Traffic Engineering the Multi-Service Internet

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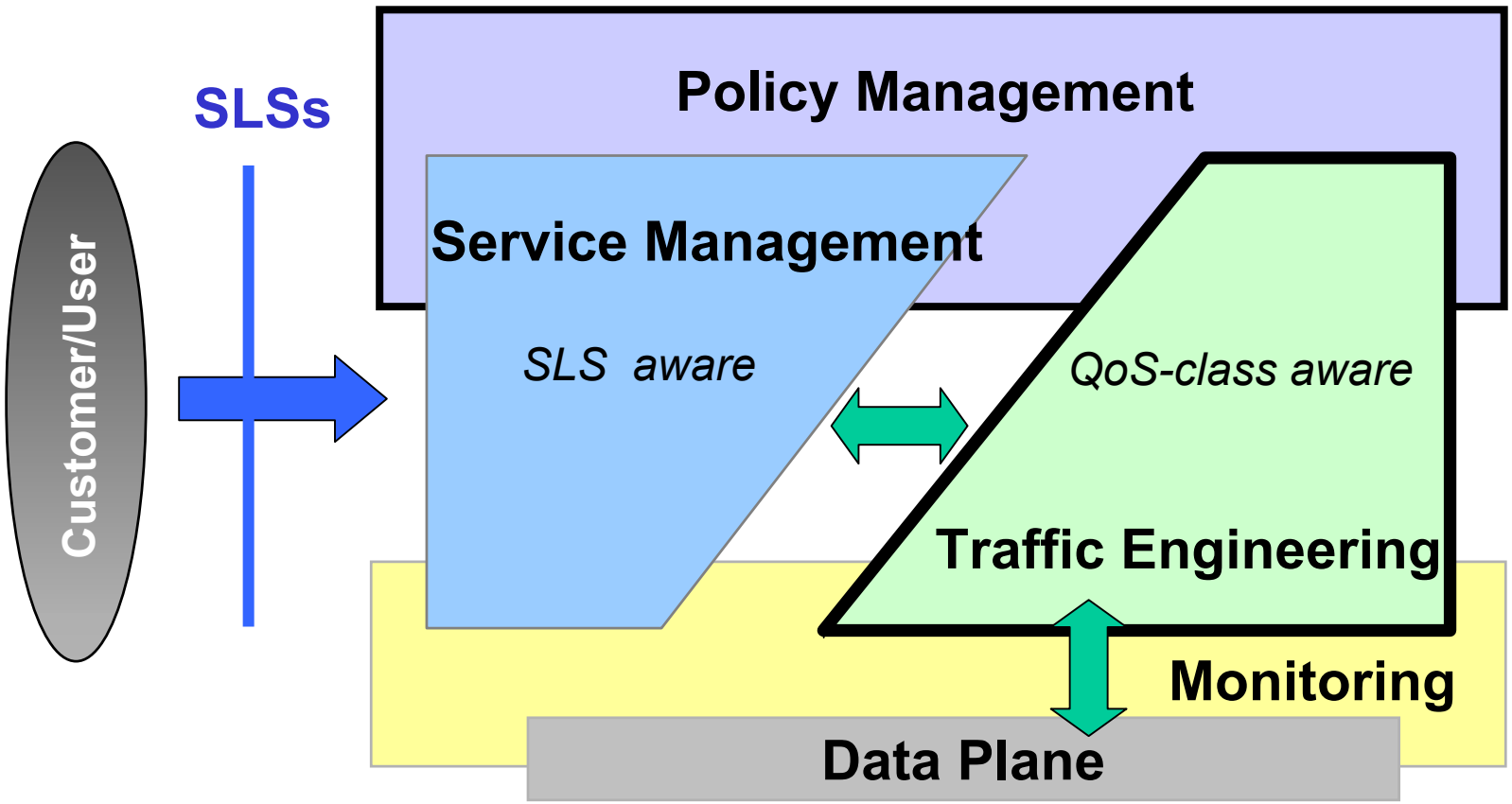
TEQUILA Consortium

Introduction

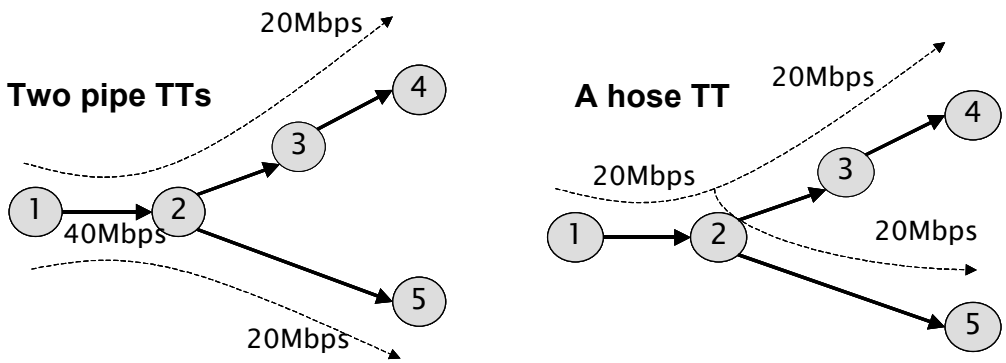
- Internet: the global multi-service network
- Need for scalable Quality of Service (QoS) solutions
- Differentiated Services (DiffServ)
  - Classify, mark and police at the edges
  - Specified “per-hop behaviours” (PHBs) to traffic aggregates
  - Scalability compared to per-flow reservation approaches
- Traffic Engineering
  - Control the manner traffic is mapped to and treated by network to achieve specific performance objectives
  - Of paramount importance in DiffServ since there are no explicit resource reservations to flows within the network
- Key problem: how to traffic engineer a DiffServ domain to meet edge-to-edge QoS requirements as dictated by contracted SLSs

Functional Model for QoS

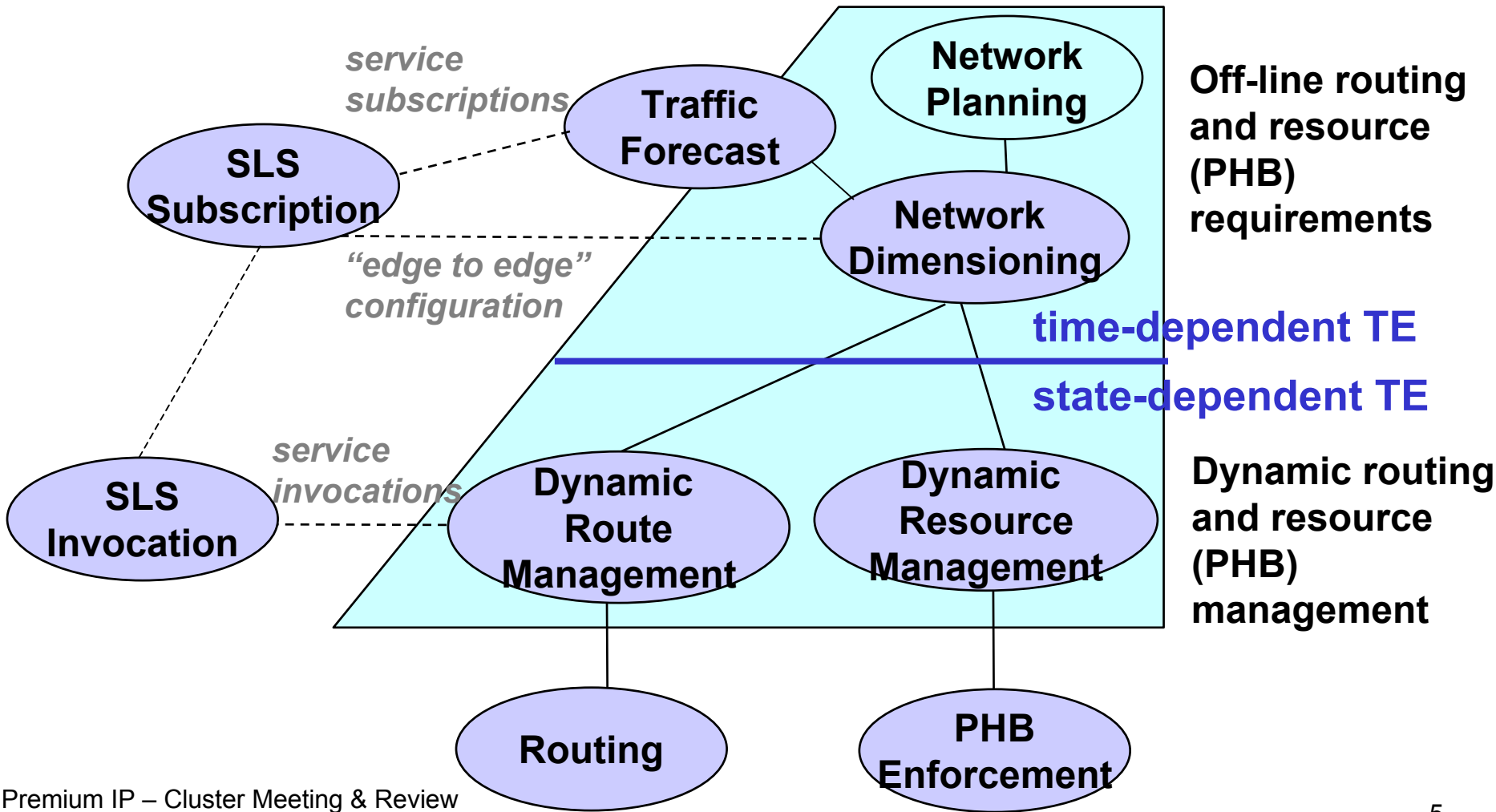


Traffic Model

- **Traffic Trunk (TT)**
  - **Ingress, set of egresses**
    - **pipe (1:1) or hose (1:N) model**
  - **General case the hose model**
    - **results in a tree with logically associated "tree bandwidth"**



Traffic Engineering Model



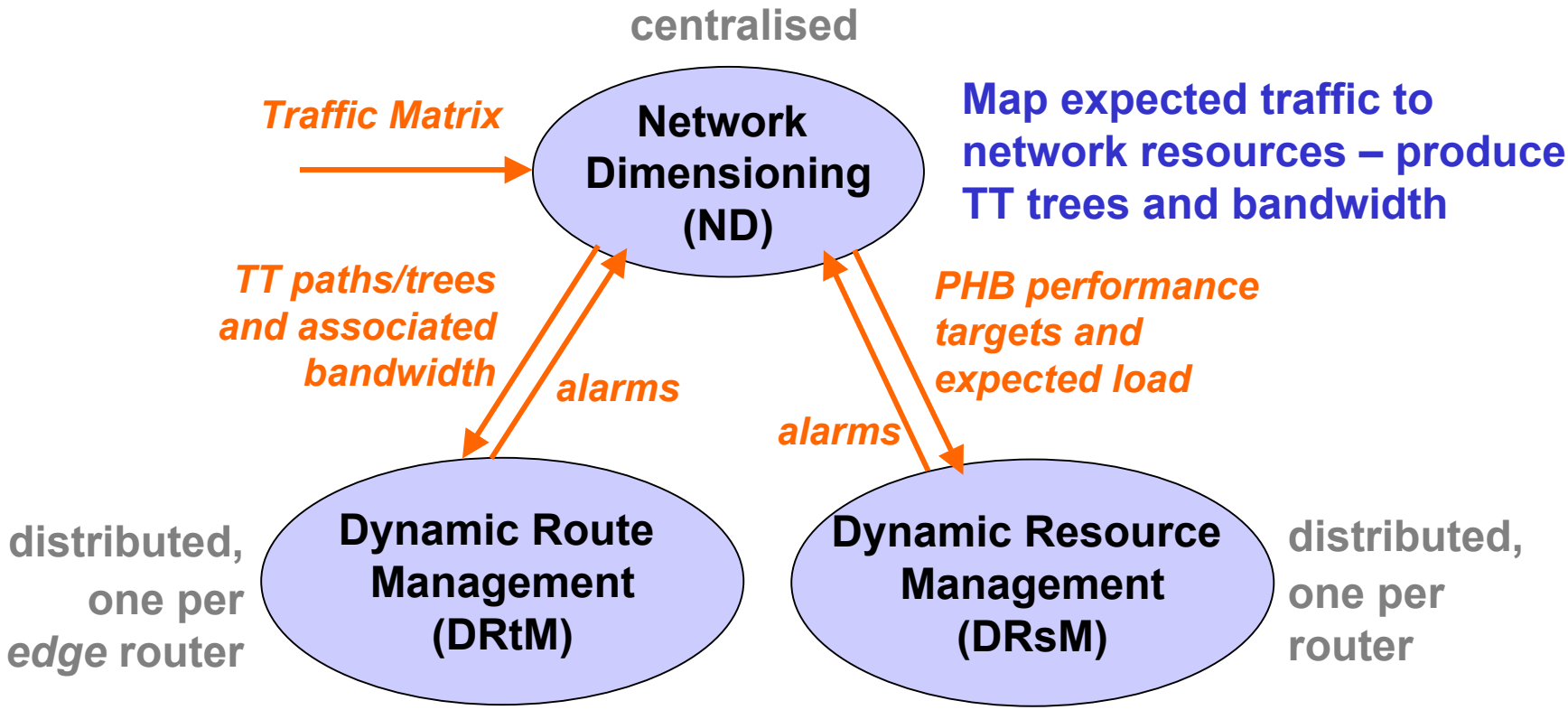
Traffic Forecast

- **Traffic Forecast is the "glue" between the customer-oriented (SM) and resource-oriented (TE) parts**
- **Estimates expected traffic demand (Traffic Matrix)**
  - **Derived from service contracts (SLSs) and other information (SLS usage, business policies, forecast/projection)**
  - **A traffic matrix for every provisioning cycle**
- ***Aggregation* required for scalability**
  - **Maximum entries per edge node $N*2^{N-1}*Q$ for N edge nodes and Q QoS classes**

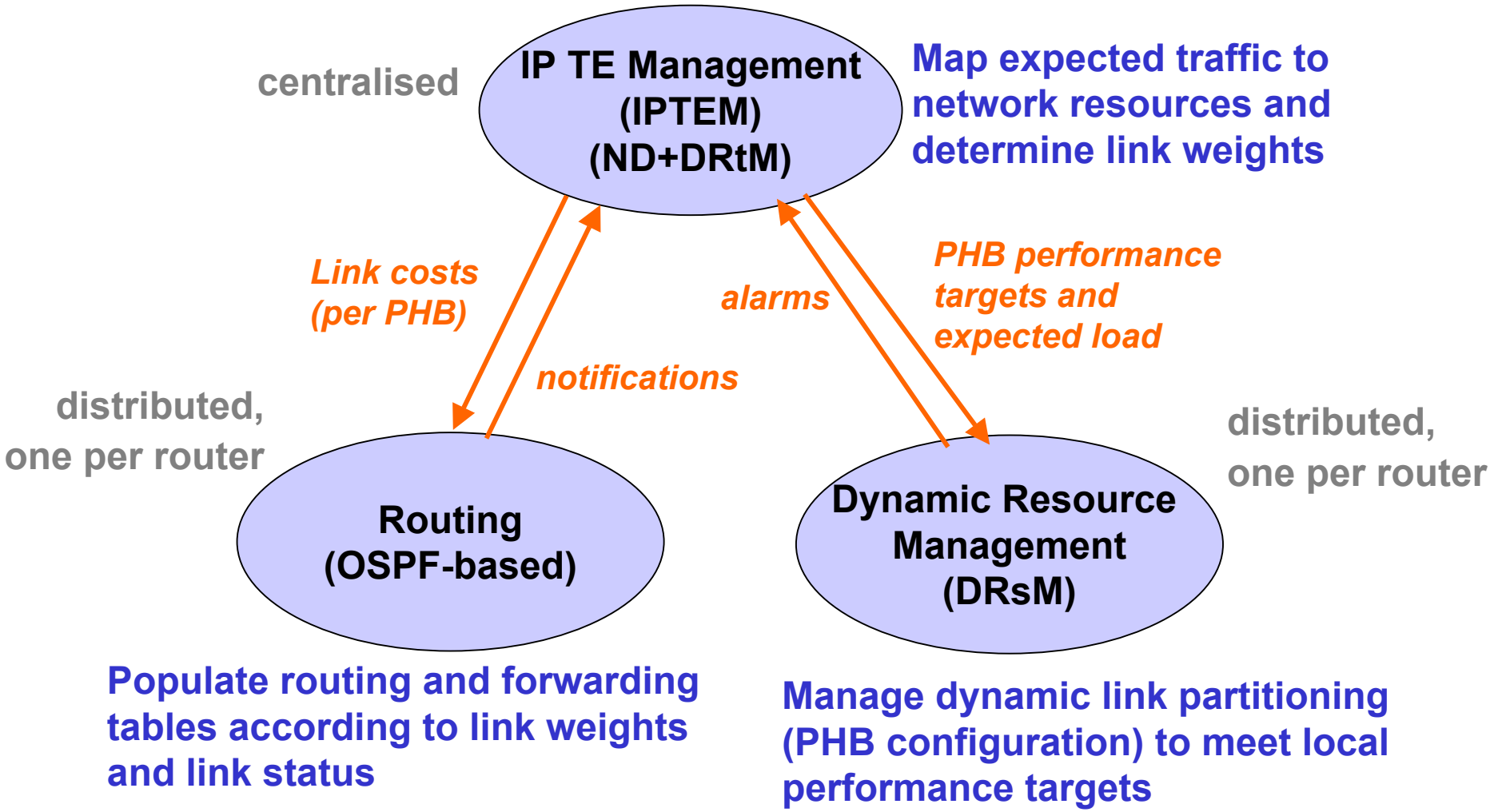
TE Approaches

- **MPLS-based**
  - **Explicit routing through LSPs with alternative LSPs for source-destination combinations for load balancing**
  - **LSPs are *not* explicitly associated with bandwidth**
- **IP-based**
  - **Hop-by-hop routing, OSPF-based with Equal Cost Multi Path (ECMP) for load balancing**
  - **Assignment of link-weights**
- **Loss and delay constraints are translated to route hop-count constraints (PHBs are associated with delay and loss bounds)**

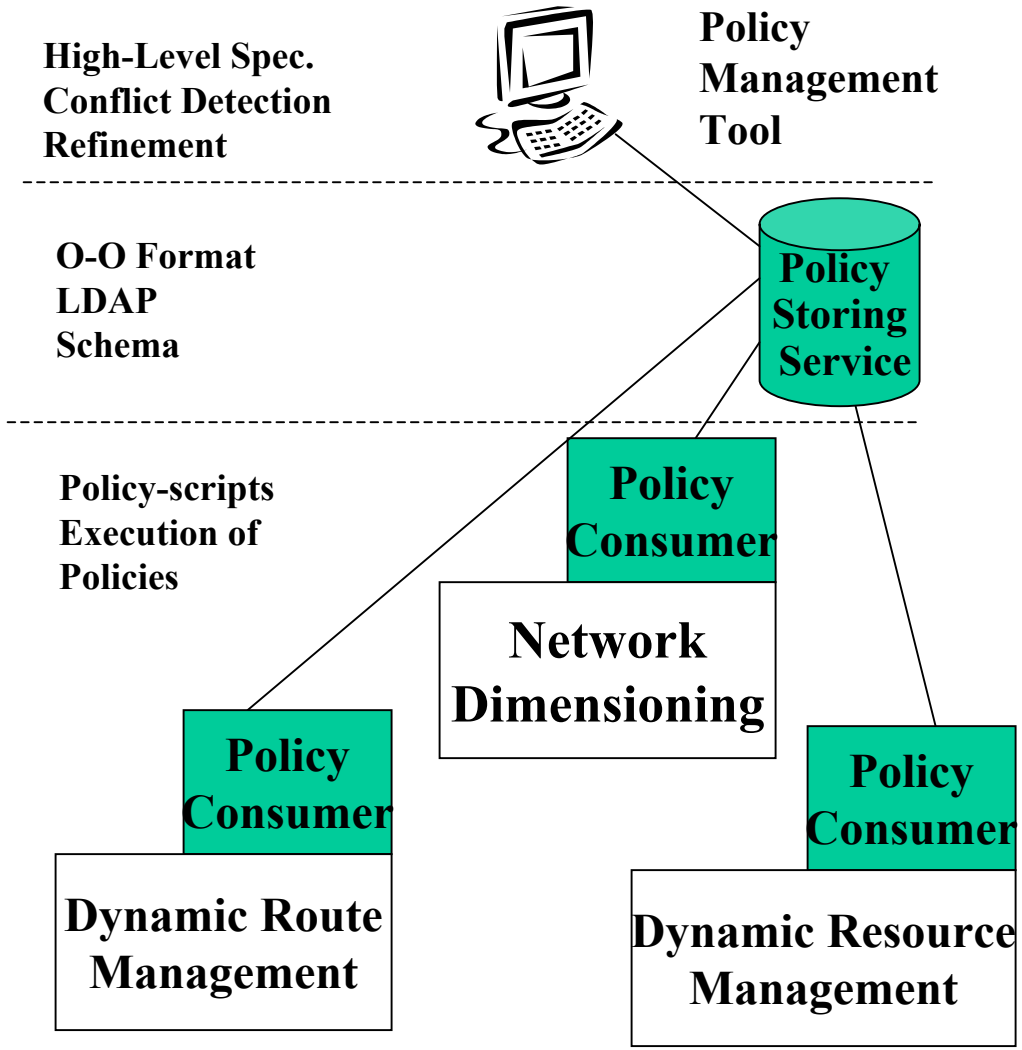
MPLS-based TE



IP-based TE


centralised
IP TE Management (IPTEM) (ND+DRtM)
Map expected traffic to network resources and determine link weights
Link costs (per PHB)
notifications
alarms
PHB performance targets and expected load
distributed, one per router
distributed, one per router
Routing (OSPF-based)
Dynamic Resource Management (DRsM)
Populate routing and forwarding tables according to link weights and link status
Manage dynamic link partitioning (PHB configuration) to meet local performance targets

Policy-based TE - Hierarchical Approach



High-level Policies may result in the introduction of related policies at lower layers, mirroring the system's hierarchy:

ND Policies

DRtM/DRsM Policies

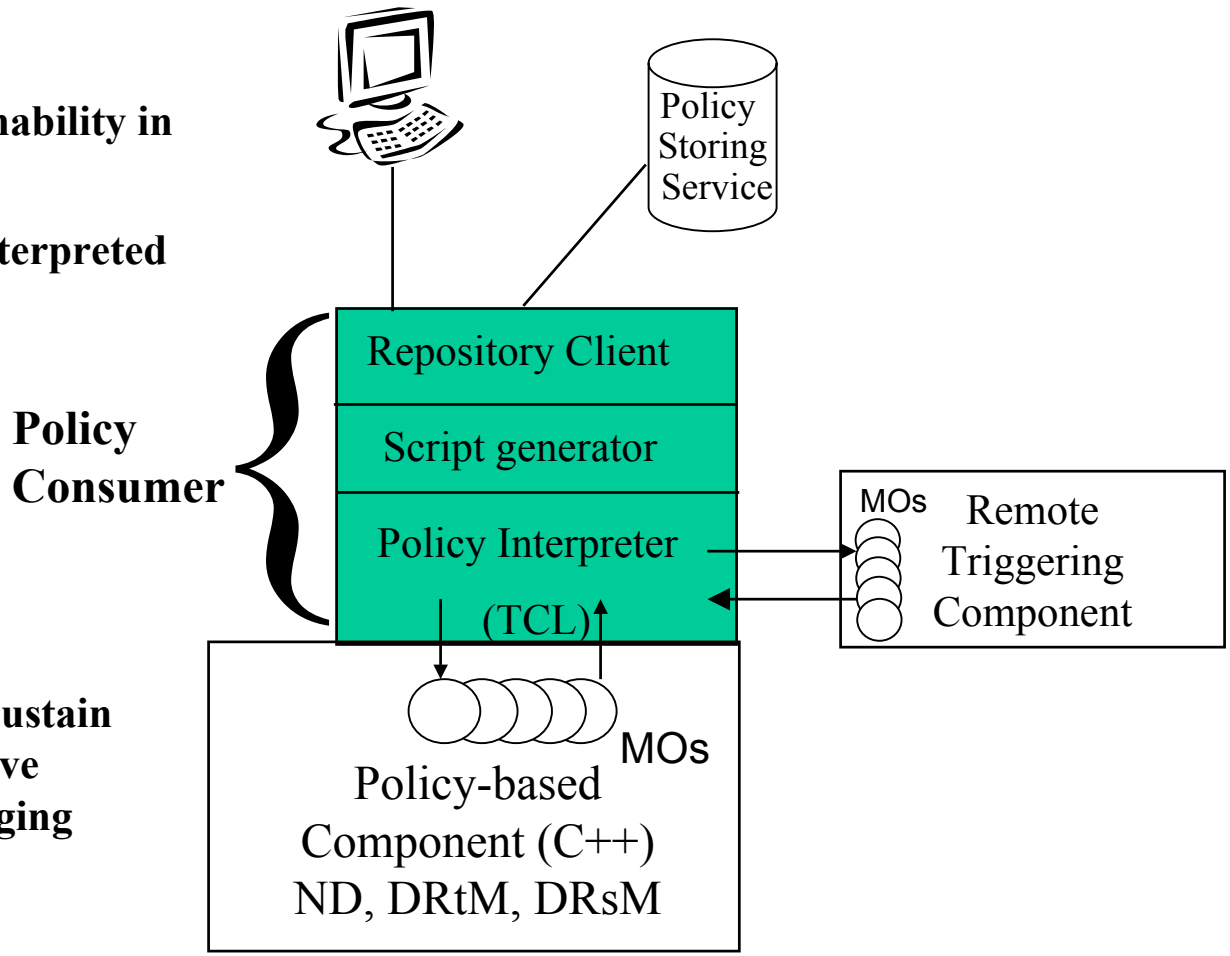
Policy Consumer Decomposition

Policies are seen as:

- **a means to achieve programmability in the Tequila System**
- **logic (scripts) downloaded, interpreted and executed on the fly**

Target:

- **a TEQUILA system able to sustain requirement changes and evolve through policies without changing its initial "hard-wired" logic**



Network Dimensioning Policies

- **Setting initial ND parameters e.g. maximum number of alternative trees, cost function, dimensioning period**

- **Influencing the capacity allocation and LSP creation e.g. allocation of network/link allocated bandwidth per class of service, explicit setup of LSPs, treatment of spare/over-provisioned capacity**

Network Dimensioning Optimisation Problem (MPLS)

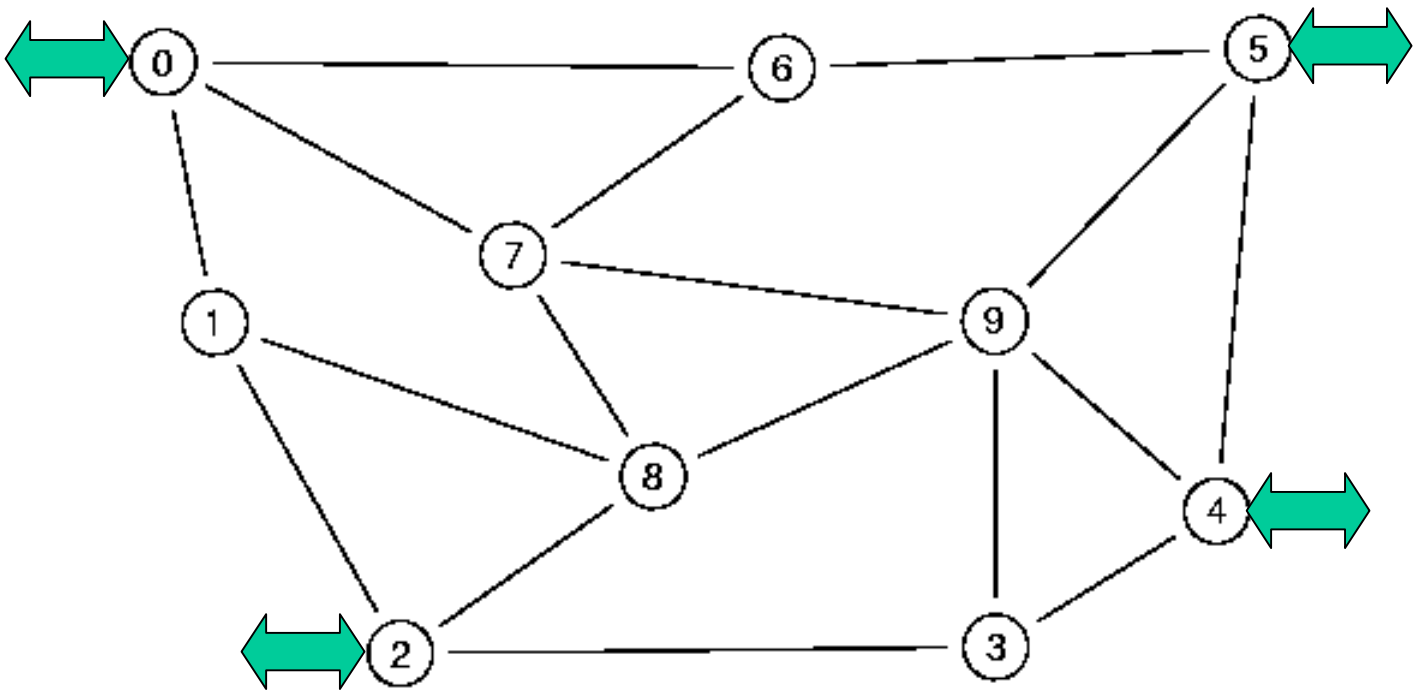
- **Satisfy the QoS requirements of traffic trunks**
  - **Avoid overloading parts of the network (I)**
  - **Minimise overall network utilisation (II)**
- **Assuming a cost function *f(x)* per PHB depending on the current load and *F(x)* the derived cost function per link**
  - **minimise** $(\max_{l \in E} F_l)$ **satisfies (I)**
  - **minimise** $\sum_{l \in E} F_l$ **satisfies (II)**
- **Combined objective function**
  - **minimise** $\sum_{l \in E} (F_l)^n$ **satisfies both: (II) for n=1 and (I) for n-> ∞**

Optimisation Approach

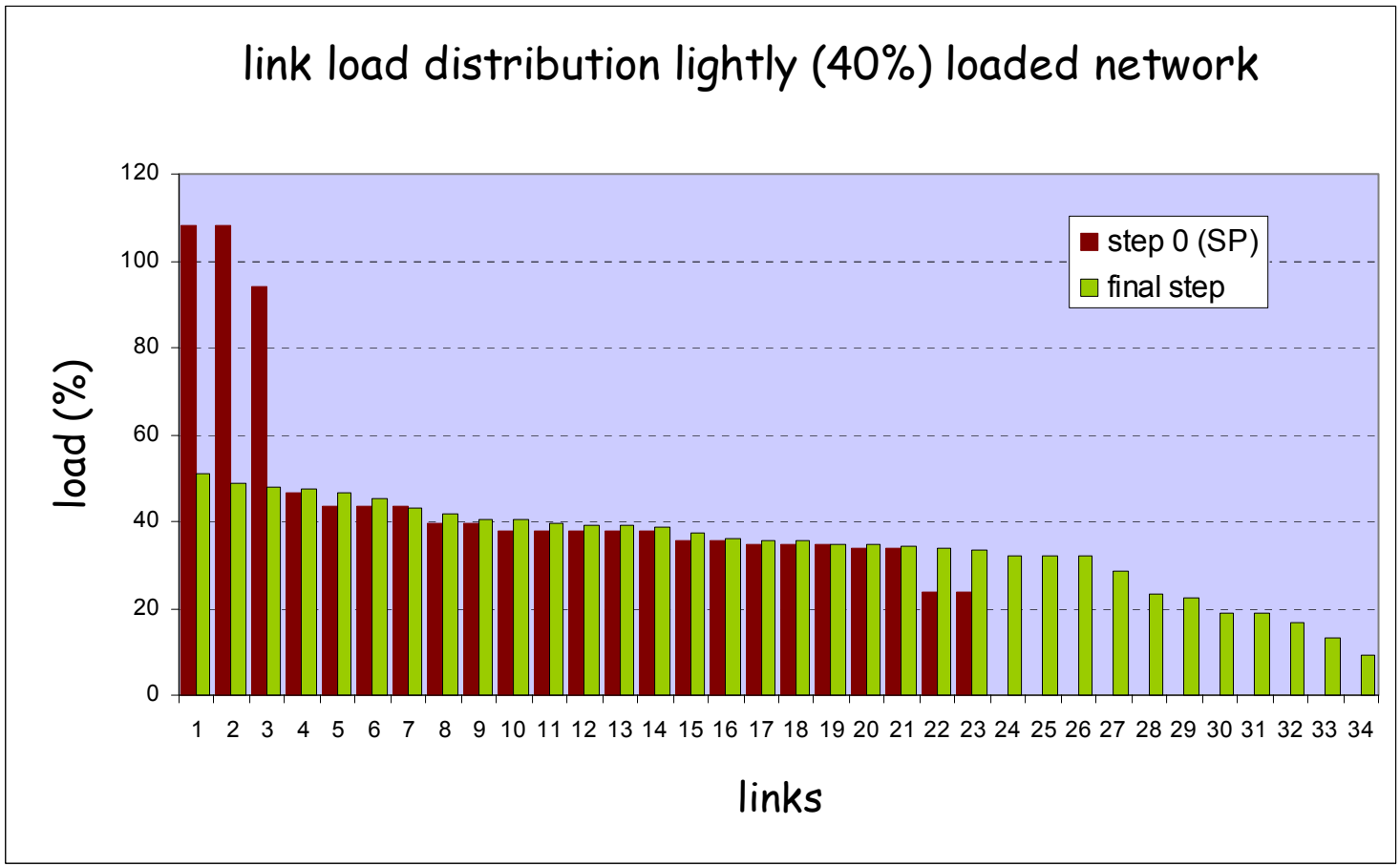
- **Solution-based on an iterative procedure**
  - **Start with an initial TT allocation**
  - **Improve gradually on this solution by moving capacity to "better" paths**
- **At each step, a constrained shortest path algorithm is used for pipe trunks and a constrained Steiner tree algorithm for hose trunks**
  - **The algorithms are constrained due to delay & loss bounds, translated to a hop count constraint**
- **Iterative algorithm works well and converges quickly for pipe trunks**
  - **Results are presented next**
- **The constrained Steiner tree algorithm also works well, in the next step we will be integrating the two**

Example Network

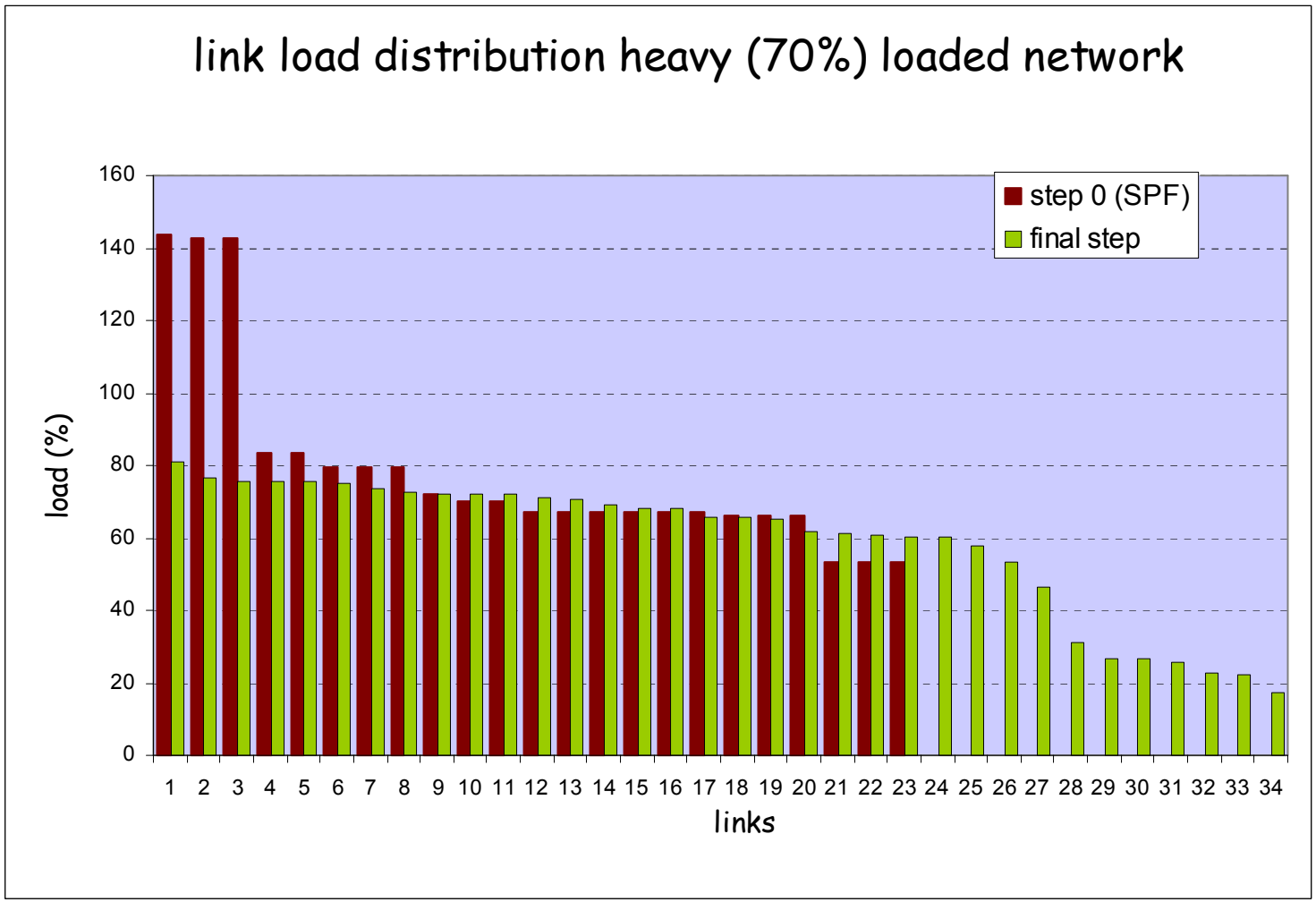
- **10 node network – 4 edge nodes { 0, 2, 4, 5 }**



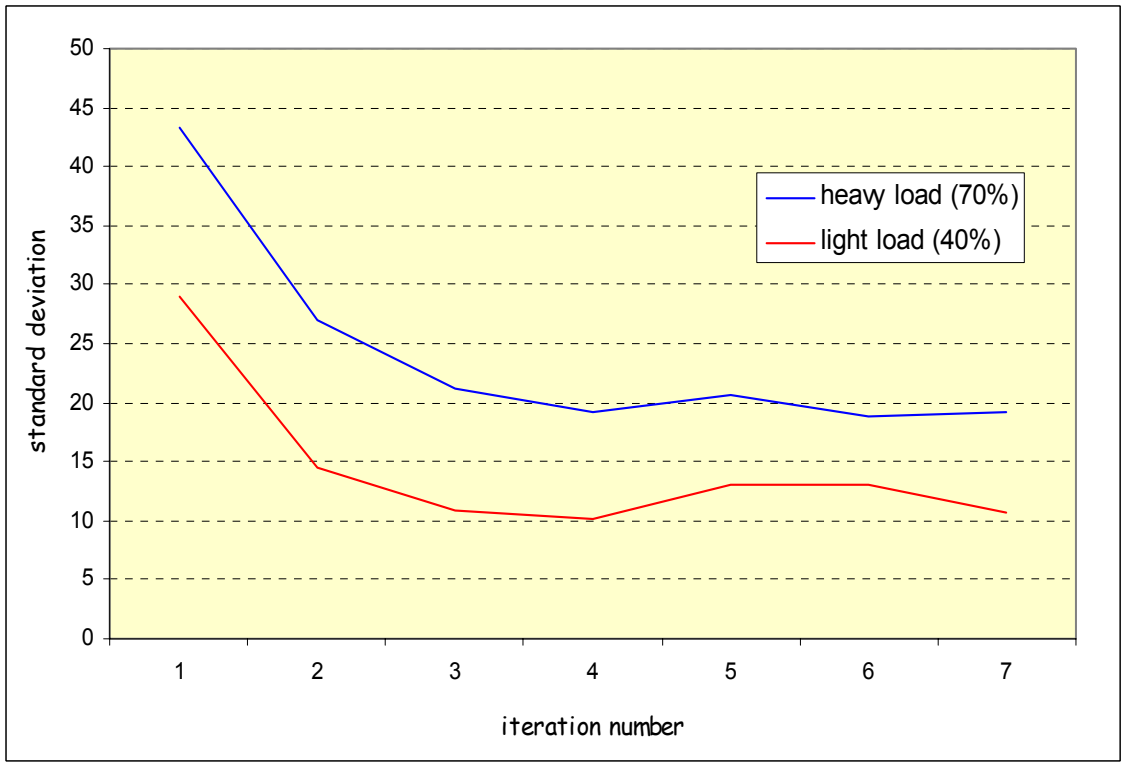
Link Load Distribution – light load (40%)



Link Load Distribution – heavy load (70%)

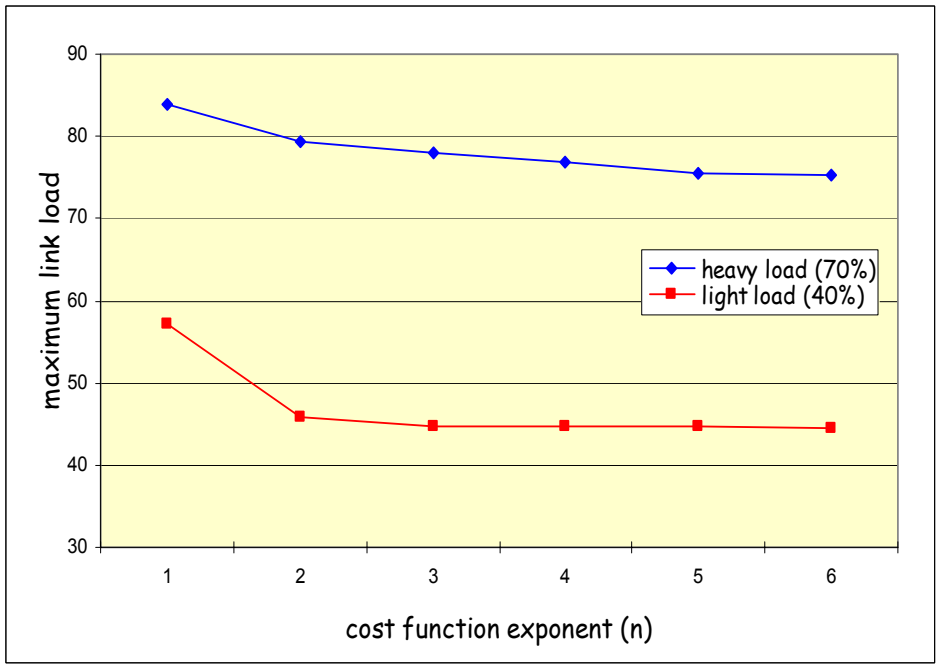


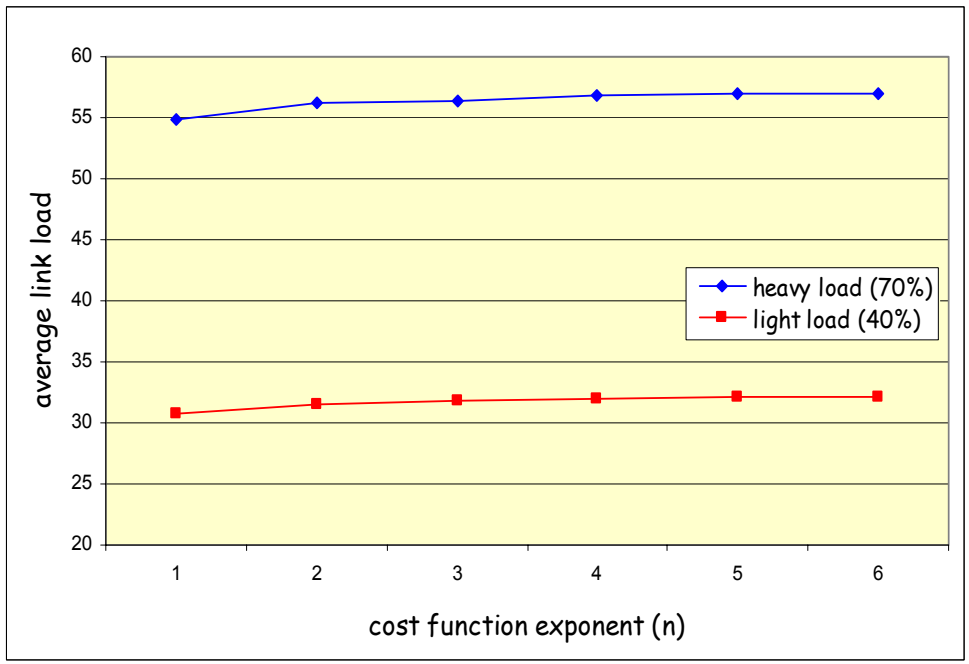
Stepwise (Per-Iteration) Solution Improvement



cost function exponent n=2

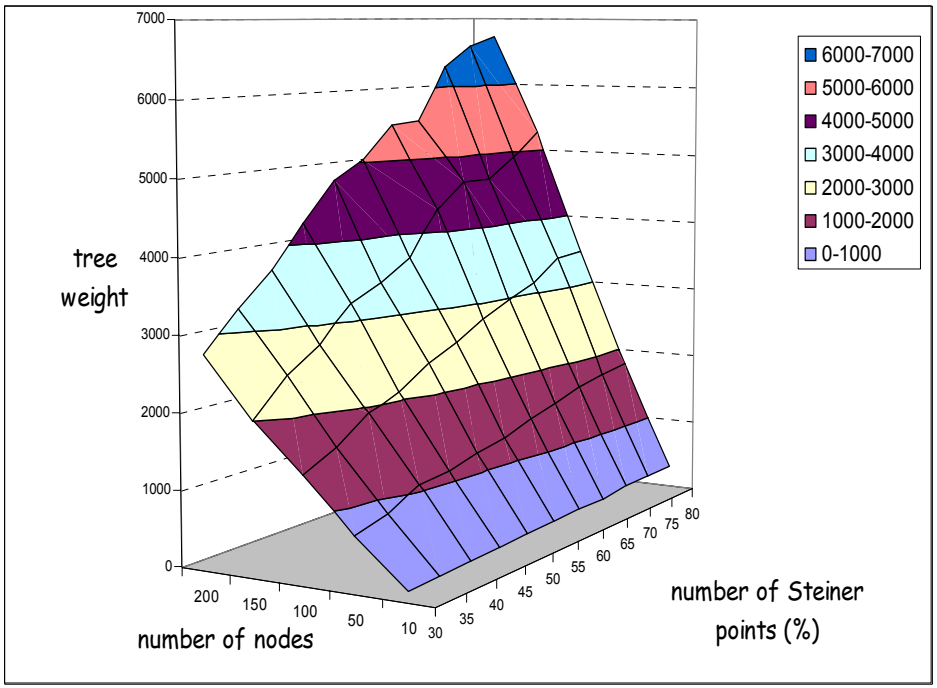
Effect of Optimisation Criterion (Cost Function)

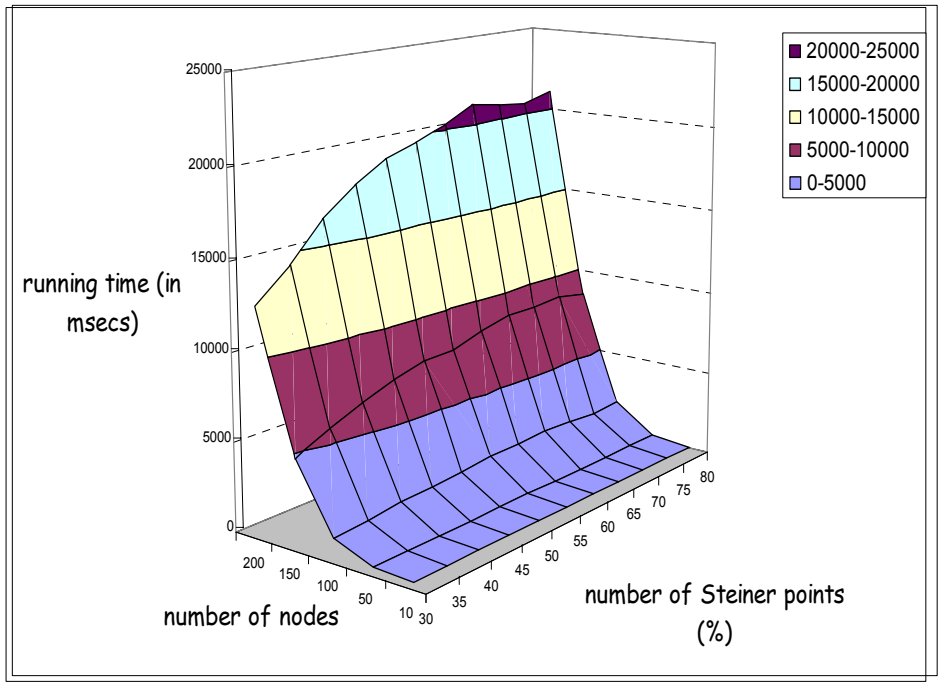




minimise $\sum_{l \in E} (F_l)^n$

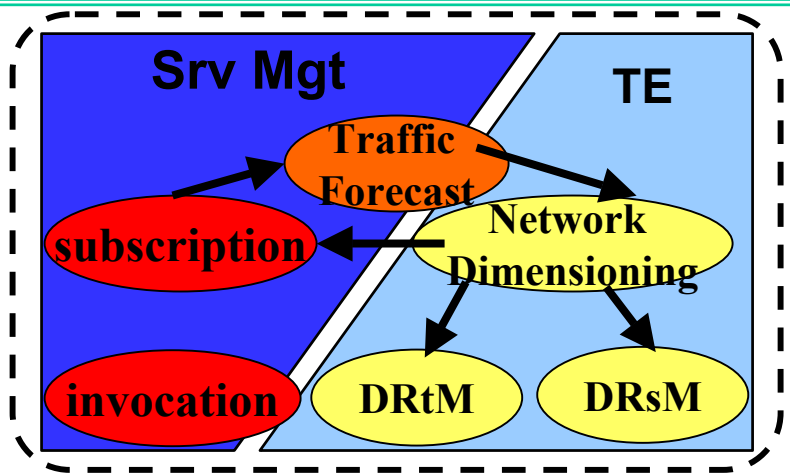
Steiner-tree Algorithm Evaluation





Since this experimentation, we have improved the above results by approximately 50% (tree weight/cost) and 20% (running time)

Conclusions



- Service driven traffic-engineering
- Two-level TE approach
  - long-term --> guidelines for network operation
  - short-term --> handling traffic fluctuations
- Policy-driven TE operation
  - graceful evolution to requirements changes
- Interim results prove the feasibility of the approach

TE Functionality

- **Network Dimensioning**
  - Input: network topology, traffic matrix, policies, alarms
  - Objective: optimisation problem
    - Maintain low link cost while satisfying QoS objectives
  - Output in the form of configuration directives:
    - Explicitly routed paths (MPLS-based TE) – via DRtM
    - Values for the link cost metrics (IP-based TE) – directly configuring routers through combined DRtM and ND (IPTEM)
    - Configuration of PHB partitioning per link – via DRsM
- **Dynamic Route Management (DRtM)**
  - Multi-path load distribution at ingress nodes for load balancing
  - Explicit component in MPLS, implicit in OSPF/ECMP
- **Dynamic Resource Management (DRsM)**
  - Re-configuration of PHBs within allowed bounds i.e. dynamic link (re-)partitioning among service classes
  - Same functionality in both MPLS and IP-based TE

Policy Information Model/Language

- **Information Model based on PCIM and PCIMe and corresponding LDAP schema**
- **High-level policy language syntax:**

  [Policy ID] [Group ID] [time period condition] [if **{condition [and] [or]}]** then **{action [and]}**
- **Example :**

  PolicyRule1: From **Time=0800** to **Time=1800** If **(OA == EF)** then **allocateNwBw > 30%**

  Description: At least 30% of Network Bw should be available for EF traffic between 08:00 and 18:00”

Dynamic Route Management (MPLS) – static part

- **Explicit component only in MPLS-base TE**
  - **One instance in every *edge* Label Switch Router (LSR), uses monitoring facilities within that LSR**
- **Static part gets as input from ND TT trees (and paths) with logically associated bandwidth**
- **Creates LSPs to support paths and trees**
  - **For trees, one LSP per egress leaf is created (unique path)**
  - **LSPs are created via LDP from the ingress nose with the full explicit path**
  - **No bandwidth is associated to LSPs but the edge LSR knows the logically associated bandwidth with each LSP for a path or set of LSPs realising a tree**
- **Maps "address spaces" from collected prior statistics (and SLS information) to LSPs according to their bandwidth**
  - **Configures LSR forwarding tables according to this assignment**

Dynamic Route Management (MPLS) – dynamic part

- Re-maps address spaces to alternative LSPs for load balancing according to traffic fluctuations
  - Difficult issue since existing micro-flows should be left to terminate
- Sends TT over-utilisation alarms to ND
- Sends alarms to SLS Invocation that traffic capacity to particular egress nodes is saturated
  - These act as "Congestion Notifications" to admission control
- Learns about critical PHB QoS performance at nodes crossed by its LSPs in order to take *proactive* measures
- Learns about critical end-to-end LSP QoS performance in order to take *reactive* measures
  - Knowledge about PHB and LSP performance is obtained from monitoring
  - Critical performance means "persevering conditions" and not instantaneous inability to deliver the specified QoS

Dynamic Resource Management

- Common in both MPLS and IP-based TE
  - one instance in every router, uses monitoring facilities within that router
- Static part configures PHB parameters
  - queue type – Drop tail, RED, etc.
  - queue parameters – buffer size, precedence/drop levels
  - scheduling parameters – RR, WRR, PRI, etc.
- Also configures performance targets set by ND per PHB
  - bandwidth, max loss probability, max delay
  - allowed bounds for dynamic (state-dependent) operation
- Dynamic part manages PHB resources in real-time
  - re-distributes (within allowed bounds) bandwidth, buffer and scheduling resources to meet dynamic traffic fluctuations
  - sends over-utilisation alarms to ND