Network Architecture and Topology

1. Introduction
2. Fundamentals and design principles
3. Network architecture and topology
4. Network control and signalling
5. Network components
   5.1 links
   5.2 switches and routers
6. End systems
7. End-to-end protocols
8. Networked applications
9. Future directions

3.1. Topology and geography
3.2. Scale
3.3. Resource Tradeoffs
Network Architecture and Topology

3.1 Topology and geography
   3.1.1 Scalability
   3.1.2 Latency
   3.1.3 Bandwidth
   3.1.4 Virtual overlays and lightpaths
   3.1.5 Practical constraints

3.2 Scale

3.3 Resource tradeoffs

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Ideal Network Model

Network Path Principle

The network must provide high-bandwidth low-latency paths between end systems.
Scalable Topologies

Mesh vs. Shared Medium

Mesh network technologies scale better than shared medium. Use power control and directional antennae to increase spatial reuse in shared medium wireless networks.

Latency

Network Path

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 $D = (h-1)d_s + \sum_i d_i$
  - Geography: speed of light delay $d_s$
  - Topology: number of hops $h$; switching delay $d_i$

<table>
<thead>
<tr>
<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>
</tr>
<tr>
<td>RTT</td>
<td>1 µs</td>
<td>10 µs</td>
<td>1 ms</td>
<td>200 ms</td>
<td>480 ms</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>400 x 10^6 km</td>
<td>6 - 45 min</td>
</tr>
</tbody>
</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.

Network Bandwidth Principle

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 from 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

3.2.2 Hierarchy

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 Engineering Parameters

<table>
<thead>
<tr>
<th>topology</th>
<th>degree</th>
<th># nodes</th>
<th>diameter</th>
<th>aggregation</th>
</tr>
</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>
</tbody>
</table>

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
- Constrained by:
  - D latency
  - W power and/or energy

Network Resource Tradeoff & Engineering Principle

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.

Example 3.5 Content Cache Location

- Objective function to determine optimal mix
  \[ f(\pi(P), \beta(B), \mu(M), \lambda(L), \omega(W)) \]
- Example:
  - content cache location
  - \( B = \infty, M = 0 \)
    \( \Rightarrow \) everyone has local copy
  - \( B = 0, M = \infty \)
    \( \Rightarrow \) single copy on server
  - \( l_{opt} = \beta(B) + \mu(M) \)
  - L 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-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.

Active and Programmable Networking

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