Differentiated Traffic Engineering for Providing QoS in Networks

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Introduction

Objective:

- ***To provide an efficient and simple mechanism for QoS provisioning in IP networks.***

Alternative Approaches for QoS Provisioning:

1- Bandwidth Management:

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

Advantages:

- *BW efficiency.*
- *Flexibility.*

Problems:

- *Management Complexity and Cost.*
- *Functional complexity in routers.*

Introduction

Objective:

- ***To provide an efficient and simple mechanism for QoS provisioning in IP networks.***

Alternative Approaches for QoS Provisioning:

2- Bandwidth Over-provisioning:

- *Operate at low utilization and over design network to avoid congestion*

Advantages:

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

Problems:

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

Differentiated Traffic Engineering (DTE)

- DTE is a mechanism for path selective over-provisioning.

- Main Objective of Traffic Engineering:
  - To balance load in network and avoid congestion for better performance.

    Better Performance Requires Lower Congestion and Utilization.
  - *Load balancing concept work well for a homogenous network.*

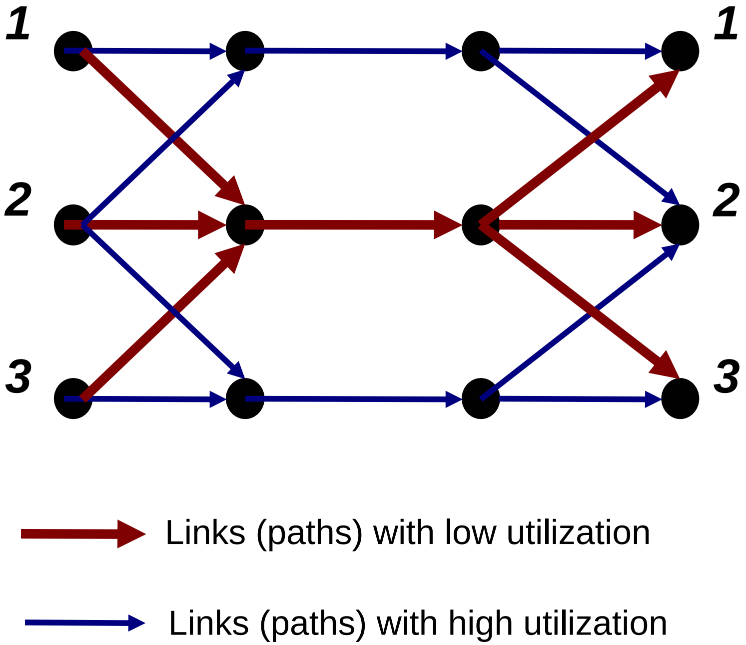
- *Differentiated services require different performance levels, and hence can tolerate different levels of congestion and utilization in network.*

DTE Advantages

Main idea:

Distribute traffic classes among different paths so that the acceptable utilization levels for all classes are satisfied.

- Efficiency
- Flexibility
- Simplicity

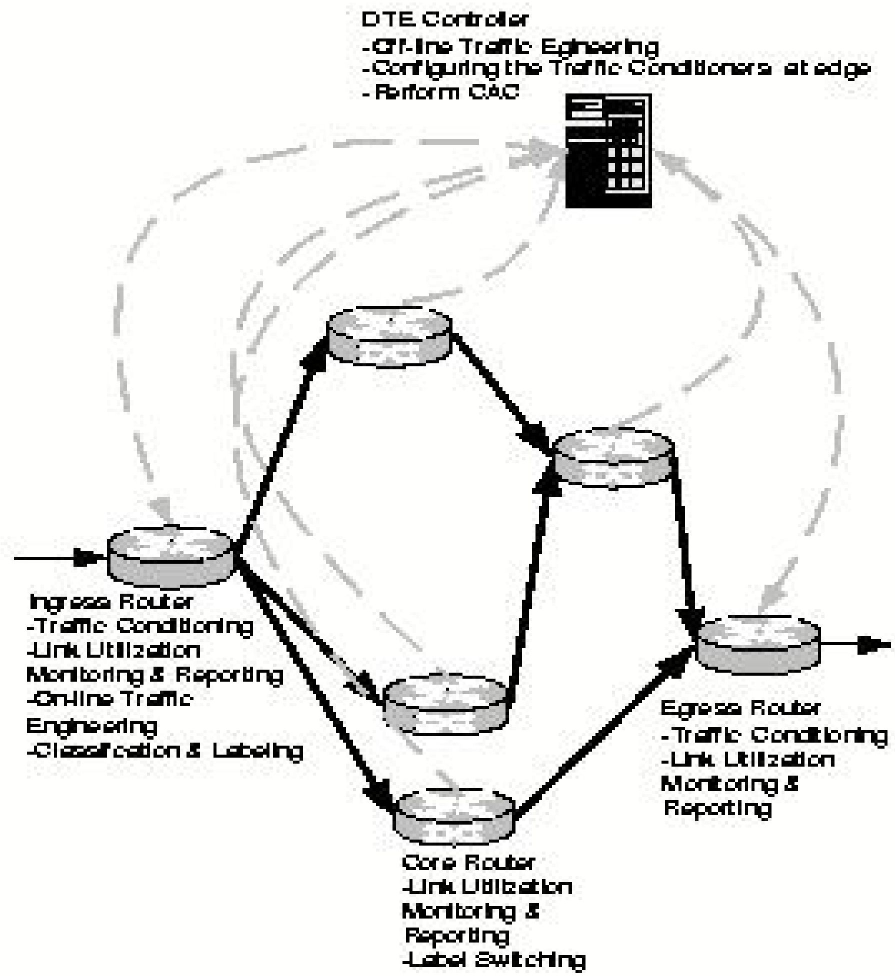


Outline

- Assumptions and Model
- Path Selection Algorithm
- Simulation Results
- Future Work

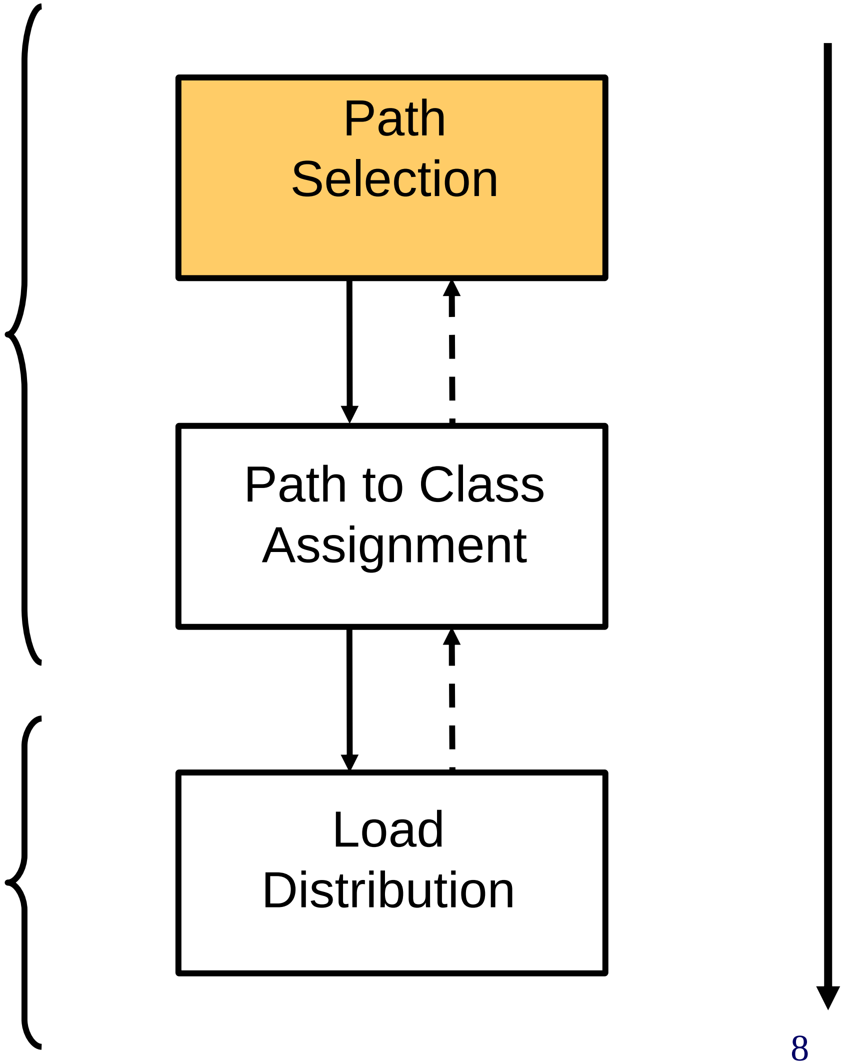
Assumptions and Model

- Traffic Demand for two traffic classes:
  - Class 1: Real Time (RT).
  - Class 2: Best Effort (BE).
- Centralized DTE Controller.
- MPLS Network
- Edge Routers:
  - Link Utilization Monitoring.
  - Traffic Classification and labelling.
  - Traffic Shaping.
- Core Routers:
  - Link Utilization Monitoring.
  - Routing (label switching).



DTE Algorithms

- Path Selection (Centralized): Our focus today
- Path Assignment (Centralized): Simulated Annealing (Talked about it in last meeting)
- Load Distribution (Distributed): Gradient Projection



Problems with simulated annealing

- It is very slow.
- It should be run centralized and off-line.
- It needs to re-compute the entire solution.

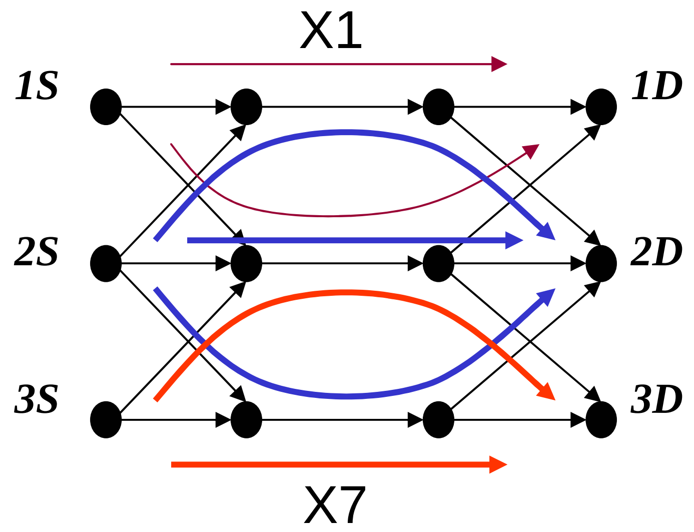
Path Selection Algorithm

Path Selection (Single Class Case)

- Cost function: $D(\underline{X}) = \sum_{l=1}^{L} d_l,$

$$d_l = \frac{u_l}{c_l - u_l}$$

- Constraint: $\sum_{p \in P_s} x_p = r_s \quad s = 1, \cdots, S$



- We can use Gradient Projection Method to find the optimal solution.
- ***Problem:*** Number of the paths grows exponentially. It is not scalable to consider all paths explicitly.
- But, do we need to consider all paths all the time?
  - *No, because most paths have zero rate.*

Path length and the optimality condition

- *Optimality Condition: All non-zero rate paths have minimum cost gradient.*

$$D(X) = \sum_{l=1}^{L} \frac{u_l}{c_l - u_l}, \qquad \frac{\partial D(X)}{\partial x_i} = \sum_{l \in L_p} \frac{d\left(\frac{u_l}{c_l - u_l}\right)}{du_l}$$

- Link length $= \frac{d\left(\frac{u_l}{c_l - u_l}\right)}{du_l}$

All non-zero rate paths are shortest paths.

- Algorithm:
  - Start with an initial set of active paths, after convergence find the shortest path, and add it to the active set and run the algorithm with the augmented active path set.
  - Continue, until no new path is added.

Path Selection for DTE (cost function)

- What is an appropriate cost function?
  - u_l is the class 1 traffic rate.
  - v_l is the class 2 traffic rate.

$K = 0.5$

$H = 0.9$

$$d_l(u_l, v_l) = \begin{cases} \dfrac{u_l}{KC-(u_l+v_l)} + \dfrac{v_l}{C-(u_l+v_l)} & if \quad u_l+v_l < KHC \\ \dfrac{u_l \exp((u_l+v_l)/(KC(1-H))}{KC(1-H)\exp(H/(1-H)} + \dfrac{v_l}{C-(u_l+v_l)} & if \quad KHC \le u_l+v_l < HC \\ \dfrac{u_l \exp((u_l+v_l)/(KC(1-H))}{KC(1-H)\exp(H/(1-H)} + \dfrac{v_l \exp((u_l+v_l)/(C(1-H))}{C(1-H)\exp(H/(1-H)} & if \quad u_l+v_l \ge HC \end{cases}$$

Non-Convexity Problem

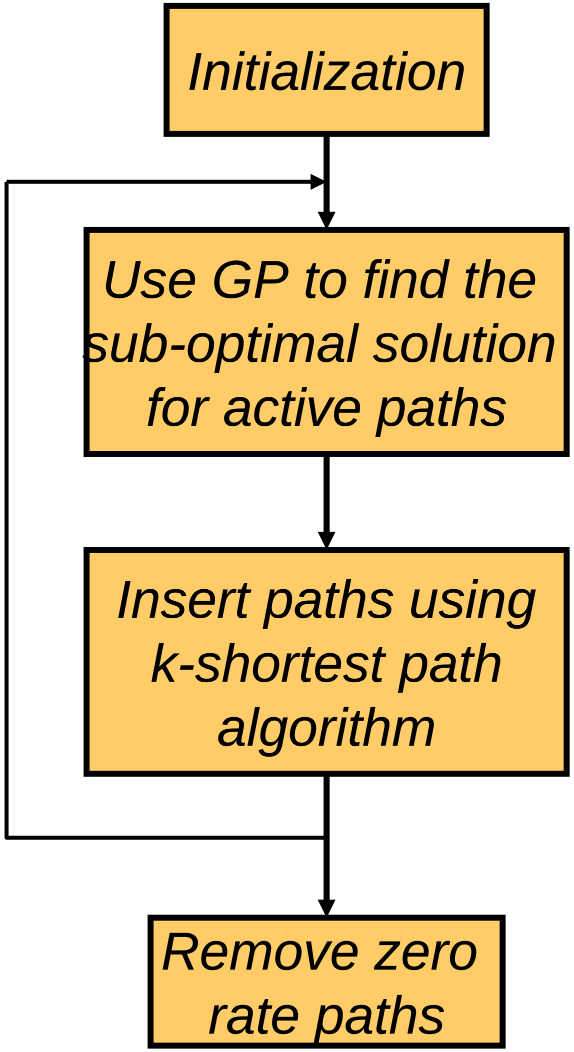
- Problem: There might be non-shortest-paths that should be introduced.
- Solution: Instead of inserting shortest path

  introduce k-shortest paths w.r.t $\frac{\partial d_l(u,v)}{\partial u}, \frac{\partial d_l(u,v)}{\partial v}$.

- Problem: We can fall into a cycle of inserting and removing paths.
- Solution: At the intermediate stages only insert path and remove paths at the end.

The Path Selection Algorithm

- *Start with k=1 and an initial path set*
- *While (k <= Kmax) && (solution is not admissible)*
  - *While there is new paths added to the active path set*
    - *Use Gradient Projection to find the sub-optimal load distribution over active paths.*
    - *Find k-shortest paths based on MDL of class 1 and 2 traffic and add them to the active path set.*
  - *Increment k.*
- *Remove those paths with zero rate in the active path set.*



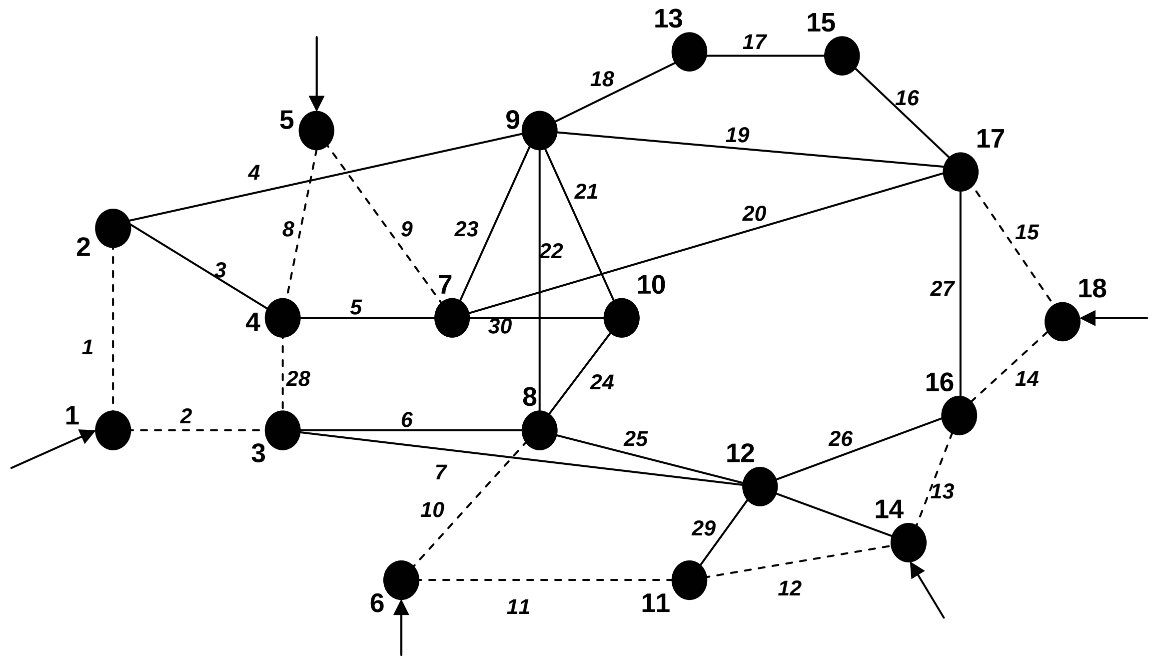
Simulation Results

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
- Capacity of the dashed links 50
- Capacity of the solid links 20
- Traffic demand for every S-D pair is the same: (R1, R2).



Path Selection Algorithm

Traffic Rate (4, 5), k=1

Path Count	10	19	30	42	51	55	41	31
Added Path	9	11	12	9	4	10	0	
Removed Path	0	0	0	0	0	24	10	

Admissible

Traffic Rate (5, 5), k=1

Path Count	31	43	52	56	43	33
Added Path	12	9	4	8	0	
Removed Path	0	0	0	21	10	

Admissible

Traffic Rate (6, 5), k=1

Path Count	33	44	55	64
Added Path	11	11	9	
Removed Path	0	0	0	

Not admissible

Path Selection Algorithm

Traffic Rate (6, 5), k=1

Path Count	33	44	55	64
Added Path	11	11	9	
Removed Path	0	0	0	

Not admissible

Traffic Rate (6, 5), k=2

Path Count	64	78	101	103	110
Added Path	14	23	2	7	
Removed Path	0	0	0	0	

Not admissible

Traffic Rate (6, 5), k=3

Path Count	110	140	151	64	39
Added Path	30	11	23	0	
Removed Path	0	0	110	25	

Admissible

$\text{Old paths in } P(5,5) = 25$ $\qquad$ $\text{Old paths in } P(6,5) = 21$

$\text{New paths in } P(5,5) = 6$ $\qquad$ $\text{New paths in } P(6,5) = 18$

Maximum Utilization Comparison

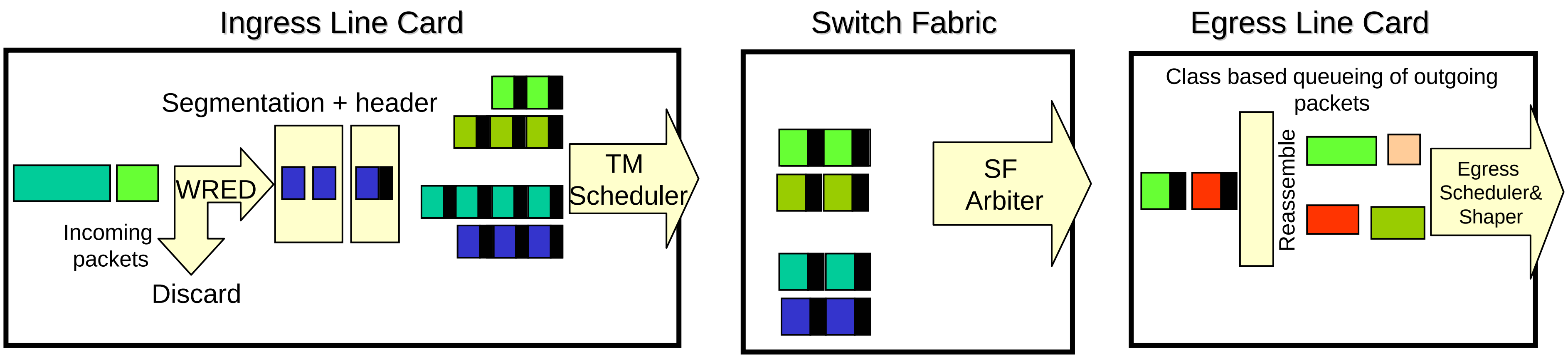
- Maximum Utilization for different rates:

Traffic Matrix	(4,5)	(5,5)	(6,5)
U1max	0.4	0.4545	0.4588
U2max	0.6532	0.7586	0.8745

- What if we use k-Minimum hop paths with R=(6,5):
  - K = 3: U1max = U2max = 0.6572
  - K = 5: U1max = 0.6029, U2max = 0.8637
- Simulated Annealing can not improve the performance.

Recap

- QoS Provisioning relies on multi-stage per class traffic shaping and scheduling of packets in each router.



- **Operational Cost: Operator should set all the parameters correctly to provide guaranteed services.**
- **Operators nightmare: What if I did not set the parameters correctly? Do I have the tools to identify the parameters that are not set correctly?**

DTE is an alternative approach that does not rely on complex packet level processing.

What's Next?

- So far, we have relied on source based routing.
- What about a pure IP network? Can we use per-hop routing?

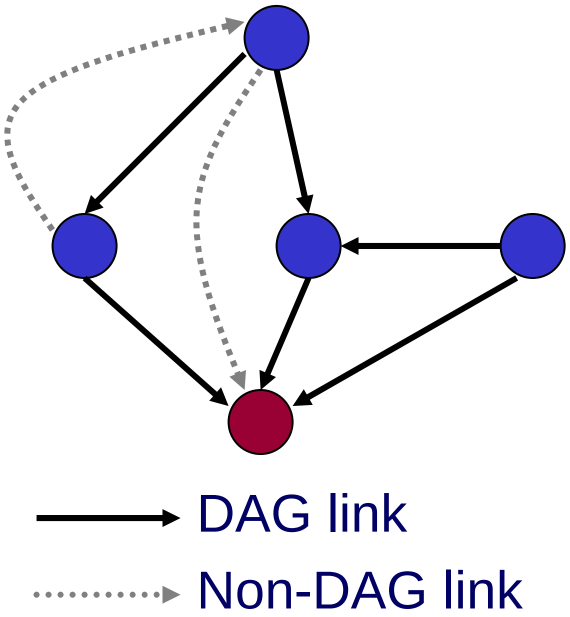
- *Observation:* We are always using minimum derivative length paths.

- Every router can use shortest path routing and move traffic to the next hops with minimum distance to the destination.

- *Problem:*
  - It is possible to have loops in paths due to asynchronous info. updates.
  - Slow convergence to the final solution.

General Sketch

- Every destination is responsible for computing, updating and informing other nodes of their successor set (next hops) .
  - Destination uses the information regarding average utilization of the network links and k-shortest path algorithm to establish the DAG.
  - To avoid loops every node will use a successor node only after receiving updated info. from it.
- Every node locally decides how to balance the load between its successors, based on the local information received from its successor.



Summary

- DTE is introduced as a simple and efficient mechanism for QoS provisioning in networks.
- Path assignment algorithm: Based on simulated annealing.
- Path selection algorithm: Based on k-shortest path, MDL, and gradient projection.
- Path selection algorithm: Appears to be effective and fast and does not need to rely on path assignment for load distribution.
- Next step: Get rid of the source based routing assumption.