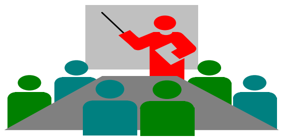
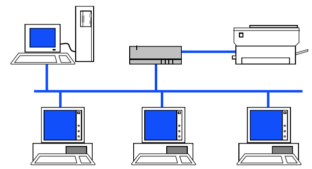




Distributed Systems
600.437
Overlay Networks

Department of Computer Science
The Johns Hopkins University

Overlay Networks

Lecture 4

Further reading:

www.dsn.jhu.edu/publications/

The Internet Revolution
A Technical Perspective

A single, multi-purpose, IP-based network

- Each additional node increases its reach and usefulness (similar to any network)
- Each additional application domain increases its economic advantage
- Will therefore swallow most other networks
  - Happened: mail to e-mail, Phone to VoIP, Fax to PDFs
  - Started the process: TV, various control systems
  - Still to come: Cell phone networks

The Internet Revolution
A Technical Perspective

A single, multi-purpose, IP-based network

- The art of design – a successful paradigm
  - Keep it simple in the middle
    - Best-effort packet switching, routing (intranet, Internet)
  - Smart at the edge
    - End-to-end reliability, naming
- Could therefore adapt and scale
  - Survived for 4 decades and counting
  - Sustained at least 7 orders of magnitude growth
- Standardized and a lot rides on it
  - The basic services are not likely to change

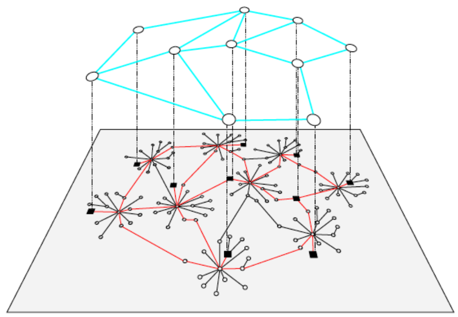
New Applications Bring New Demands

- Communication patterns
  - From Point-to-point – to point-to-multipoint – to many-to-many
- High performance reliability
  - "Faster than real-time" file transfers
- Low latency interactivity
  - 150ms key stroke mirroring
  - 100ms for VoIP
  - 80-100ms for interactive games (65ms one way for remote surgery?)
- End-to-end dependability
  - From "Internet" dependability – to "phone service" dependability – to "TV service" dependability – to "remote surgery" dependability
- System resiliency
  - From E-mail fault tolerance – to financial transaction security – to critical infrastructure (SCADA) intrusion tolerance

So, What Can Be Done?

- Build specialized networks
  - Was done decades before the Internet
  - Think Cable/TV distribution (Satellite + last mile)
  - Extremely expensive
- Build private IP networks
  - Avoids the resource sharing aspects of the Internet, solves some of the scale issues
  - Expensive
  - Still confined to basic IP network capabilities
- Build a better Internet
  - Improvements and enhancements to IP (or TCP/IP stack)
  - "Clean slate design"
- Build overlay networks

The Overlay Paradigm

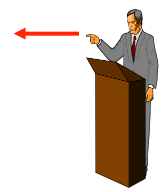


- Overlay paradigm:
  - In contrast to “keep it simple in the middle and smart at the edge”
  - Move intelligence and resources to the middle
    - Software-based overlay routers working on top of the internet
    - Overlay links translated to Internet paths
- Smaller overlay scale (# nodes) ➔ smarter algorithms, better performance, and new services.

Initial Overlay Research

- Flexible Routing
  - RON – resilient routing using alternate paths [*Andersen et al, 01*]
  - XBone – flexible routing using IP in IP tunneling [*Touch, Hotz, 98*]
- Content Distribution
  - Yoid – host-based content distribution [*Francis 00*]
  - Overcast – reliable multicast for high bandwidth content distribution [*Janotti et al, 00*]
  - Bullet – multi-path data dissemination [*Kostic et al 03*]
- Multicast
  - ESM – provides application-level multicast [*Chu et al, 00*]
  - HTMP – interconnects islands of IP Multicast [*Zhang et al, 02*]
- Peer to Peer
  - Chord – logarithmic lookup service [*Stoica et al, 01*]
  - Kelips – O(1) lookup with more information stored [*Gupta et al, 03*]
- Group Communication
  - The Spread toolkit – scalable wide area group communication using an overlay approach [*Amir, Danilov, Stanton, 00*]

Outline



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- First Steps
  - Low-latency reliable protocol
  - Spines – from Concepts to Systems
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  - Almost-reliable, real-time protocol for Live TV
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  - The LiveTimeNet Cloud
- Going even Faster
  - Reliability and timeliness
  - How fast can it get

End-to-End Reliability

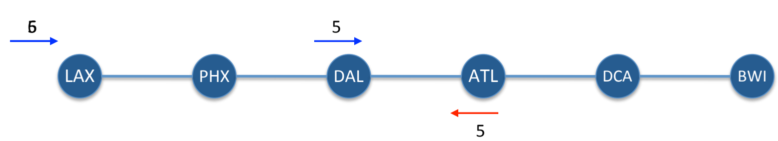
- 50 millisecond network
  - E.g. Los Angeles to Baltimore
  - 50 milliseconds to tell the sender about the loss
  - 50 milliseconds to resend the packet
- At least 100 milliseconds to recover a lost packet

End-to-End Reliability

- 50 millisecond network
  - E.g. Los Angeles to Baltimore
  - 50 milliseconds to tell the sender about the loss
  - 50 milliseconds to resend the packet
- At least 100 milliseconds to recover a lost packet
  - Can we do better ?

Hop-by-Hop Reliability

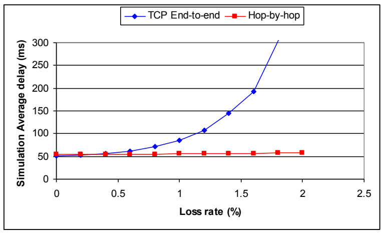
- 50 millisecond network, five hops
  - 10 milliseconds to tell node DAL about the loss
  - 10 milliseconds to get the packet back from DAL
- Only 20 milliseconds to recover a lost packet
  - Lost packet sent twice only on link DAL – ATL



Average Latency and Jitter

Simulation

Latency



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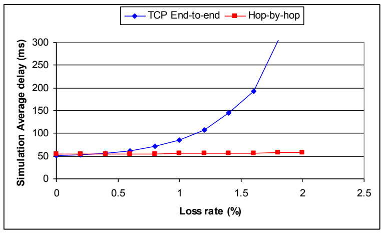
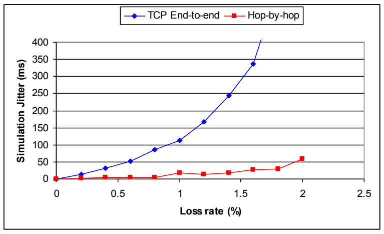


Jitter

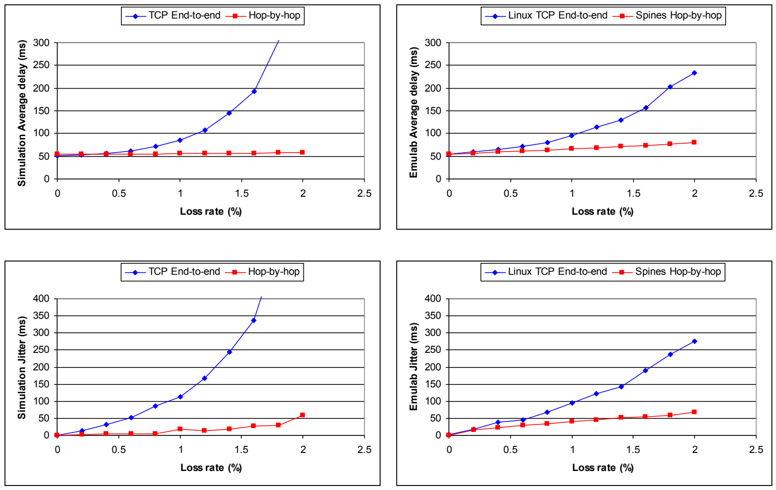


Average Latency and Jitter

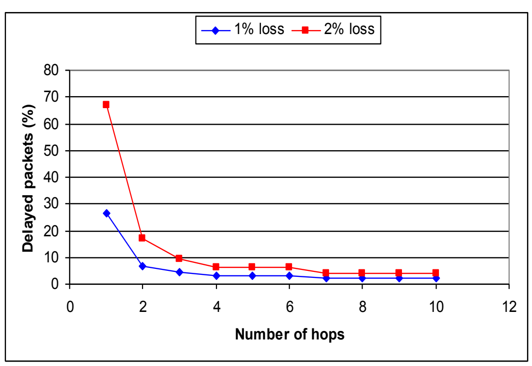
Simulation | Spines on Emulab

Latency

Jitter



How Dense Should an Overlay Be?



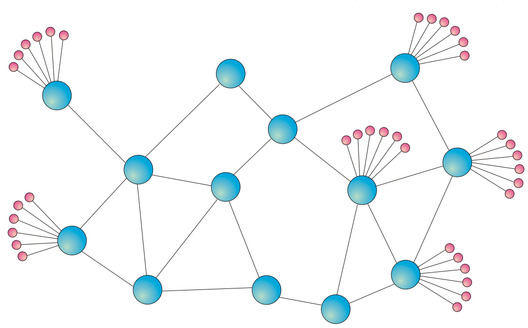
- 50 ms network divided evenly into x hops
- Delayed packets: arrive after more than 50+10ms

Spines – from Concepts to Systems

- The Spines Overlay Messaging system
  - An Overlay software router (daemon) on top of UDP
  - Running as a normal Internet application
- Easy to use programming platform
  - Transparent interface identical to the socket interface, giving TCP, UDP and IP Multicast functionality
- "Commercial grade" deployable system
  - Improving application performance over the Internet
  - Enabling new services
  - Open source (www.spines.org)

Spines – from Concepts to Systems

www.spines.org

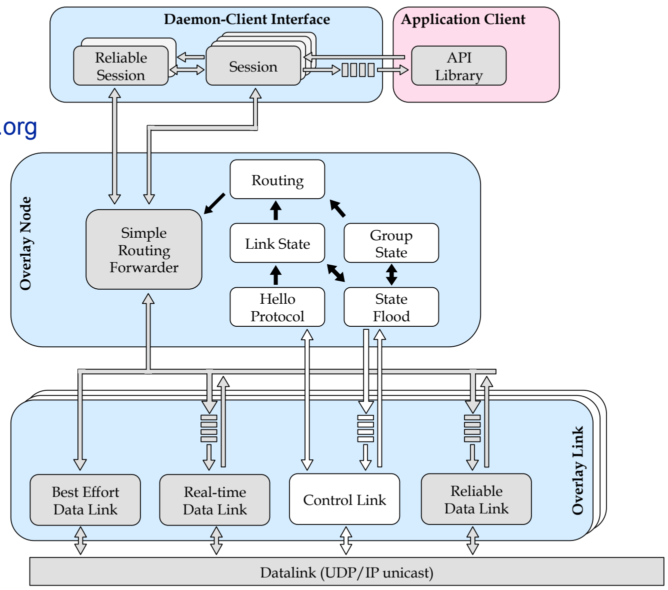


[DSN03, NOSSDAV05, TOM06, Mobisys06, TOCS10, LADIS12, ICDCS16]

- Daemons create an overlay network on the fly
- Clients are identified by the IP address of their daemon and a port ID
- Clients feel they are working with UDP and TCP using their IP and port identifiers
- Protocols designed to support up to 1000 daemons (locations), each daemon can handle up to about 1000 clients

The Spines Architecture

www.spines.org



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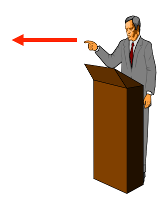
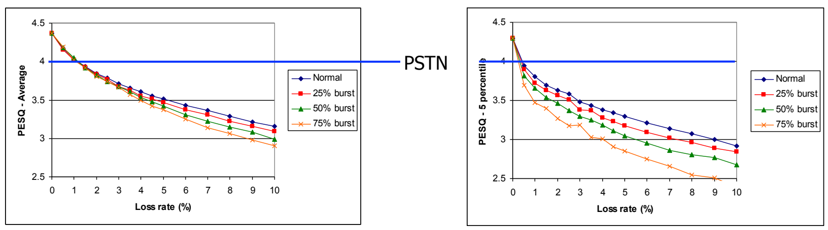


The Siemens VoIP Challenge

- Can we maintain a "good enough" phone call quality over the Internet?
- High quality calls demand predictable performance
  - VoIP is interactive. Humans perceive delays at 100ms
  - The best-effort service offered by the Internet was not designed to offer any quality guarantees
  - Communication subject to dynamic loss, delay, jitter, path failures



50ms network delay

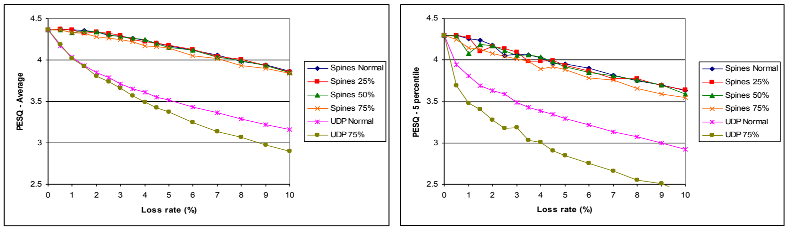
Almost Reliable, Real-time Protocol for VoIP

- Localized real-time recovery on overlay hops
  - Retransmission is attempted only once
- Each Overlay node keeps a history of the packets forwarded in the last 100ms
  - When the other end of a hop detects a loss, it requests a retransmission and moves on
  - If the upstream node still has the packet in its history, it resends it
- Not a reliable protocol
  - No ACKs. No duplicates. No blocking.

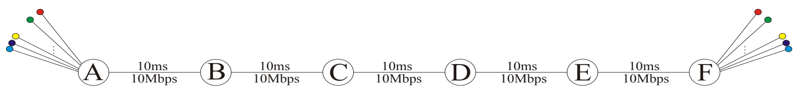
$$loss \approx 2 \cdot p^2 \qquad retr\_delay = 3 \cdot T + \Delta$$

- Recovery works for hops shorter than about 30ms
  - This is ok: overlay links are short !

VoIP Quality Improvement



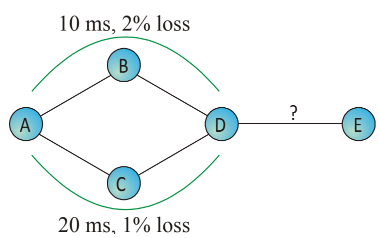
- Spines overlay – 5 links of 10ms each
- 10 VoIP streams sending in parallel
- Loss on middle link C-D



50ms network delay

Real-Time Routing for VoIP

- Routing algorithm that takes into account retransmissions
- Which path maximizes the number of packets arriving at node **E** in under 100 ms ?



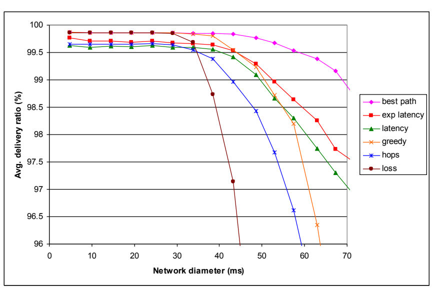
- Finding the best path by computing loss and delay distribution on all the possible routes is very expensive
- Weight metric for links that approximates the best path

$$Exp\_latency = (1-p)\cdot T + (p - 2\cdot p^2)\cdot(3\cdot T + \Delta) + 2\cdot p^2 \cdot T_{\max}$$

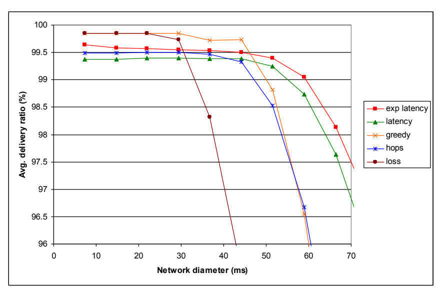
Real-Time Routing for VoIP

- Different routing metrics evaluated on random topologies generated by BRITE
  - On each topology, the nodes defining the diameter of the network (furtheest apart) are chosen as sender and receiver
  - Random loss rate from 0% to 5% on half of the links
- Optimizing Exp_latency metric compared with:
  - hops: Number of hops in the path
  - latency: Delay of the path
  - loss: Cumulative loss on the path
  - greedy: Dijkstra algorithm that computes delay distributions at each iteration and selects the partial path with maximum delivery ratio
  - best path: Computed out of all the possible paths

Real-Time Routing for VoIP



15 nodes; 30 links



50 nodes; 100 links

- Each point in the graphs is an average over 1000 different topologies generated with BRITE
- Our simulator could not compute best path for topologies with more than 16 nodes in a timely manner

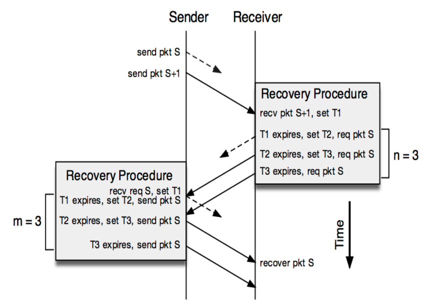
Overlay Approach to VoIP

- Localized real-time protocol on overlay hops
  - Retransmission is attempted only once
- Flexible routing metric avoids currently congested paths
  - Cost metric based on measured latency and loss rate of the links
  - Link cost equivalent to the expected packet latency when retransmissions are considered

What About Live TV ?

- Is it more or less demanding than VoIP?
  - The ear is more sensitive than the eye
  - But we really want to see a clear picture on our large-screen HD TVs (less tolerance for error)
- How demanding is it?
  - Personal experience: could not notice problems with up to 100 misses per million with MPEG-2 encoding, 20 misses per million with H.264 encoding.
  - Broadcast standard: 5-6 errors per million for Standard TV, about 1 error per million for HD TV.
- What is Live?
  - Common TV transport systems usually add a few seconds.
  - Live service for interviews requires less than half a second delay
  - End-to-end transport window is therefore about 150-200ms.

Almost Reliable, Real-time Protocol for Live TV



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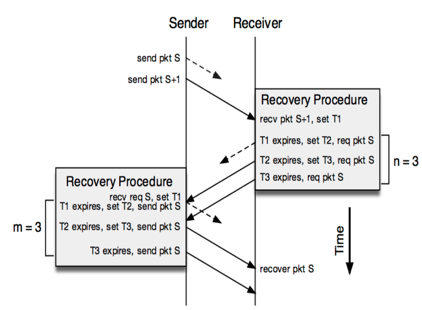

Network packet loss on one link (assuming 66% burstiness)	Loss experienced by flows on the LTN Network
2%	< 0.0003%
5%	< 0.003%
10%	< 0.03%

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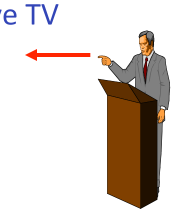
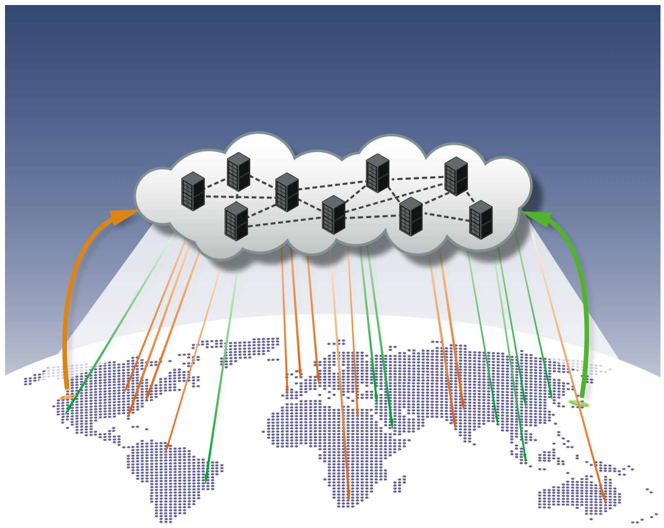


Overlays on a Global Scale

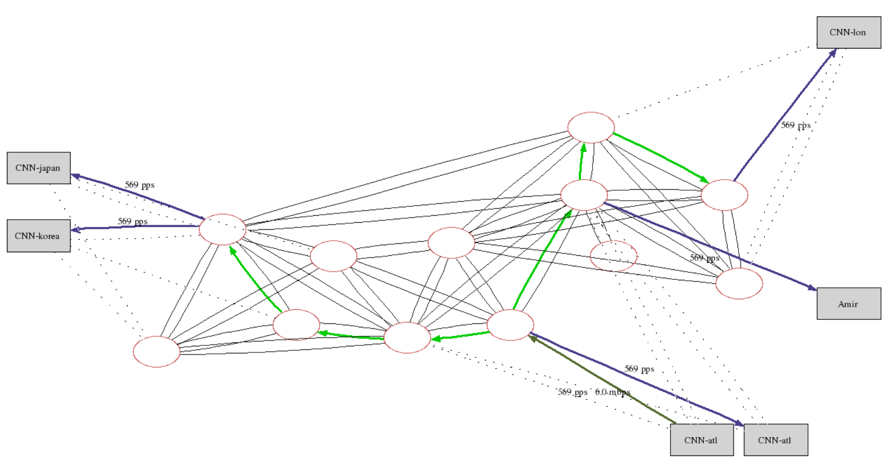
The service provider point of view

- A service rather than software or hardware
- Control over where overlay nodes are located
- Multiple network providers in each overlay node (Super Nodes)
- Guaranteed capacity with admission control
- Monitoring and Control – near automation

The LiveTimeNet Cloud



Time for a Demonstration



State-of-the-art: Combining Timeliness and Reliability over the Internet

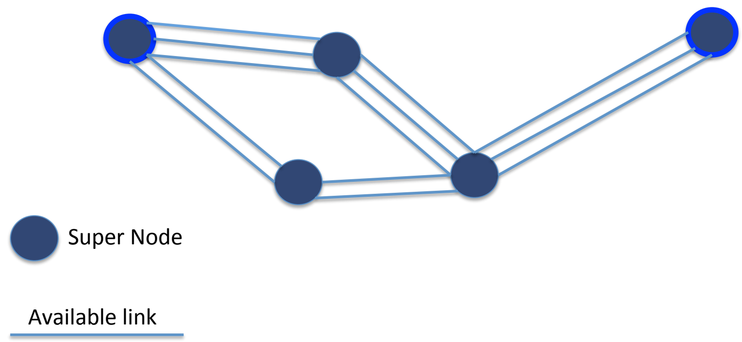
200ms one-way latency requirement, 99.999% reliability guarantee
40ms one-way propagation delay across North America

Addressing the Technical Challenge

- Scalable overlay network architecture
  - Parallel overlays
- Real-time monitoring and control
  - Automated – take the human out of the loop
- Three levels of protection
  - Link level: real-time protocol for Live TV
  - Overlay level: responsive overlay routing
  - Cloud level: NxWay failover for overlay routers

Responsive Overlay Routing

- Utilizes multiple Tier 1 IP backbones
- Optimized overlay paths determine selected links
- Automatically and instantaneously switch to a better path



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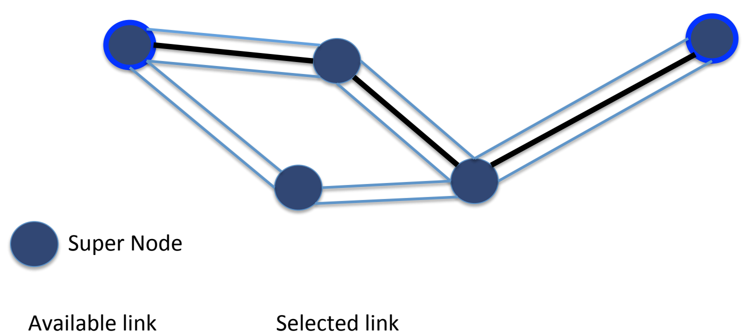

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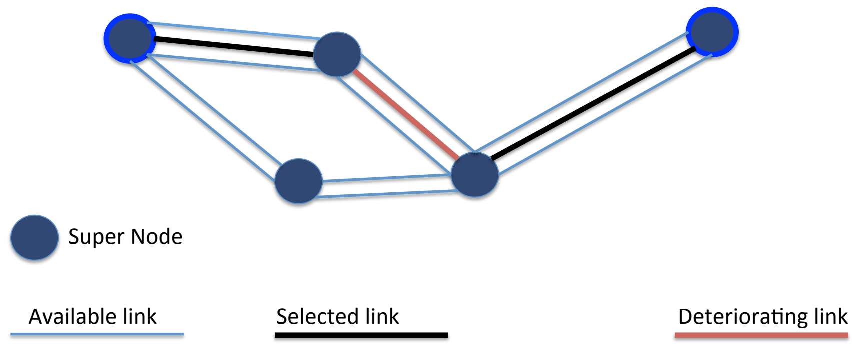

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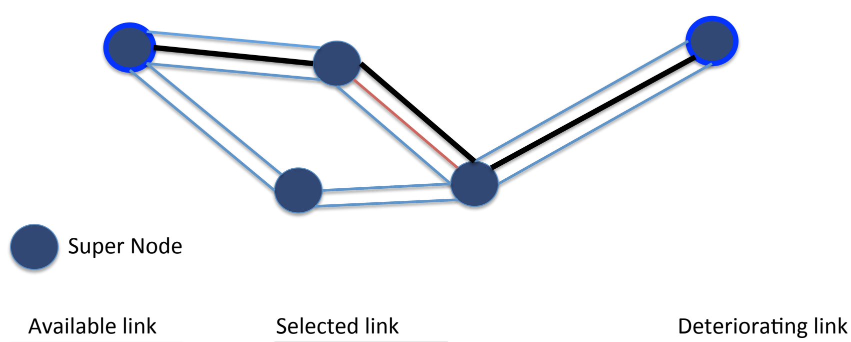

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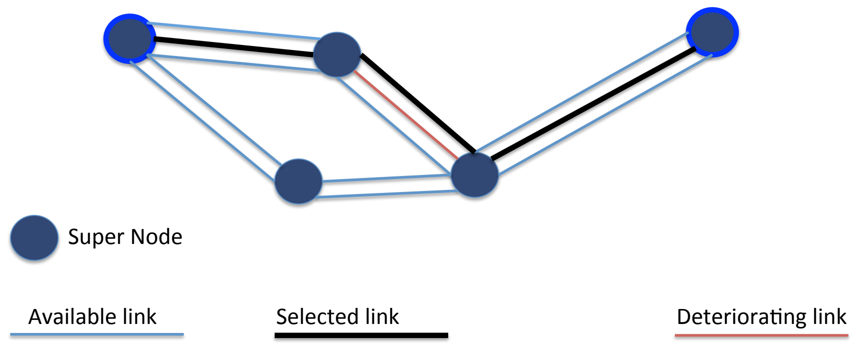

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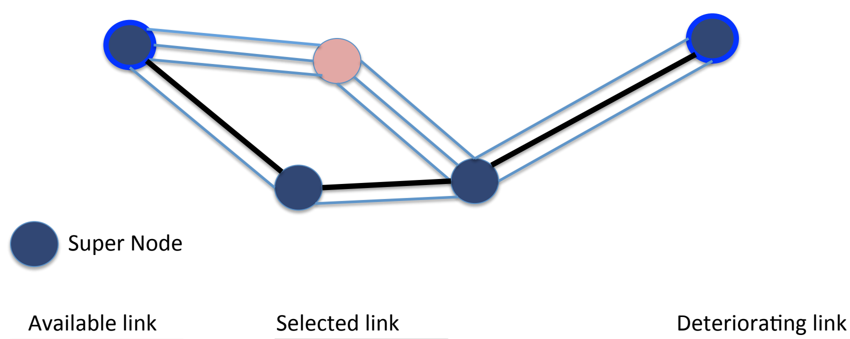

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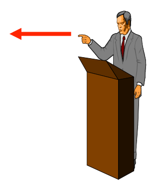
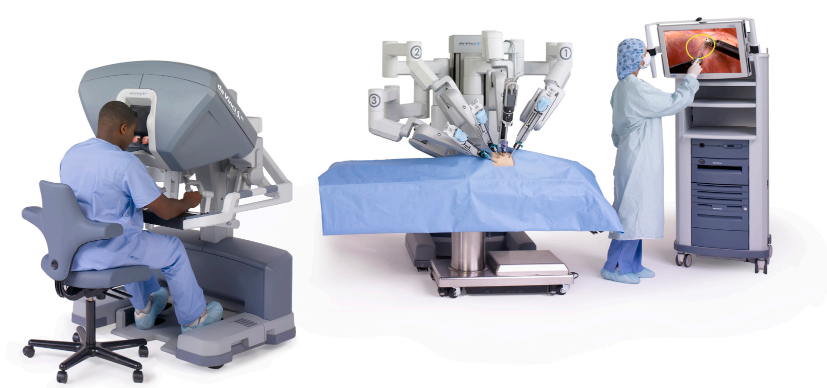


New Challenges: Combining Timeliness and Reliability



130ms **round-trip** latency requirement

New Challenges: Combining Timeliness and Reliability

130ms **round-trip** latency requirement
80ms round-trip propagation delay across North America

Addressing New Challenges: Dissemination Graph Approach

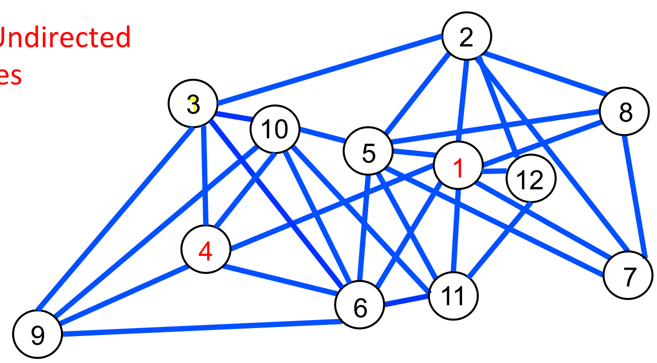
- Stringent latency requirements give less flexibility for buffering and recovery
- Core idea: Send packets redundantly over a subgraph of the network to maximize the probability of at least one copy arriving on time

How do we select the subset of overlay links on which to send each packet?

Selecting a Dissemination Graph

- Overlay Flooding: send on all overlay links
  - Optimal in timeliness and reliability but expensive

32 Undirected Edges



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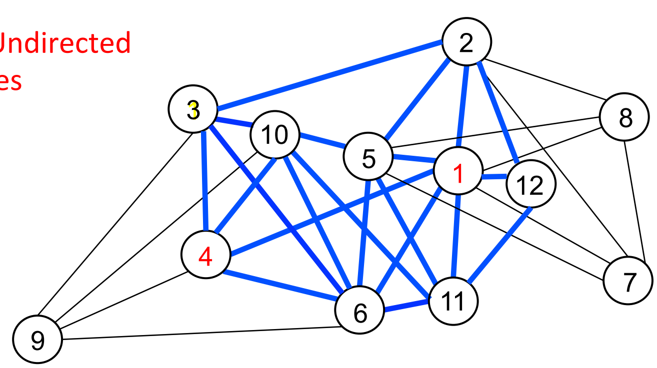
Selecting a Dissemination Graph

- Time-Constrained Overlay Flooding: send on all overlay links that are on some simple path that arrives in the deadline.

21 Undirected Edges



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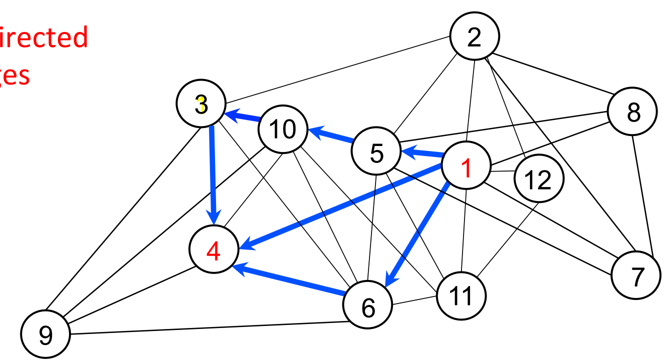
Selecting a Dissemination Graph

- Disjoint Paths: send on several paths that do not share any nodes (or edges)
  - Common trade-off between cost and timeliness/reliability
  - Uniformly invests resources across the network

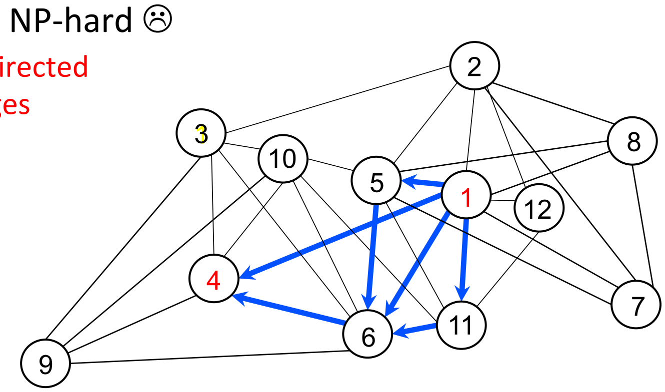
7 Directed Edges



Selecting an Optimal Dissemination Graph

- Optimal Calculation: Optimal calculation based on the current edge latencies and loss rates
  - NP-hard ☹

7 Directed Edges



Data-Informed Approach

- Data-informed: Collect pings on the network every 10ms. Develop a simulator to evaluate the performance of various dissemination graphs for flows of arbitrary frequency.
- Key Finding: 2 node-disjoint paths does very well except if there is a problem at the source or destination
  - < 0.01% of late or dropped packets when using 2 node-disjoint paths are not due to problems solely at the source or destination

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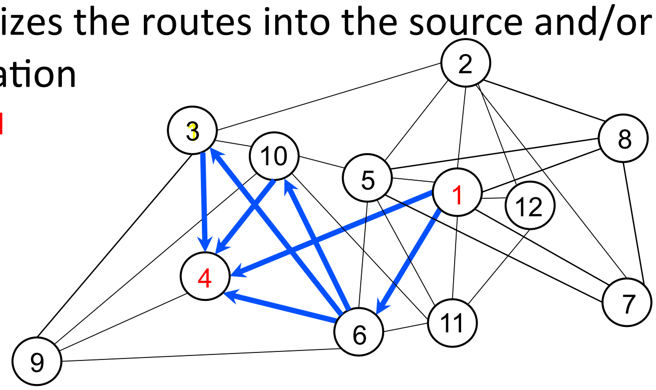
Data-Informed Approach

- Use 2 disjoint paths normally
- If a problem at the source or destination is detected, use a precomputed graph that maximizes the routes into the source and/or destination

7 Directed Edges



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Preliminary Simulation Results

- 5 weeks of data with different ISP topologies, 12 flows between the east coast and west coast
- 1000 simulated packets/second (36,000,000,000 packets total)
- Consider time-constrained flooding performance to be optimal for the network at that time
  - If time-constrained flooding could not get the packets to the destination on time, then nothing could

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Preliminary Simulation Results

- Sum all late and lost packets across all flows for all 5 weeks for each dissemination approach. Subtract out packets that time-constrained flooding could not deliver on time
  - On average, source/destination dissemination graph approach costs < .01 additional edges more than 2 node-disjoint paths

Late or Dropped Packets Across All
(vs. Time-Constrained Flooding)

	2 node-disjoint paths with reroutes	Source/destination graph approach
No recoveries	117,195	1,136
Real-time VoIP Recovery	59,702	1,062

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- First Steps
  - Low-latency reliable protocol
  - Spines – from Concepts to Systems
- The Quest for QoS
  - Almost-reliable, real-time protocol for VoIP
  - Almost-reliable, real-time protocol for Live TV
- Overlays on a Global Scale
  - The LiveTimeNet Cloud
- Going even Faster
  - Reliability and timeliness
  - How fast can it get