begin{cases} 0.5c_l & \text{if link } l \text{ belongs to a path } p \text{ with } s_p = 1 \\ c_l & \text{otherwise} \end{cases}$$

- Cost:

$$\omega_l = \begin{cases} \dfrac{w_l}{\tilde{C} - w_l} & \text{if} \quad w_l < H\tilde{C}_l \\ \dfrac{\exp((w_l)/(\tilde{C}_l(1-H))}{\tilde{C}_l(1-H)^2 \exp(1/(1-H))} & \text{if} \quad w_l \geq H\tilde{C}_l \end{cases}$$

$$COST(\underline{X}) = \sum_{l=1}^{L} \omega_l$$

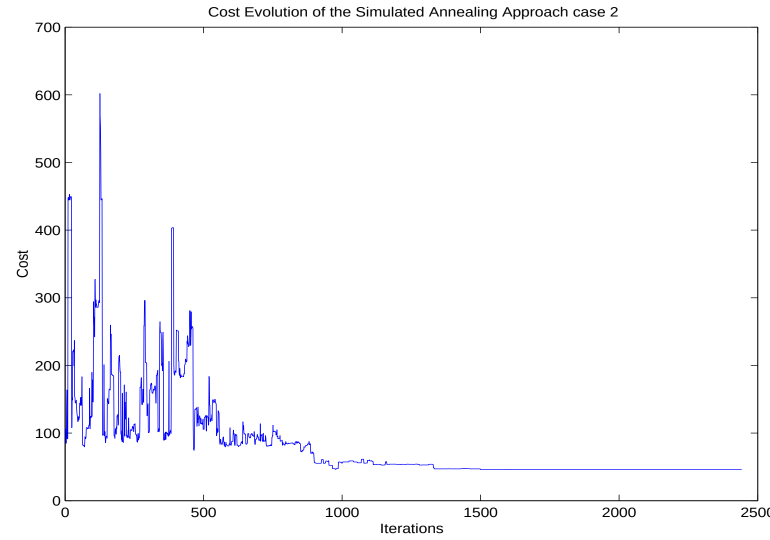
- Network Constraints are presented in the cost function.
- Source Constraints: (p: paths, s: S-D pairs, c :classes of traffic)

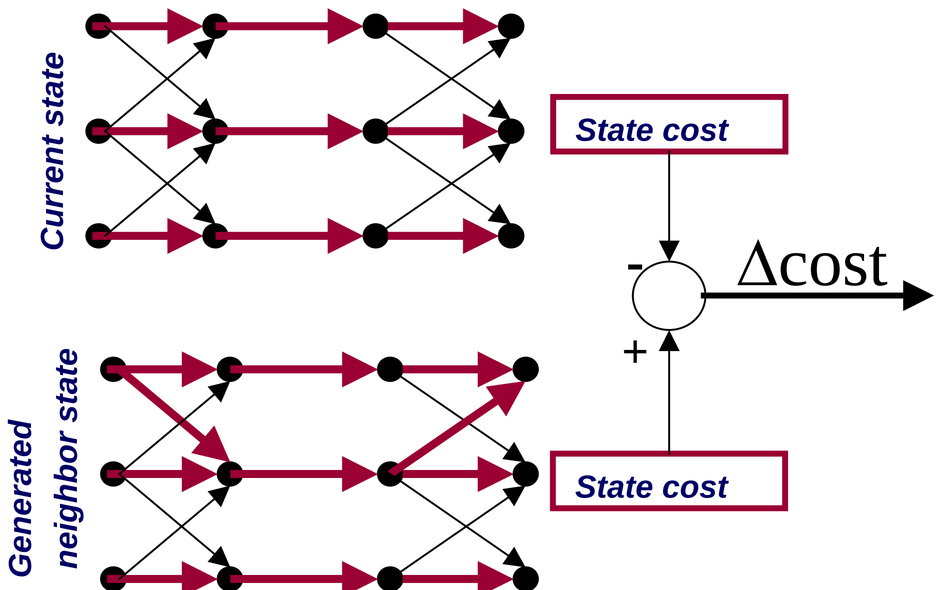
$$\sum_{p \in s} x_{cp} = r_{cs} \quad c \text{ (class)} = 1,2 \quad s \text{ (source)} = 1, \cdots, S$$

- Measurement based gradient algorithm can be used to solve this problem

Simulated Annealing for the Path to Class Assignment

- Simulated annealing is a randomized optimization algorithm.
- Objective:To find the state with minimum cost (energy).
- Initial value for the parameter T (temperature) is high and it decreases slowly.
- At every iteration a neighbor state of the current state is generated randomly.





Neighbor state is selected if:

Delta is negative

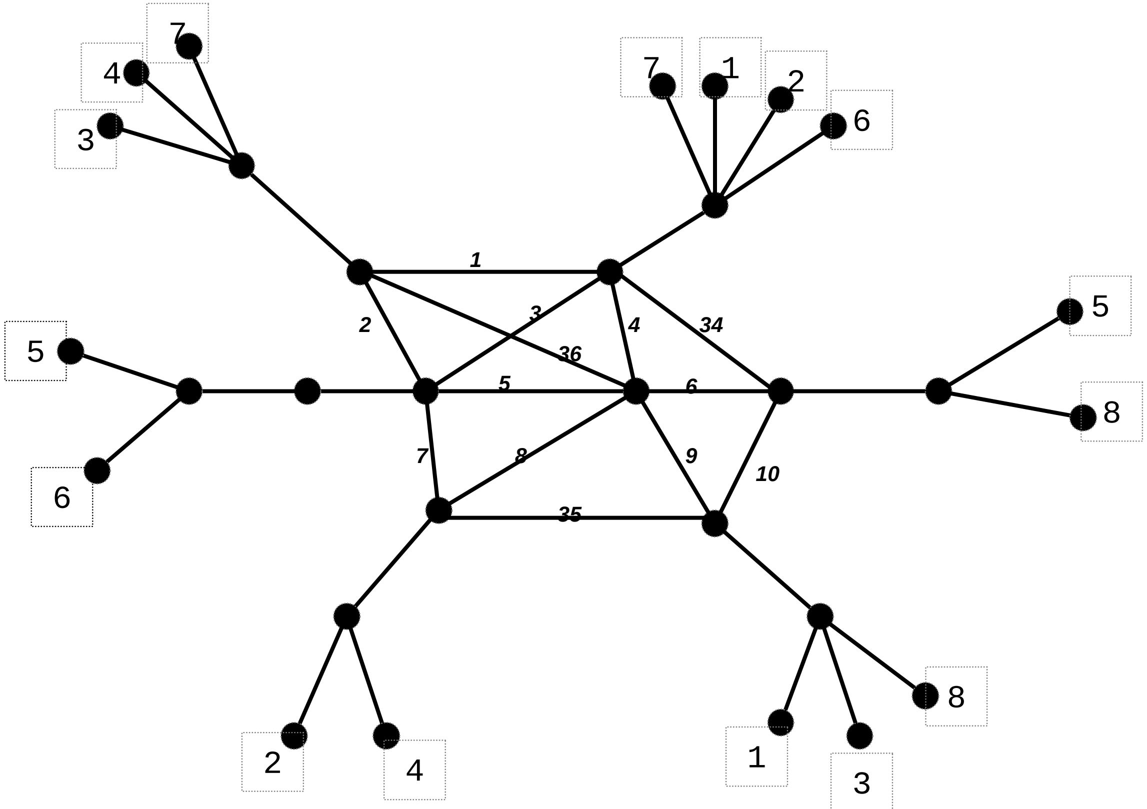
And with probability

$$p = \exp\left(-\frac{(\Delta \text{cost})}{T_k}\right)$$

for positive delta

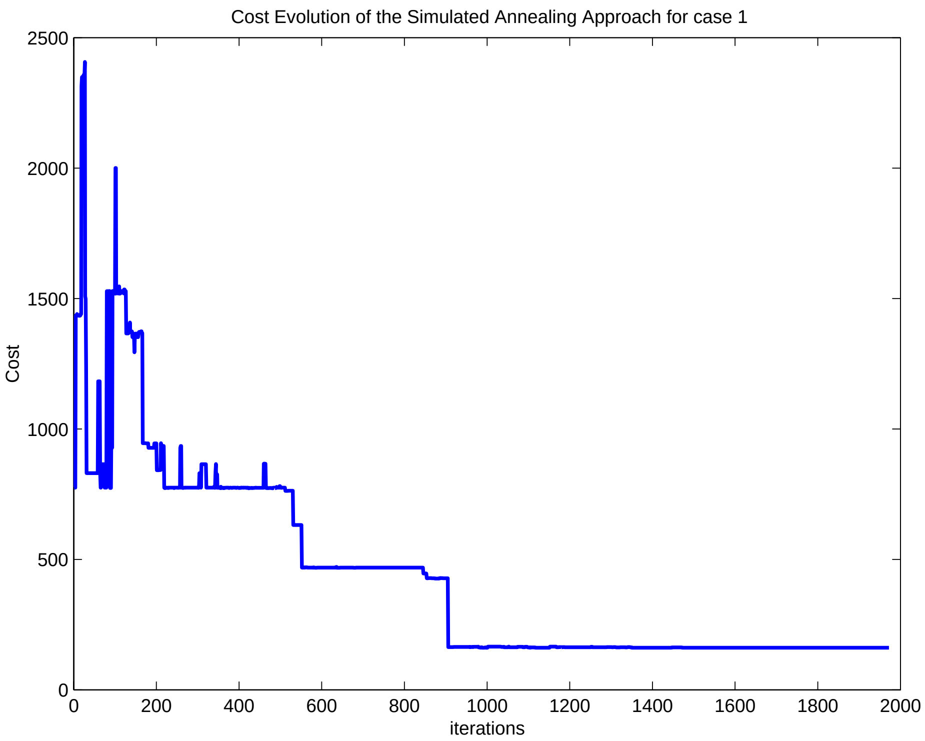
Simulated Network

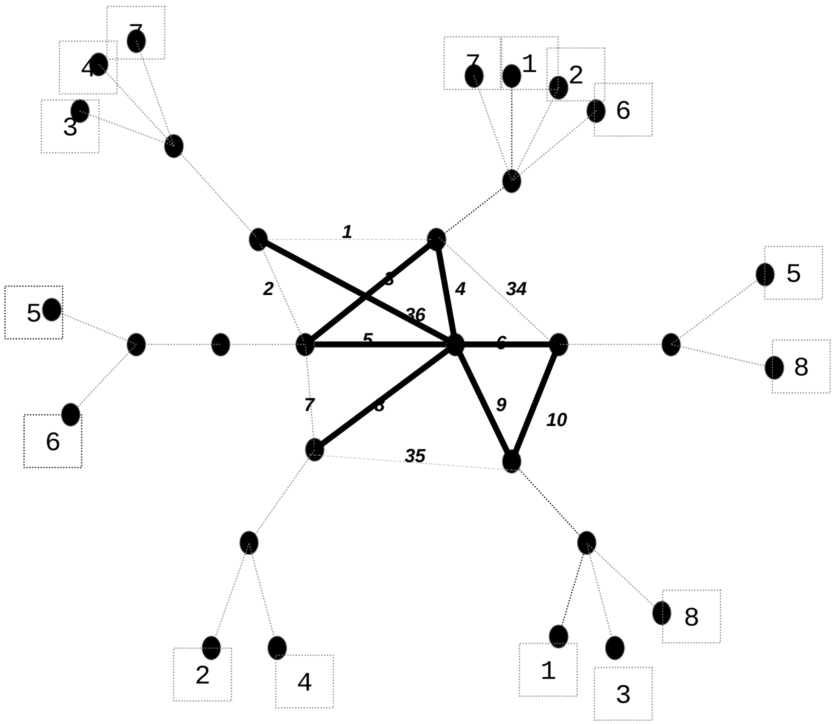
- Traffic rate for each S-D pair:
  - Class 1: 1 unit
  - Class 2: 2 units
- Capacity of the links:
  - Outer loop links: 7 units
  - In the loop link: 8 units
- Total of 29 paths:
  - (5, 3, 4, 5, 3, 3, 4, 2)
- There is at least one path through the outer loop links and one through In the loop links for each S-D pair.



- *Outer loop links: (1, 2, 7, 35, 10, 34)*
- *In the loop links: (3, 4, 5, 6, 8, 9, 36)*

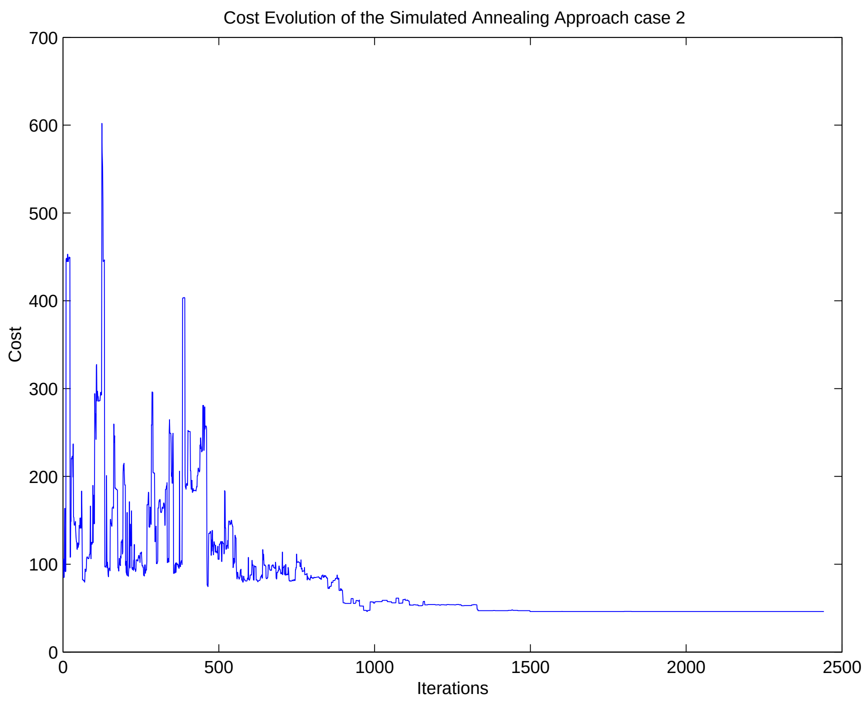
The DTE Simulation

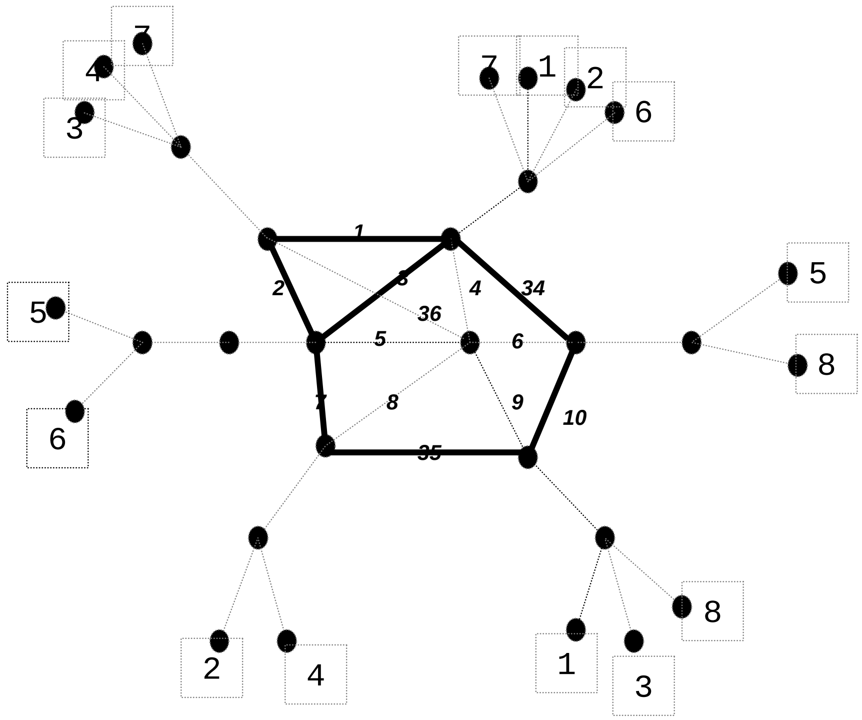




- Total Number of States = 31x7x15x31x7x7x15x3 = 222,495,525
- Total Number of Visited States = 1097
- Inner links are selected for the class 1 traffic

Results after increasing capacity of the bottleneck links in the loop





- Cost of the DTE result = 46.063
- Cost of the state that uses only outer loop links for class 1 = 62.8117

Network Graph

- 10 S-D pairs:

(1,5), (1,6), (1,14),(1,18)

(5,6), (5,14), (5,18)

(6,14), (6,18)

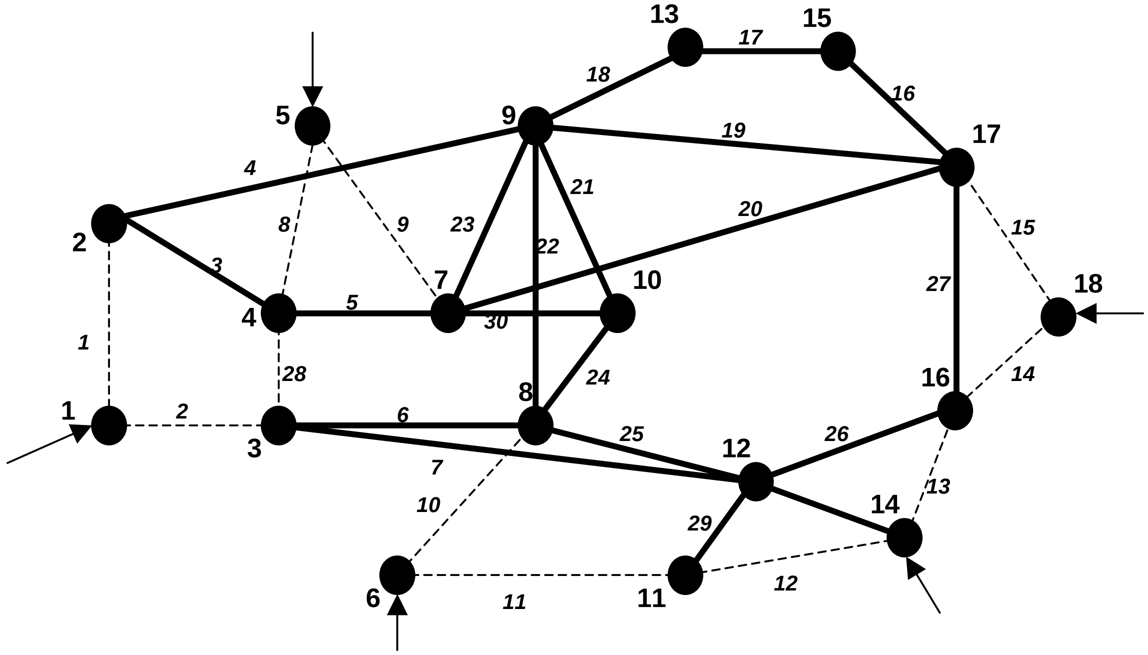
(14,18)

- 60 links, 50 paths
- Capacity of the dashed links 50
- Capacity of the solid links 20
- Traffic demand for each S-D pair:

  Run1: (2, 5)

  Run2: (3, 5)

  Run3: (4, 5)



Simulation Results

Nominal Traffic Demand \ Real Traffic Demand		(2,5)	(3,5)	(4,5)
(2,5)	U1max	0.3218	0.45	0.6
	U2max	0.6225	0.686	0.7405
(3,5)	U1max	0.3087	0.3972	0.5161
	U2max	0.7078	0.7554	0.8102
(4,5)	U1max	0.3466	0.39	0.4267
	U2max	0.7124	0.769	0.818

- Observation:

  When the real traffic demand is lower than the nominal traffic demand the utilizations are close to the optimum.

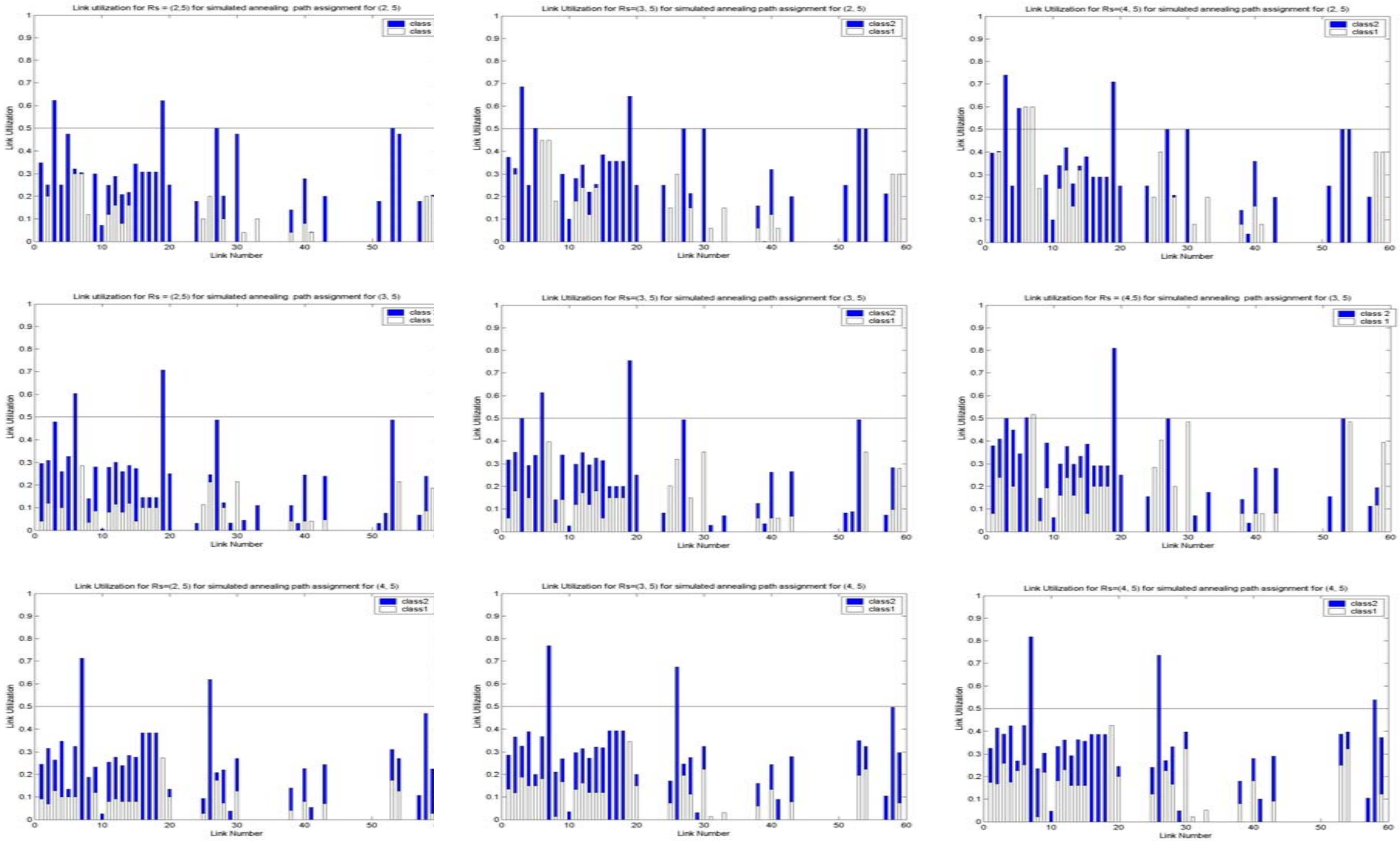
Do the path assignment with an upper estimate of the traffic demand.

Utilization charts for all links

Real Traffic Demand

Rs=(2,5) *Rs=(3,5)* *Rs=(4,5)*

Nominal Traffic Demand: *Rs=(2,5)*, *Rs=(3,5)*, *Rs=(4,5)*



Summary

- Main idea:
  - Select different paths for different classes of service and over-provision the links according to their associated classes.
- Result:
  - Simplifies packet processing and network management while providing enough flexibility and efficiency.
- Challenge:
  - Non-convex optimization problem.
- Two Stage Approach:
  - Stage 1: Simulated Annealing for path to class assignment.
  - Stage 2: Gradient Projection for load distribution.

Future Work

- Multi-path Routing
  - Robust Routing that Considers Deviations from Nominal Traffic Demand.
- Dynamic behavior of the DTE architecture:
  - CAC.
  - How to derive the Nominal Traffic Demand?
  - How often or when do we need to run the path to class assignment?
  - Alternative link cost functions?
- Implementation issues:
  - How can we employ the DTE architecture in an IP or MPLS network.