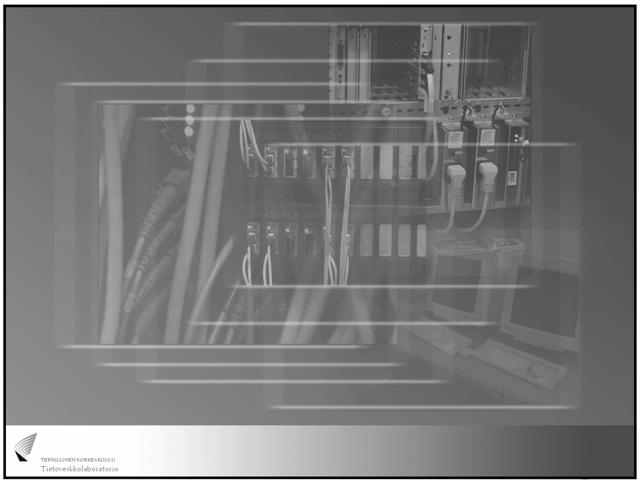

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Traffic Engineering

Lecture for QoS in the Internet –course
S-38.3180

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Concept of Traffic Engineering (TE)

- Traffic Engineering (TE) (Traffic Management) is a field of communications engineering that tries to make network operations more **effective** and **reliable** while at the same time **optimizing resource utilization**
- *"Application of technology and scientific principles to the measurement, characterization, modeling, and control of Internet traffic"*
- Traffic engineering ~ Traffic measurements + Traffic classification + Bandwidth management + Traffic Shaping + Protocol tuning
- RFC 3272: *Overview and Principles of Internet Traffic Engineering*

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Some problems that TE tries to solve

- Effective bandwidth utilization on the path that packets are *currently using*
- Effective bandwidth utilization *within an Autonomous System*
- Optimal policy usage *between Autonomous Systems* (BGP TE)
- Fast connectivity restoration after a component breakdown (IGP Fast Convergence, MPLS Fast Re-Route, etc.)

➢ Result: Happier users = more money

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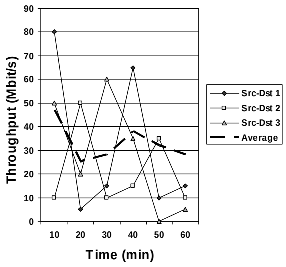
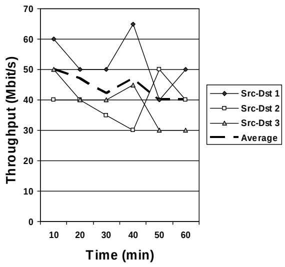
Some TE goals illustrated (1/4): Better throughput

Without TE



With TE



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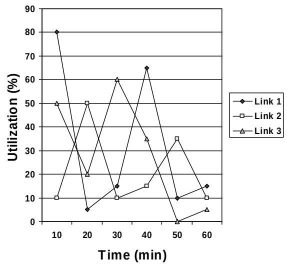
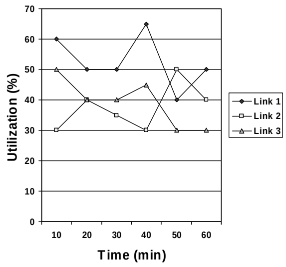
Some TE goals illustrated (2/4): More equal link utilization

Without TE



With TE



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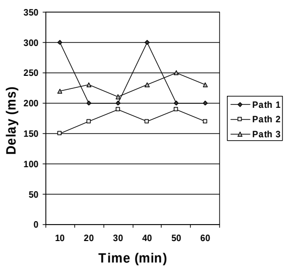
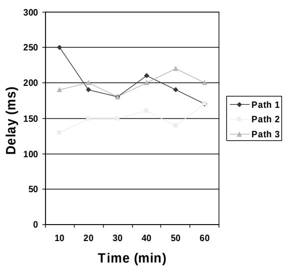
Some TE goals illustrated (3/4): Smaller delay

Without TE



With TE



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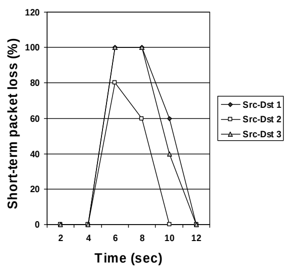
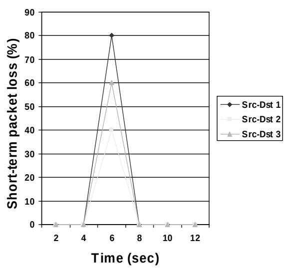
Some TE goals illustrated (4/4): Faster route convergence

Without TE



With TE



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Need for TE

- At the network's edges: Definite
  - Need to identify and stop e.g. DoS attacks
- Within ISP backbones: Questionable
  - Many ISP networks are heavily over-provisioned (peak link utilizations around 10%)
  - Backbone capacity is relatively inexpensive
  - TE introduces additional complexity into the network, which might lead to connectivity problems
  - If more capacity or higher connectivity is needed, it could be argued, that it is easier just to add hardware into the network than perform TE
  - However, by carefully using TE, some problems may be solved at lower cost
- Between ISP domains: Growing

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Requirements for TE: Policy System

- TE systems consist of a set of rules (Policy) that are propagated to enforcement points
  - Policy must be enforced to ensure that the users are behaving properly
- Policy: A definite goal, course or method of action to guide and determine present and future decisions
- Hierarchical policy systems possible (Action Policies, Goal Policies, Utility function Policies)

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Hierarchical policy system

- Three (3) policy levels may be used
  1) *Action* policies (**IF** condition **THEN** action)
     - Elements employing action policies MUST measure and/or synthesize the quantities stated in the condition
  2) *Goal* policies ("Response time must not exceed 2 sec.")
     - Elements employing goal policies MUST possess sufficient modeling or planning capabilities to translate goals into actions
  3) *Utility function* policies (automatically determine the most valuable goal in any situation)
     - Elements employing utility funtion policies MUST have sophisticated modeling and optimization capabilities to translate utility functions into actions

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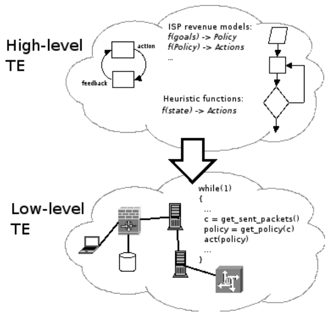
TE in practice

- High-level TE concepts (ISP revenue models, conceptual frameworks, policies, flowcharts, heuristic functions, etc.) must be mapped (coded) into the network's components



TE method classification

- TE methods can be classified in many ways:
  - Short term vs. Long term TE
  - Intra-domain vs.Inter-domain TE
  - Centralized vs. Distributed TE
  - On-line vs. Off-line TE
  - Perfomance optimizing vs. Availability maximizing TE
  - Host-based vs. Network-based TE
  - …

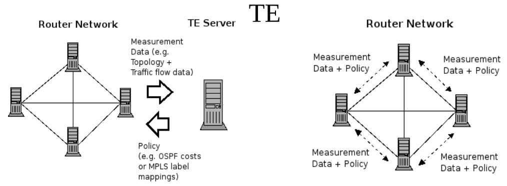
Classification 1/6: Short-term vs. Long-term TE

- Short-term TE
  - Time scale milliseconds
  - Example: What should a router do with a data packet: drop it, forward it or put it to queue?
- Medium-term TE
  - Time scale seconds-minutes
  - Example: Should a router allow a connection to be established?
- Long-term TE
  - Time scale hours-days
  - Example: Which BGP-policy should be configured to the AS?

Classification 2/6: Inter-domain vs. Intra-domain TE

- Inter-domain TE
  - Tries to optimize network resource usage on a global (inter-domain) scale
    - Example: BGP TE
- Intra-domain TE
  - Tries to optimize resource usage within the ISPs own network
    - Example: MPLS TE

Classification 3/6: Centralized vs. Distributed TE



- Centralized TE has one Policy Decision Point (PDP) (= TE Server) and routers are Policy Enforcement Points (PEP)
- Benefit: Simple implementation
- Drawback: Single point of failure

- Distributed TE has no centralized PDP
- In distributed TE, routers may exchange measurement data and decide on the policy themselves
- Benefit: Robust to failures
- Drawback: Often complicated implementation

Classification 4/6: On-line vs. Off-line TE

- Not so well-defined terms
- On-line TE basically means that policy is decided dynamically (and usually relatively quickly)
- On-line TE must usually be ”autonomic” i.e. computer-controlled (controller computer(s) must have certail utility function(s) to base their decisions on)
- Off-line TE usually has slower response times and human operator may decide the functional policies that are used in the network
- Performance may be equally good

Classification 5/6: Perfomance optimizing vs. Availability maximizing TE

- Some TE methods try to maximize the network’s throughput, minimize the average delay that users experience, or minimize the jitter in delay
  - Important in commercial networks
- Others try to maximize the robustness (availability) of the network
  - Important in mission-critical networks
- Both goals are important in most networks

Perfomance optimizing TE (Classification 5/6 continued)

- Optimization problems are often NP-hard (problem difficulty grows exponentially as a function of problem size)
- It takes too long to find a globally optimal solution -> *heuristical* algorithms needed
- *Heuristic* is usually a mathematical function that assists in making good ”guesses” about what could be a good solution
- Heuristic can be used to guide a trial-and-error (local) search algorithm

Classification 6/6: Host-based vs. Network-based TE

- In host-based TE methods, each sender-receiver pair controls traffic based on some policy (e.g. TCP)
- In network-based TE, the networks controls traffic (e.g. queuing methods, MPLS, IGP Metric Based TE)
- Both methods used in most networks

TE method 1/9: TCP

- TCP tries to optimize the bandwidth utilization on the path that packets are currently using
- However, it cannot solve the problem of effective resource sharing within the *network*
- Short term/Medium term, Inter-domain/Intra-domain, Distributed, On-line, Host-based, Perfomance optimizing

TE method 2/9: Queuing methods

- Also queuing methods try to optimize the band-width utilization on the path that packets are currently using
- Data packets can be placed in different queues within a router (packets must be classified before this)
- These queues may be served according to diffe-rent policies so that the packets in those queues will get service that is most suitable (according to traffic characteristics and operator policies)
- Short term, Inter-domain/Intra-domain, Distributed, (Off-line), Network-based, (Perfomance optimizing)

TE method 3/9: BGP TE

- Example: Commonly used Hot-potato BGP policy tries to minimize internal network congestion
- BGP TE may also try to optimize network resource usage on a global (inter-domain) scale
- Hasn't been so popular among ISPs for a couple of reasons (lack of business incentives, lack of available data, and a lack of sophisticated inter-domain TE tools)
- However, as the demand placed on the networks continually increases, there is a growing need for inter-domain load balancing also
- Long term, Inter-domain, Distributed, (Off-line), Network-based, (Availability maximizing)

TE method 4/9: IGP Fast Convergence

- IGP Fast Convergence tries to make optimizations to IGPs that reduce the time it takes for routes to converge
- With clever optimizations it is possible to reduce the time from 10-30 seconds to as low as one second (or even below one second) for first 500 prefixes in a well designed backbone
- What is needed to achieve fast convergence without sacrificing stability is good damping algorithms which can separate unstable components from the stable components
- Medium term, Intra-domain, Distributed, (Off-line), Network-based, Availability maximizing

TE method 5/9: Fast Re-Route

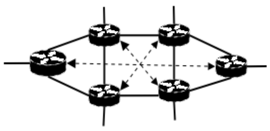
- Fast Re-Route (FRR) can be implemented with MPLS
- If correctly configured, it is usually slightly faster and more deterministic than IGP fast convergence, however, it can also perform a lot worse
- FRR uses local detection and protection at the point of failure
- May be needed for telephony users
- Medium term, Intra-domain, Distributed, (Off-line), Network-based, Availability maximizing

TE method 6/9: ECMP TE

- Equal Cost Multipath (ECMP) balances load for all equal cost paths towards a destination
- Every router performs a hash on received packets to determine which one of the paths should be used for the packet
- The hash may be a function of source address, destination address, source port, destination port etc. and can be static or dynamic
- The hashing can be performed separately for each packet or based on flows
- Medium term, Intra-domain, Distributed, (Off-line), Network-based, Availability maximizing

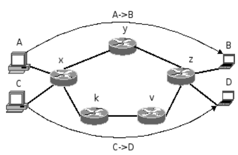
ECMP TE (continued)

- ECMP is often considered to be sufficient TE method if both topology and traffic demands are symmetrical like in the figure



TE method 7/9: MPLS TE

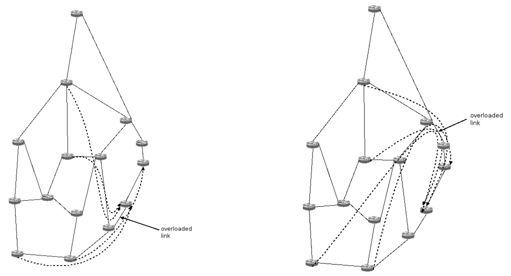
- MPLS TE enables explicit (source) routing, which is quite significant, since it makes unequal-cost load sharing possible
- In the figure, traffic load is divided evenly to unequal-cost router-paths x->y->z and x->k->v->z
- MPLS TE is somewhat complicated to deploy but when correctly configu-red, it is very effective



MPLS TE (continued)

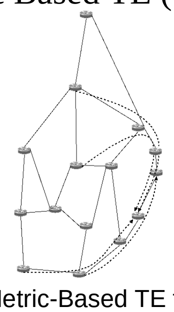
- Medium term, Intra-domain, Centalized/ Distributed, On-line/Off-line, Network-based, Performance optimizing

TE method 8/9: IGP Metric Based TE



- Tactical IGP Metric Based TE tries to alter link costs in some specific points of congestion
  - Often only shifts the point of congestion

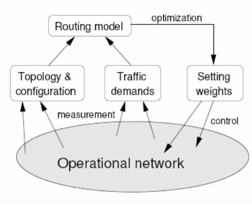
IGP Metric Based TE (continued)



- Strategic IGP Metric-Based TE tries to find an optimal link weight setting for the network (using some optimization goal(s))

IGP Metric Based TE (continued)

- The main idea in strategic IGP Metric Based TE is to 1) obtain topology and traffic information from the network, 2) feed this data to an optimization algorithm, and 3) send the optimal link weights back to the network
- The routers calculate routes based on the optimal weights and traffic gets forwarded to optimal paths
- Medium term, Intra-domain, Centralized/Distributed, On-line/Off-line, Network-based, (Performance optimizing)



TE method 9/9: Probing

- Probing in the context of traffic engineering basically means that edge routers send additional packets (probes) to the network in order to find out if certain paths towards a destination have less load than others
- Based on the responses to these probes, routers can divide load to different paths that have been pre-configured to them
- Very good results have been obtained by using the probing approach, however, this approach seems to require quite radical changes to current router software
- Short term, Inter-domain/Intra-domain, Distributed, On-line, Network-based, Perfomance optimizing

Summary

- Traffic Engineering (TE) methods try to make network operations more effective and reliable while at the same time optimizing resource utilization
- TE methods can be classified along many axis
- Many TE methods can (and should) be used at the same time
- Most suitable TE method(s) depend on the network's and users' properties