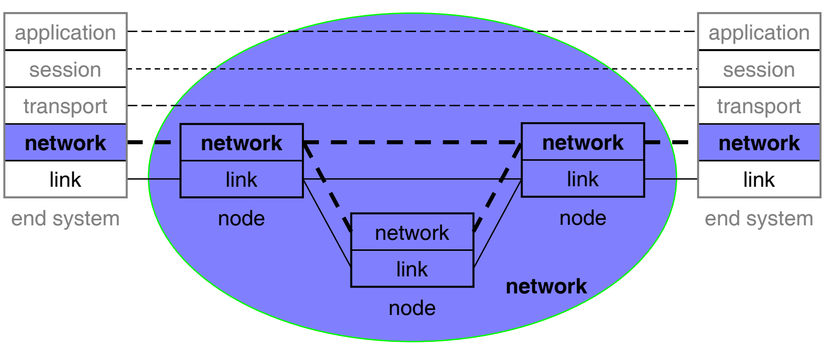
Network Architecture and Topology

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

Network Architecture and Topology



3.1. Topology and geography

3.2. Scale

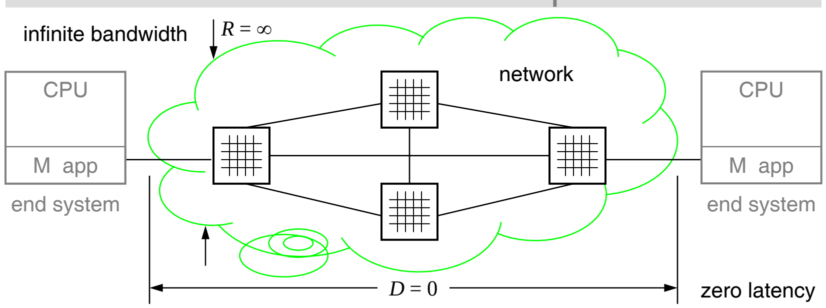
3.3. Resource Tradeoffs

Network Architecture and Topology

Topology and Geography

Ideal Network Model

Network Path Principle

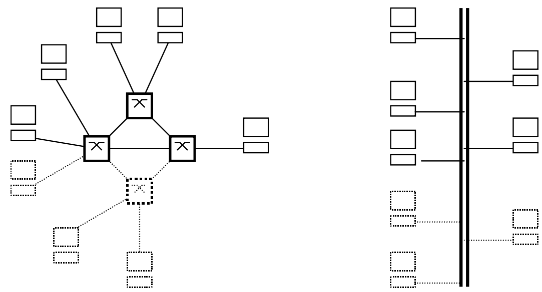


Network Path Principle N-II

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

Scalable Topologies

Mesh vs. Shared Medium



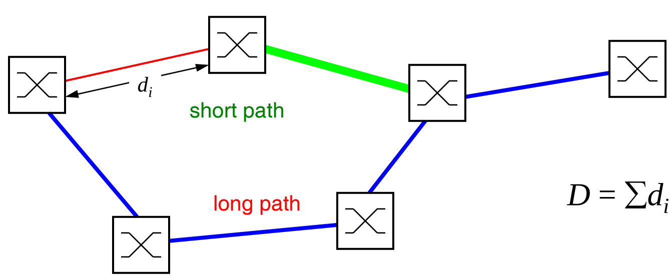
Scalability of Mesh Topologies

N-II.4

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

Latency

Network Path



$$D = \sum d_i$$

Network Latency Principle

N-1A/

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

	SAN	LAN	MAN	WAN	GEO	Mars
Dia	100 m	1 km	100 km	20 000 km	72 000 km	400×10^6 km
RTT	1 µs	10 µs	1 ms	200 ms	480 ms	6 – 45 min

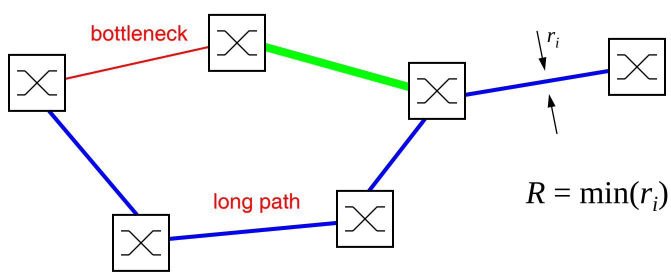
  - Topology: number of hops h; switching delay d_s

Network Diameter Principle N-1A*h*

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.

Bandwidth

Network Path



Network Bandwidth Principle N-1A*b*

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

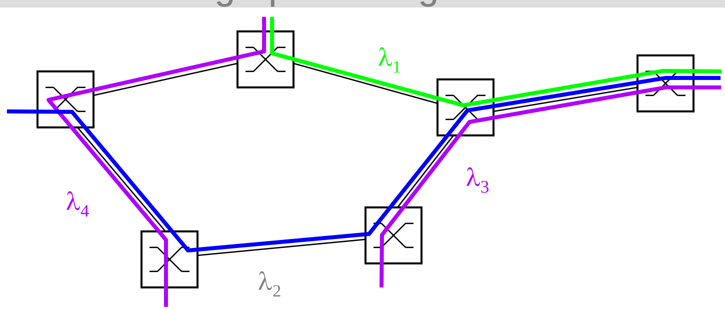
- Overlay networks hide underlying topology
  - VPNs (virtual private networks)
  - secure overlay sessions
  - datagram overlay meshes
  - lightpaths

Network Overlay Principle N-II*o*

Overlay networks must provides the same high-performance paths as he 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.

Overlay Networks

Lightpath Assignment

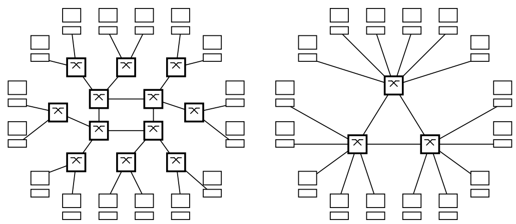


- Lightpath assignment problem
  - preserve high-performance along overlay such that
  - no link carries more than one light path of given wavelength

Network Architecture and Topology
Network Scale

Network Scale
Network Engineering Parameters

sparse



dense

topology	degree	# nodes	diameter	aggregation
sparsely connected	low	high	high	low
densely connected	high	low	low	high

Network Scaling Principle N-5C*t*

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

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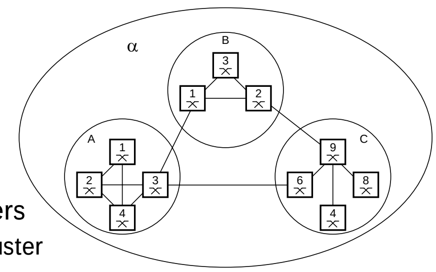
Network Scale

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 N-5C

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

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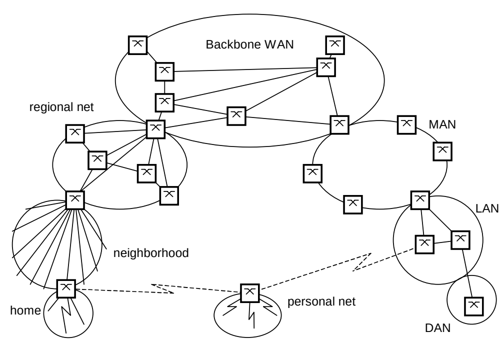
Network Scale

Aggregation, Isolation, Latency



- Physical hierarchy to
  - limit number of hops and control aggregation
  - example: Internet (NSFNET) prior to 1994

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Network Scale

Aggregation, Isolation, Latency

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

Hierarchy to Aggregate and Isolate Bandwidth N-5B

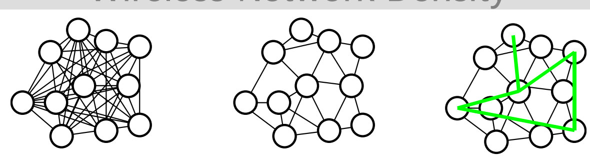
Use hierarchy to manage bandwidth aggregation in the core of the network, and to isolate clusters of traffic locality from one another.

Hierarchy to Minimise Latency N-5C*l*

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

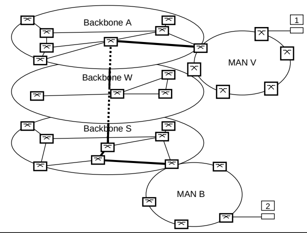
Wireless Density Control to Optimise Degree and Diameter N-5C*w*

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 N-III.2

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 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.

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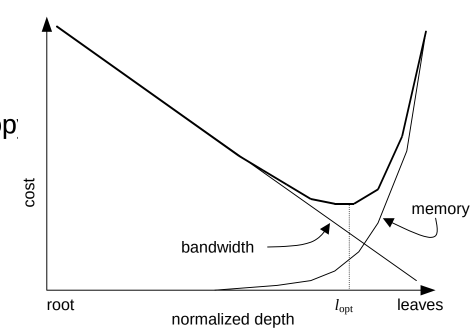
Resource Tradeoffs

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 cop
  - $B = 0$, $M = \infty$
    - $\Rightarrow$ 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 N-2A *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 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