Network Architecture and Topology

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Ideal Network Model

Network Path Principle

The network must provide high-bandwidth low-latency paths between end systems.
Mesh network technologies scale better than shared medium. Use power control and directional antennae to increase spatial reuse in shared medium wireless networks.
The latency along a path is the sum of all its components. The benefit of optimising an individual link is directly proportional to its relative contribution to the end-to-end latency.
Latency
Topology and Geography

- Constituents of network latency \( D = (h-1)d_s + \sum h d_i \)
  - Geography: speed of light delay \( d_i \)
  - Topology: number of hops \( h \); switching delay \( d_s \)

<table>
<thead>
<tr>
<th></th>
<th>SAN</th>
<th>LAN</th>
<th>MAN</th>
<th>WAN</th>
<th>GEO</th>
<th>Mars</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dia</td>
<td>100 m</td>
<td>1 km</td>
<td>100 km</td>
<td>20 000 km</td>
<td>72 000 km</td>
<td>400×10^6 km</td>
</tr>
<tr>
<td>RTT</td>
<td>1 (\mu)s</td>
<td>10 (\mu)s</td>
<td>1 ms</td>
<td>200 ms</td>
<td>480 ms</td>
<td>6 – 45 min</td>
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</table>

**Network Diameter Principle**

The number of per hop latencies along a path is bounded by the diameter of the network. The network topology should keep the diameter low.
The maximum bandwidth along a path is limited by the minimum bandwidth link or node, which is the bottleneck. There is no point in optimising a link that is not a bottleneck.
Overlay Networks

Abstract and Hide Underlying Network

- Overlay networks hide underlying topology
  - VPNs (virtual private networks)
  - secure overlay sessions
  - datagram overlay meshes
  - lightpaths

Network Overlay Principle

Overlay networks must provide the same high-performance paths as the physical networks. The number of overlay layers should be kept as small as possible, and overlays must be adaptable based on end-to-end path requirements and topology information form the lower layers.
• **Lightpath assignment problem**
  - preserve high-performance along overlay such that
  - no link carries more than one light path of given wavelength
Network Architecture and Topology

Network Scale

3.1 Topology and geography

3.2 Scale

3.2.1 Network engineering
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3.2.3 Bandwidth aggregation and isolation
3.2.4 Latency optimisation
3.2.5 Wireless network density
3.2.5 Practical constraints

3.3 Resource tradeoffs
Network Scale

Network Engineering Parameters

<table>
<thead>
<tr>
<th>topology</th>
<th>degree</th>
<th># nodes</th>
<th>diameter</th>
<th>aggregation</th>
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</thead>
<tbody>
<tr>
<td>sparsely connected</td>
<td>low</td>
<td>high</td>
<td>high</td>
<td>low</td>
</tr>
<tr>
<td>densely connected</td>
<td>high</td>
<td>low</td>
<td>low</td>
<td>high</td>
</tr>
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Network Scaling Principle

Networks should be able to scale in size while balancing switch cost against hop count.
Network Scale

Hierarchy

• Hierarchy
  - important technique to
    • control latency
      and aggregation
    • bound state maintained
  - divide network into clusters
    • state aggregated per cluster
    • examples: Nimrod, P-NNI

Network Hierarchy Principle

Use hierarchy and clustering to manage network scale and complexity, and reduce the overhead of routing algorithms.
Network Scale

Aggregation, Isolation, Latency

- Physical hierarchy to
  - limit number of hops and control aggregation
  - example: Internet (NSFNET) prior to 1994
Network Scale
Aggregation, Isolation, Latency

• Hierarchy
  - isolate bandwidth in different subnet layers
  - control network diameter and latency

**Hierarchy to Aggregate and Isolate Bandwidth**

*Use hierarchy to manage bandwidth aggregation in the core of the network, and to isolate clusters of traffic locality from one another.*

**Hierarchy to Minimise Latency**

*Use hierarchy and cluster size to minimise network diameter and resultant latency.*
Network Scale

Wireless Network Density

- Transmission power gives tradeoff between
  - transmission range
  - degree of connectivity

Wireless Density Control to Optimise Degree and Diameter

Use density control and long link overlays to optimise the tradeoff between dense low-diameter and sparse high-diameter wireless networks.
Network Scale

Practical Constraints

- Policy-based routing
- Network provider deployment
  - complex topologies
  - peering not high-performance
  - many hops/POP

Administrative Constraints Increase the Importance of Good Design

Policy and administrative constraints distort the criteria that govern the application of many high-performance network design principles. The importance of good (principled) design is elevated when these constraints are present.
Network Architecture and Topology

Resource Tradeoffs

3.1 Topology and geography

3.2 Scale

3.3 Resource tradeoffs
   3.3.1 Bandwidth, processing, and memory
   3.3.2 Latency as a constraint
   3.3.3 Relative scaling with high speed
   3.2.4 Active networking
Resource Tradeoffs
Resources and Constraints

- Network is a collection of resources:
  - P processing
  - M memory
  - B bandwidth
  - E energy or power

- Constrained by: (resources may also be constraints)
  - L latency

**Network Resource Tradeoff & Engineering Principle N-2**

Networks are collections of resources. The relative composition of these resources must be balanced to optimise cost and performance, and to determine network topology, engineering, and functional placement.
Resource Tradeoffs

Example 3.5 Content Cache Location

- Objective function to determine optimal mix
  \[ f(\pi(P), \beta(B), \mu(M), \lambda(L), \varepsilon(E)) \]

- Example:
  content cache location
  \[ B = \infty, M = 0 \]
  \[ \Rightarrow \text{everyone has local copy} \]
  \[ B = 0, M = \infty \]
  \[ \Rightarrow \text{single copy on server} \]
  \[ l_{\text{opt}} = \beta(B) + \mu(M) \]
  \[ L \text{ constrains distance from client} \]
Resource Tradeoffs

Relative Scaling

• Relative scaling of resources is important
  – If all resources/constraints scale *uniformly*, no change
  – Speed of light remains constant
    • latency becomes relatively more important
    • bandwidth-$\times$-delay product requires increasing $M$
  – Technology scales non-uniformly
    • example: Moore’s law increase in $P$
      – enables IP lookup/classification in hardware, active networking

Resource Tradeoffs Change and Enable New Paradigms

The relative cost of resources and constraints changes over time due to non-uniform advances in different aspects of technology. This should motivate constant rethinking about the way in which networks are structured and used.
Resource Tradeoffs

Active Networking

• Decreasing cost of processing and memory
  - enables more computation in the network nodes

• Active networking
  - strong AN
    • users inject *capsules* of code
    • executed on nodes
  - moderate AN
    • network service providers provisions protocols and services
    • may be dynamically provisioned with active packets