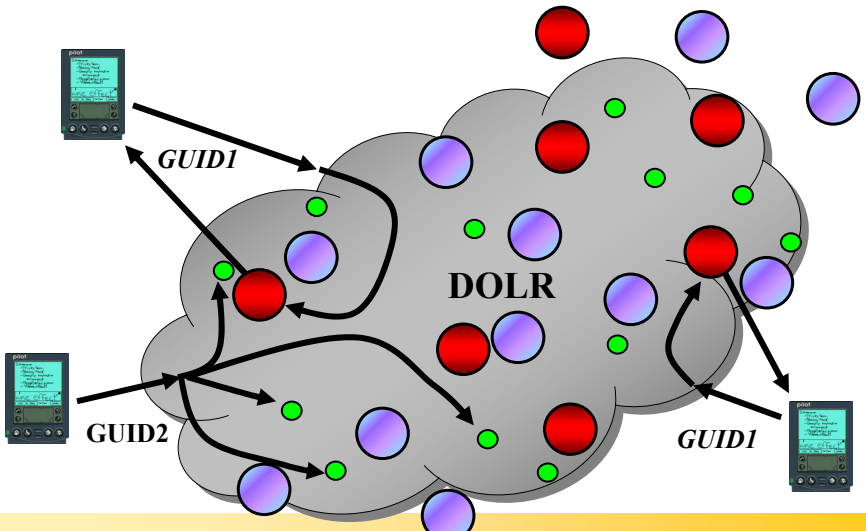
Implementation and Deployment of a Large-scale Network Infrastructure

Ben Y. Zhao
L. Huang, S. Rhea, J. Stribling,
A. D. Joseph, J. D. Kubiatowicz
EECS, UC Berkeley
HP Labs, November 2002

Next-generation Network Applications

- Scalability in applications
  - Process/threads on single node server
  - Cluster (LAN): fast, reliable, unlimited comm.
  - Next step: scaling to the wide-area
- Complexities of global deployment
  - Network unreliability
    - BGP slow convergence, redundancy unexploited
  - Lack of administrative control over components
    - Constrains protocol deployment: multicast, congestion ctrl.
  - Management of large scale resources / components
    - Locate, utilize resources despite failures

Enabling Technology: DOLR
(Decentralized Object Location and Routing)



A Solution

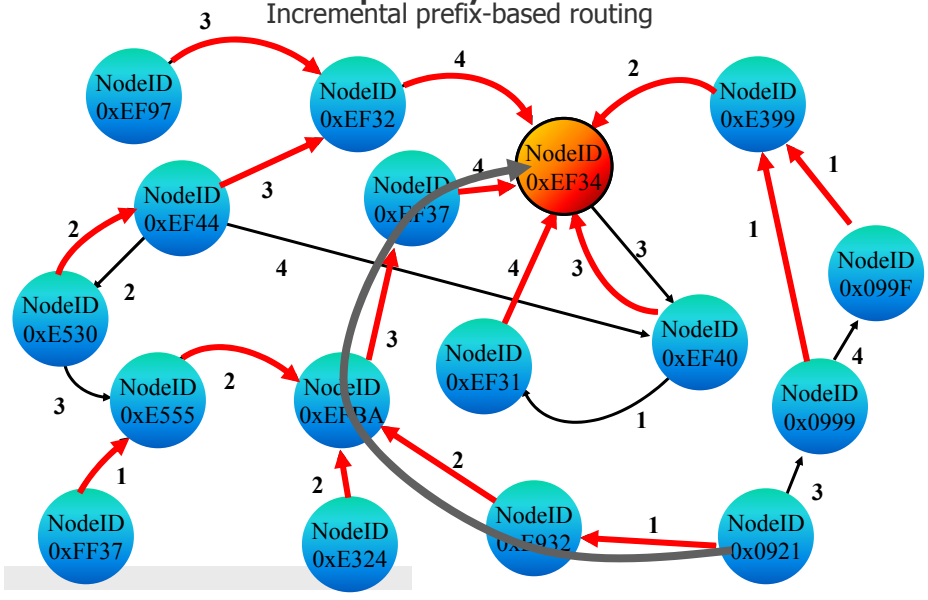
- Decentralized Object Location and Routing (DOLR)
  - wide-area overlay application infrastructure
    - Self-organizing, scalable
    - Fault-tolerant routing and object location
    - Efficient (b/w, latency) data delivery
  - Extensible, supports application-specific protocols
- Recent work
  - Tapestry, Chord, CAN, Pastry
  - Kademlia, Viceroy, …

What is Tapestry?

- DOLR driving OceanStore global storage
  (Zhao, Kubiatowicz, Joseph et al. 2000)
- Network structure
  - Nodes assigned bit sequence **nodeIds**
    namespace: 0-2^{160}, based on some radix (e.g. 16)
  - **keys** from same namespace
    Keys dynamically map to 1 unique live node: *root*
- Base API
  - Publish / Unpublish (Object ID)
  - RouteToNode (NodeId)
  - RouteToObject (Object ID)

Tapestry Mesh

Incremental prefix-based routing

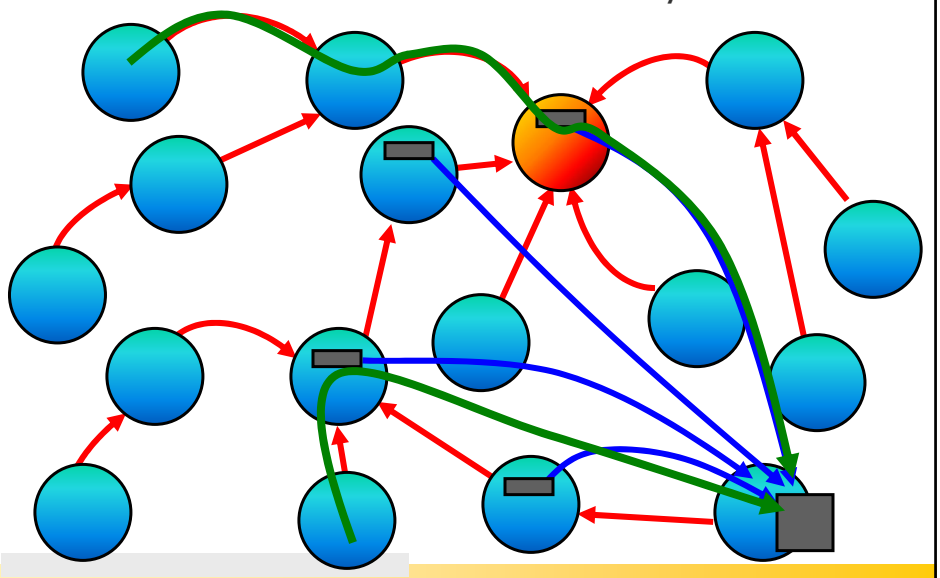


Routing Mesh

- Routing via local routing tables
  - Based on incremental prefix matching
  - Example: 5324 routes to 0629 via 5324 → 0231 → 0667 → 0625→ 0629
  - At n^{th} hop, local node matches destination at least *n* digits (if any such node exists)
  - i^{th} entry in n^{th} level routing table points to nearest node matching: *prefix(local_ID, n)+i*
- Properties
  - At most log(N) # of overlay hops between nodes
  - Routing table size: b ∗ log(N)
  - Actual entries have *c-1* backups, total size: c ∗ b ∗ log(N)

Object Location

Randomization *and* Locality



Object Location

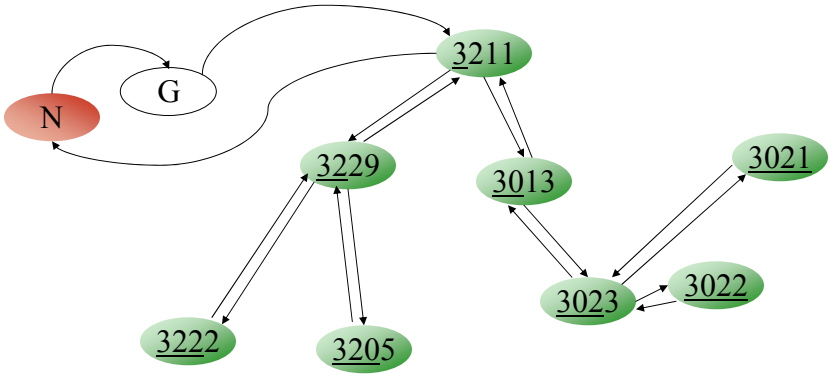
- Distribute replicates of object references
  - Only references, not the data itself (level of indirection)
  - Place more of them closer to object itself
- Publication
  - Place object location pointers into network
  - Store hops between object and “root” node
- Location
  - Route message towards root from client
  - Redirect to object when location pointer found

Node Insertion

- Inserting new node *N*
  - Notify *need-to-know* nodes of *N*, *N* fills null entries in their routing tables
  - Move locally rooted object references to *N*
  - Construct locally optimal routing table for *N*
  - Notify nearby nodes to *N* for optimization
- Two phase node insertion
  - Acknowledged multicast
  - Nearest neighbor approximation

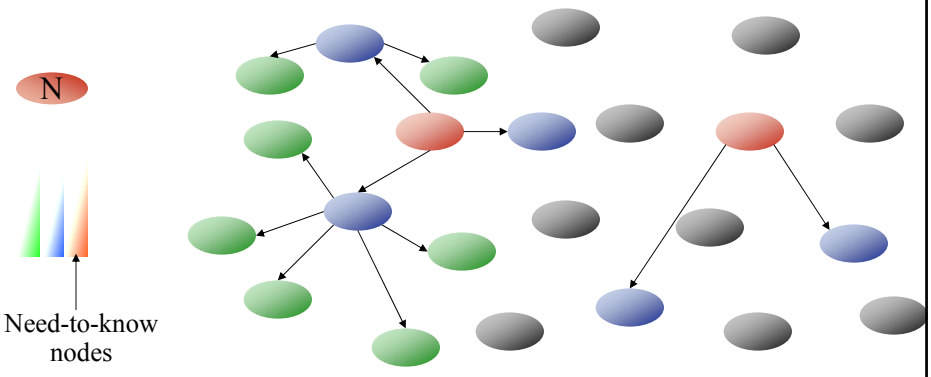
Acknowledged Multicast

- Reach *need-to-know* nodes of *N (e.g. 3111)*
  - Add to routing table
  - Move root object references



Nearest Neighbor

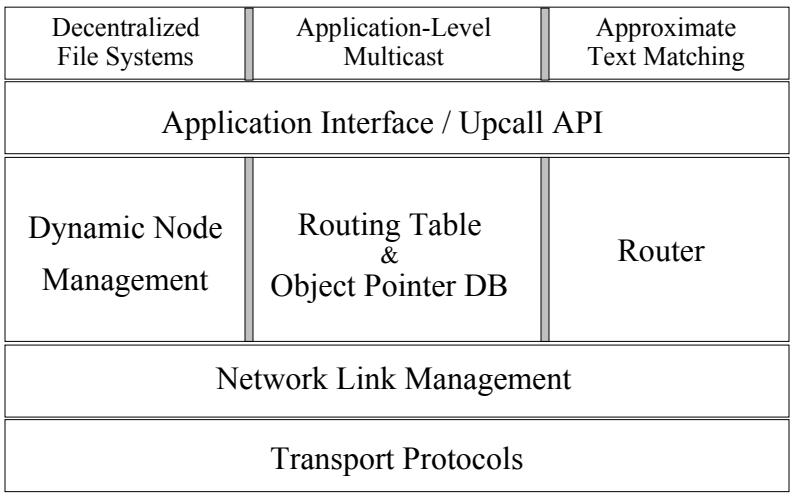
- N iterates: list = *need-to-know* nodes, L = *prefix* (N, S)
  - Measure distances of List, use to fill routing table, level L
  - Trim to *k* closest nodes, list = backpointers from *k* set, L--
  - Repeat until L == 0



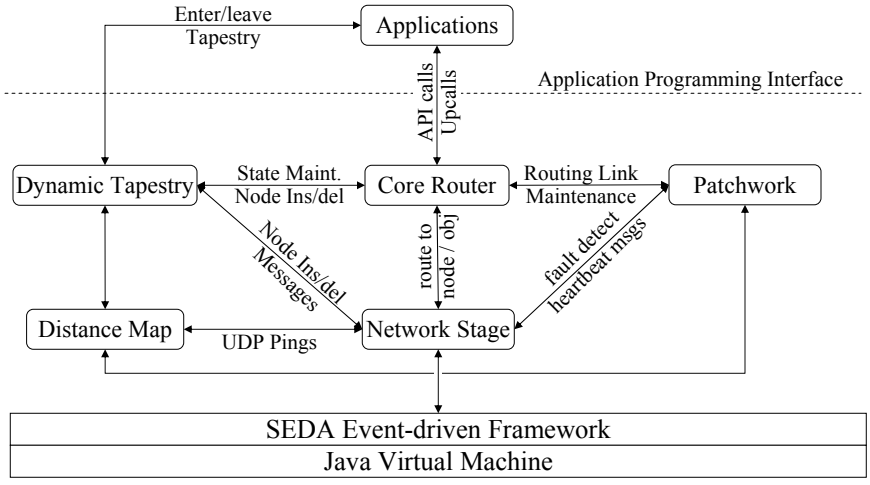
Talk Outline

- Algorithms
- Architecture
  - Architectural components
  - Extensibility API
- Evaluation
- Ongoing Projects
- Conclusion

Single Tapestry Node

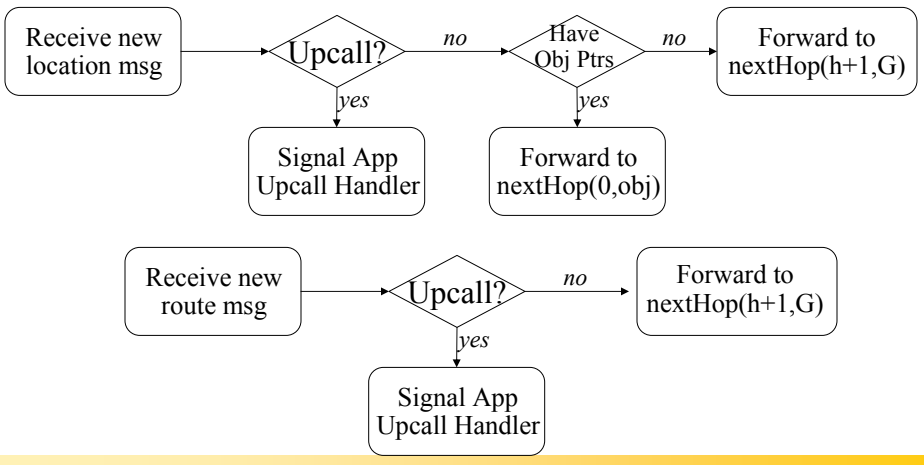


Single Node Implementation



Message Routing

- Router: fast routing to nodes / objects



Extensibility API

- **deliver** (*G*, A_{id}, Msg)
  - Invoked at message destination
  - Asynchronous, returns immediately
- **forward** *(G,* A_{id}, Msg)
  - Invoked at intermediate hop in route
  - No action taken by default, application calls route()
- **route** *(G,* A_{id}, Msg, NextHopNodeSet)
  - Called by application to request message be routed to set of NextHopNodes

Local Operations

- Accessibility to Tapestry maintained state
- **nextHopSet = Llookup(*G*, Num)**
  - Accesses routing table
  - Returns up to num candidates for next hop towards *G*
- **objReferenceSet = Lsearch(*G*, num)**
  - Searches object references for *G*
  - Returns up to num references for object, sorted by increasing network distance

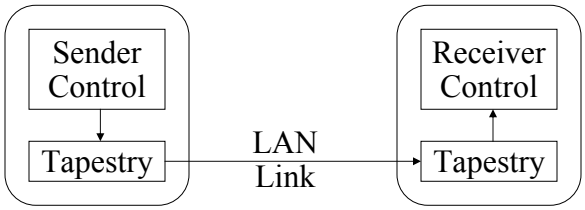
Deployment Status

- C simulator
  - Packet level simulation
  - Scales up to 10,000 nodes
- Java implementation
  - 50000 semicolons of Java, 270 class files
  - Deployed on local area cluster (40 nodes)
  - Deployed on Planet Lab global network (~100 distributed nodes)

Talk Outline

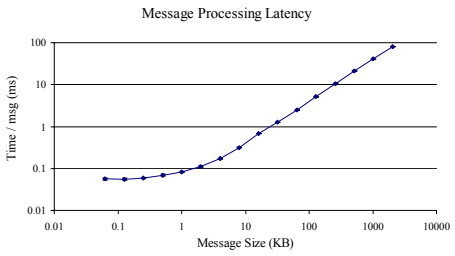
- Algorithms
- Architecture
- Evaluation
  - Micro-benchmarks
  - Stable network performance
  - Single and parallel node insertion
- Ongoing Projects
- Conclusion

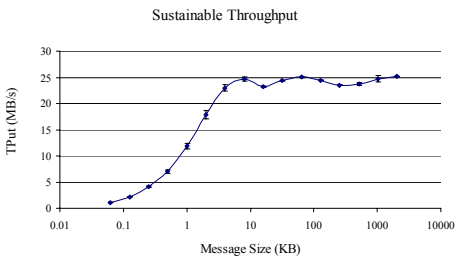
Micro-benchmark Methodology



- Experiment run in LAN, GBit Ethernet
- Sender sends 60001 messages at full speed
- Measure inter-arrival time for last 50000 msgs
  - 10000 msgs: remove cold-start effects
  - 50000 msgs: remove network jitter effects

Micro-benchmark Results



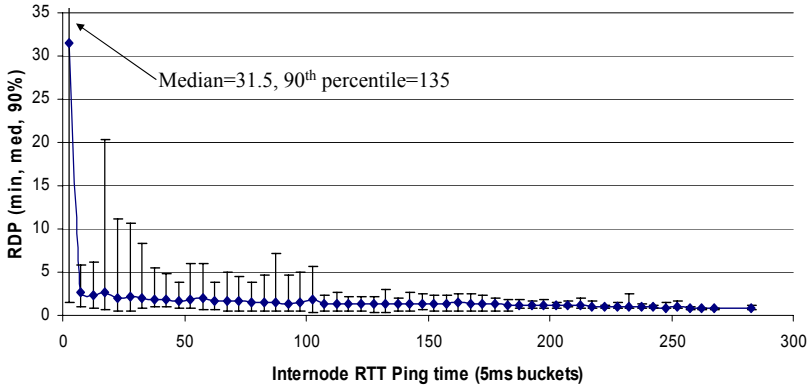


- Constant processing overhead ~ 50μs
- Latency dominated by byte copying
- For 5K messages, throughput = ~10,000 msgs/sec

Large Scale Methodology

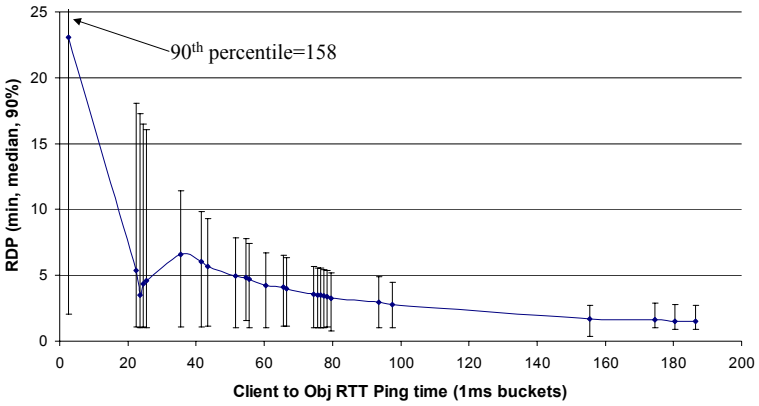
- Planet Lab global network
  - 98 machines at 42 institutions, in North America, Europe, Australia (~ 60 machines utilized)
  - 1.26Ghz PIII (1GB RAM), 1.8Ghz PIV (2GB RAM)
  - North American machines (2/3) on Internet2
- Tapestry Java deployment
  - 6-7 nodes on each physical machine
  - IBM Java JDK 1.30
  - Node virtualization inside JVM and SEDA
  - Scheduling between virtual nodes increases latency

Node to Node Routing



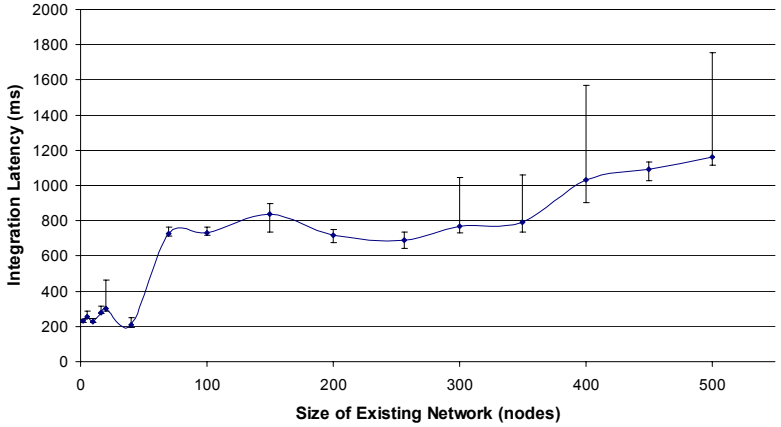
- Ratio of end-to-end routing latency to shortest ping distance between nodes
- All node pairs measured, placed into buckets

Object Location



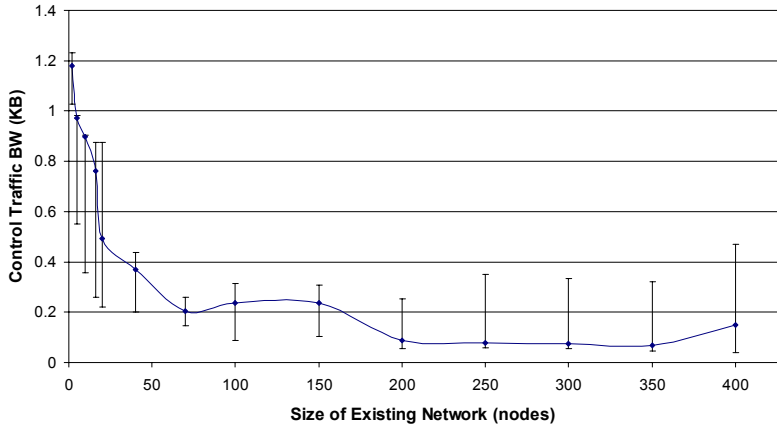
- Ratio of end-to-end latency for object location, to shortest ping distance between client and object location
- Each node publishes 10,000 objects, lookup on all objects

Latency to Insert Node



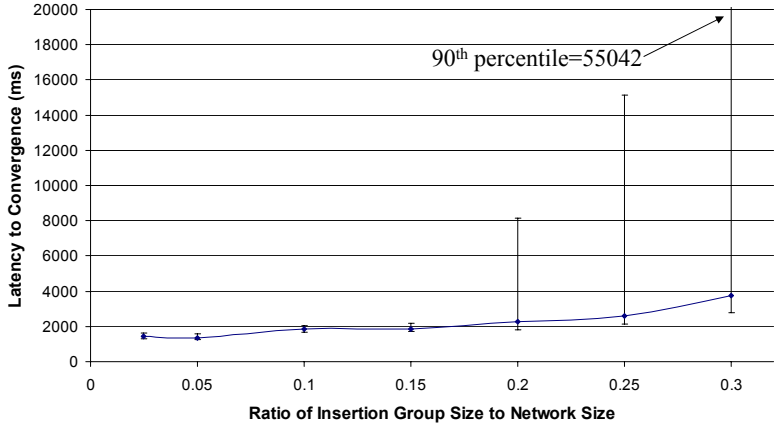
- Latency to dynamically insert a node into an existing Tapestry, as function of size of existing Tapestry
- Humps due to expected filling of each routing level

Bandwidth to Insert Node



- Cost in bandwidth of dynamically inserting a node into the Tapestry, amortized for each node in network
- Per node bandwidth decreases with size of network

Parallel Insertion Latency



- Latency to dynamically insert nodes in unison into an existing Tapestry of 200
- Shown as function of insertion group size / network size

Results Summary

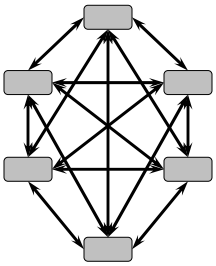
- Lessons Learned
  - Node virtualization: resource contention
  - Accurate network distances hard to measure
- Efficiency verified
  - Msg processing = 50μs, Tput ~ 10,000*msg/s*
  - Route to node/object small factor over optimal
- Algorithmic scalability
  - Single node latency/bw scale sublinear to network size
  - Parallel insertion scales linearly with group size

Talk Outline

- Algorithms
- Architecture
- Evaluation
- Ongoing Projects
  - P2P landmark routing: Brocade
  - Applications: Shuttle, Interweave, ATA
- Conclusion

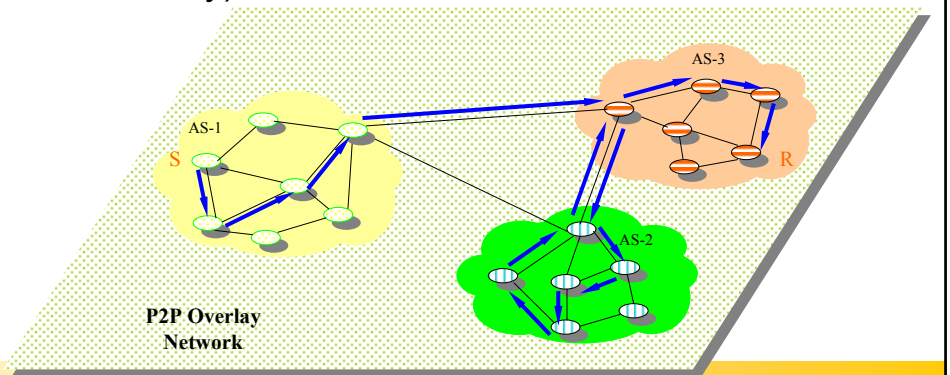
State of the Art Routing

- High dimensionality and coordinate-based P2P routing
  - Tapestry, Pastry, Chord, CAN, etc…
  - Sub-linear storage and # of overlay hops per route
  - Properties dependent on random name distribution
  - Optimized for uniform mesh style networks



Reality

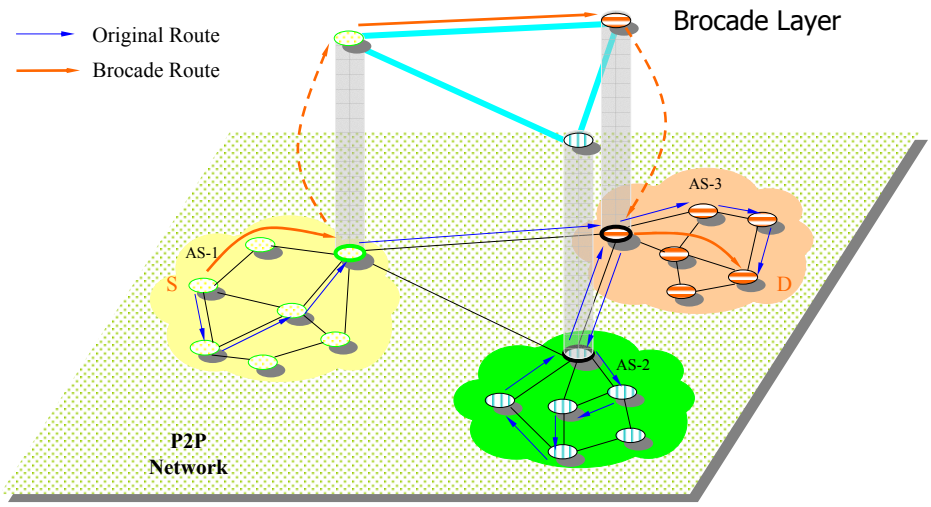
- Transit-stub topology, disparate resources per node
- Result: Inefficient inter-domain routing (b/w, latency)



Landmark Routing on P2P

- Brocade
  - Exploit non-uniformity
  - Minimize wide-area routing hops / bandwidth
- Secondary overlay on top of Tapestry
  - Select *super*-nodes by admin. domain
    - Divide network into *cover sets*
  - Super-nodes form secondary Tapestry
    - Advertise cover set as local objects
  - brocade routes directly into destination's local network, then resumes p2p routing

Brocade Routing



Applications under Development

- OceanStore: global resilient file store
- Shuttle
  - Decentralized P2P chat service
  - Leverages Tapestry for fault-tolerant routing
- Interweave
  - Keyword searchable file sharing utility
  - Fully decentralized, exploits network locality
- Approximate Text Addressing
  - Uses text fingerprinting to map similar documents to single IDs
  - Killer app: decentralized spam mail filter

For More Information

Tapestry and related projects (and these slides):

http://www.cs.berkeley.edu/~ravenben/tapestry

OceanStore:

http://oceanstore.cs.berkeley.edu

Related papers:

http://oceanstore.cs.berkeley.edu/publications

http://www.cs.berkeley.edu/~ravenben/publications

ravenben@eecs.berkeley.edu