EECS 122: Introduction to Computer Networks
Overlay Networks and P2P Networks

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Overlay Networks: Motivations

- Changes in the network happen very slowly
- Why?
  - Internet network is a shared infrastructure; need to achieve consensus (IETF)
  - Many of proposals require to change a large number of routers (e.g., IP Multicast, QoS); otherwise end-users won't benefit
- Proposed changes that haven't happened yet on large scale:
  - More Addresses (IPv6 '91)
  - Security (IPSEC '93); Multicast (IP multicast '90)

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Motivations (cont'd)

- One size does not fit all
- Applications need different levels of
  - Reliability
  - Performance (latency)
  - Security
  - Access control (e.g., who is allowed to join a multicast group)
  - …

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Goals

- Make it easy to deploy new functionalities in the network → accelerate the pace of innovation
- Allow users to customize their service

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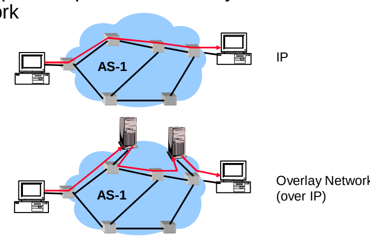
Solution

- Deploy processing in the network
- Have packets processed as they traverse the network



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Overview

- ➢ Resilient Overlay Network (RON)
- Overlay Multicast
- Peer-to-peer systems

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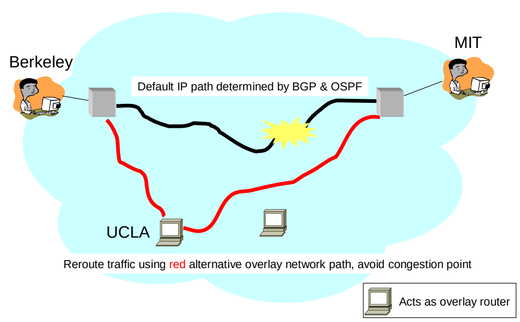
Resilient Overlay Network (RON)

- Premise: by building application overlay network, can increase performance and reliability of routing
- Install N computers at different Internet locations
- Each computer acts as an overlay network router
  - Between each overlay router is an IP tunnel (logical link)
  - Logical overlay topology is all-to-all (N^2)
- Computers actively measure each logical link in real time for
  - Packet loss rate, latency, throughput, etc
- Route overlay network traffic based on measured characteristics

Example



Overview

- Resilient Overlay Network (RON)
- ➢ Overlay multicast
- Peer-to-peer systems

IP Multicast Problems

- Seventeen years of research, but still not widely deployed
- Poor scalability
  - Routers need to maintain per-group or even per-group and per-sender state!
  - Multicast addresses cannot be aggregated
- Supporting higher level functionality is difficult
  - IP Multicast: best-effort multi-point delivery service
  - Reliability and congestion control for IP Multicast complicated
- No support for access control
  - Nor restriction on who can send → easy to mount Denial of Service (Dos) attacks!

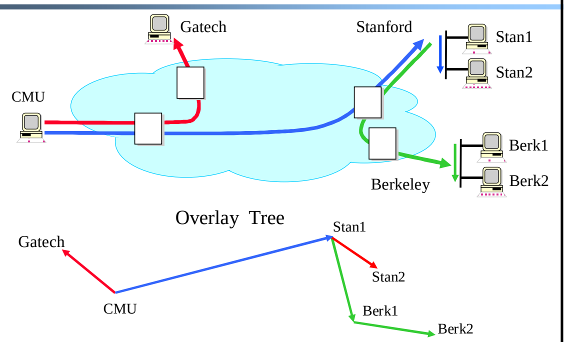
Overlay Approach

- Provide IP multicast functionality above the IP layer → application level multicast
- Challenge: do this efficiently
- Projects:
  - Narada
  - Overcast
  - Scattercast
  - Yoid
  - …

Narada [Yang-hua et al, 2000]

- Source Speific Trees
- Involves only end hosts
- Small group sizes <= hundreds of nodes
- Typical application: chat

Narada: End System Multicast



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Properties

- Easier to deploy than IP Multicast
  - Don't have to modify every router on path
- Easier to implement reliability than IP Multicast
  - Use hop-by-hop retransmissions
- But
  - Consume more bandwidth than IP Multicast
  - Typically has higher latency than IP Multicast
  - Harder to scale
- Optimization: use IP Multicast where available

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Overview

- Resilient Overlay Network (RON)
- Overlay multicast
- ➢ Peer-to-peer systems

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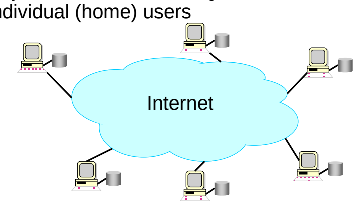
How Did it Start?

- A killer application: Naptser
  - Free music over the Internet
- Key idea: share the storage *and* bandwidth of individual (home) users



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Model

- Each user stores a subset of files
- Each user has access (can download) files from all users in the system

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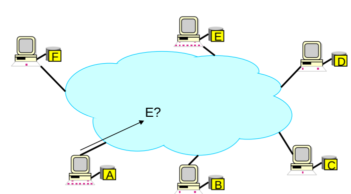
Main Challenge

- Find where a particular file is stored
  - Note: problem similar to finding a particular page in web caching (see last lecture – what are the differences?)



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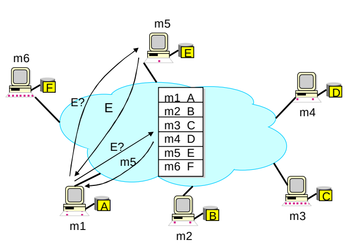
Other Challenges

- Scale: up to hundred of thousands or millions of machines
- Dynamicity: machines can come and go any time

Napster

- Assume a centralized index system that maps files (songs) to machines that are alive
- How to find a file (song)
  - Query the index system → return a machine that stores the required file
    - Ideally this is the closest/least-loaded machine
  - ftp the file

Napster: Example



Naptser: Discussion

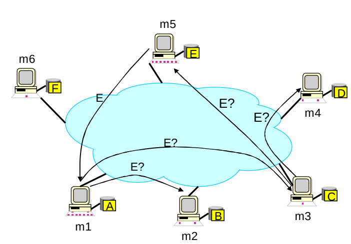
- Advantages:
  - Simplicity, easy to implement sophisticated search engines on top of the index system
- Disadvantages:
  - Robustness, scalability (?)

Gnutella

- Distribute file location
- Idea: flood the request
- How to find a file:
  - Send request to all neighbors
  - Neighbors recursively multicast the request
  - Eventually a machine that has the file receives the request, and it sends back the answer

Gnutella: Example

- Assume: m1's neighbors are m2 and m3; m3's neighbors are m4 and m5;…



Gnutella: Discussion

- Advantages:
  - Totally decentralized, highly robust
- Disadvantages:
  - Not scalable; the entire network can be swamped with request (to alleviate this problem, each request has a TTL)

Other Solutions to the Location Problem

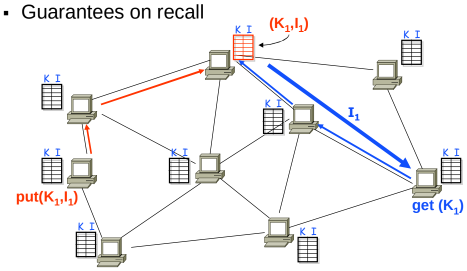
- Use a distributed rather than a centralized directory (like in the case of Napster)
- Distributed hash-table data (DHT) abstraction
  - insert(id, item);
  - item = query(id);
  - Note: item can be anything: a data object, document, file, pointer to a file…
- Proposals
  - CAN, Chord, Kademlia, Pastry, Tapestry, etc

DHT Design Goals

- Make sure that an item (file) identified is always found
- Scales to hundreds of thousands of nodes
- Handles rapid arrival and failure of nodes

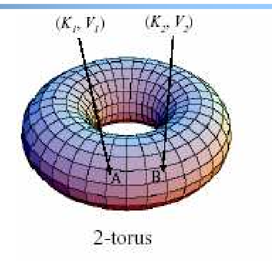
Structured Networks

- Distributed Hash Tables (DHTs)
- Hash table interface: **put**(key,item), **get**(key)
- O(log n) hops
- Guarantees on recall



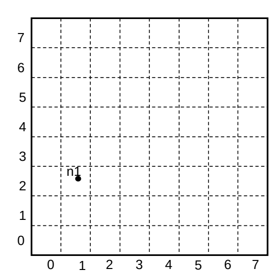
Content Addressable Network (CAN)

- Associate to each node and item a unique *id* in an *d*-dimensional Cartesian space on a *d*-torus
- Properties
  - Routing table size O(*d*)
  - Guarantees that a file is found in at most $d*n^{1/d}$ steps, where *n* is the total number of nodes



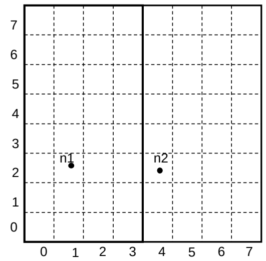
CAN Example: Two Dimensional Space

- Space divided between nodes
- All nodes cover the entire space
- Each node covers either a square or a rectangular area of ratios 1:2 or 2:1
- Example:
  - Node n1:(1, 2) first node that joins → cover the entire space



CAN Example: Two Dimensional Space

- Node n2:(4, 2) joins → space is divided between n1 and n2



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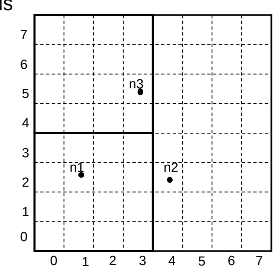
CAN Example: Two Dimensional Space

- Node n2:(4, 2) joins → space is divided between n1 and n2



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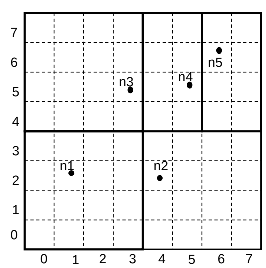
CAN Example: Two Dimensional Space

- Nodes n4:(5, 5) and n5:(6,6) join



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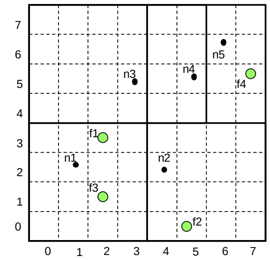
CAN Example: Two Dimensional Space

- Nodes: n1:(1, 2); n2:(4,2); n3:(3, 5); n4:(5,5);n5:(6,6)
- Items: f1:(2,3); f2:(5,1); f3:(2,1); f4:(7,5);



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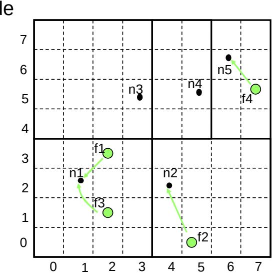
CAN Example: Two Dimensional Space

- Each item is stored by the node who owns its mapping in the space



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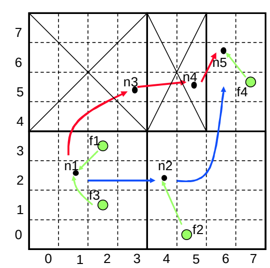
CAN: Query Example

- Each node knows its neighbors in the *d*-space
- Forward query to the neighbor that is closest to the query *id*
- Example: assume n1 queries f4
- Can route around some failures



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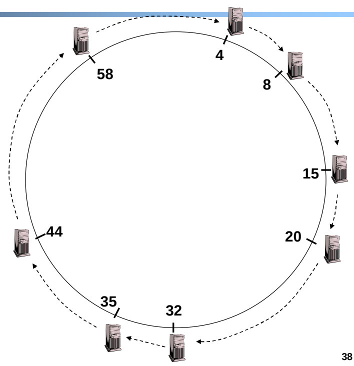
Chord

- Associate to each node and item a unique *id* in an *uni*-dimensional space 0..2^m-1
- Key design decision
  - Decouple correctness from efficiency
- Properties
  - Routing table size O(log(*N*)) , where *N* is the total number of nodes
  - Guarantees that a file is found in O(log(*N*)) steps

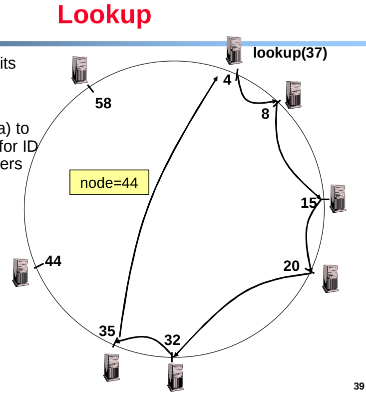
Identifier to Node Mapping Example

- Node 8 maps [5,8]
- Node 15 maps [9,15]
- Node 20 maps [16, 20]
- …
- Node 4 maps [59, 4]
- Each node maintains a pointer to its successor



Lookup

- Each node maintains its successor
- Route packet (ID, data) to the node responsible for ID using successor pointers

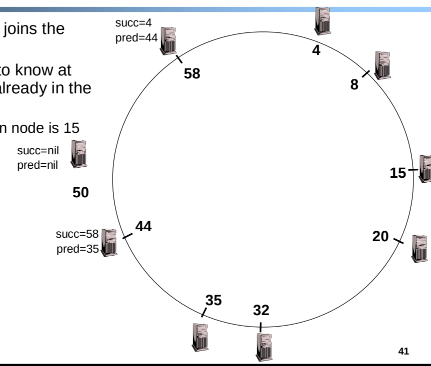


Joining Operation

- Each node A periodically sends a stabilize() message to its successor B
- Upon receiving a stabilize() message, node B
  - returns its predecessor B'=pred(B) to A by sending a notify(B') message
- Upon receiving notify(B') from B,
  - if B' is between A and B, A updates its successor to B'
  - A doesn't do anything, otherwise

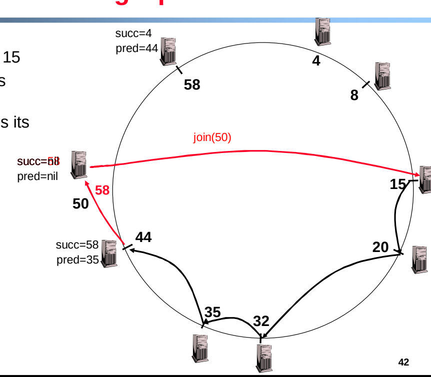
Joining Operation

- Node with id=50 joins the ring
- Node 50 needs to know at least one node already in the system
  - Assume known node is 15



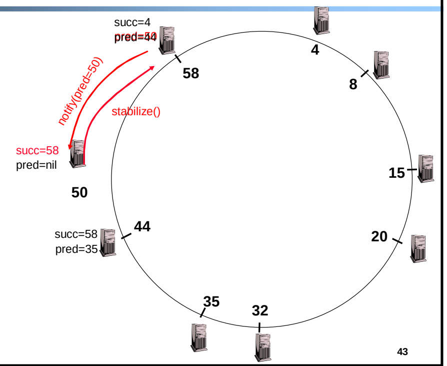
Joining Operation

- Node 50: send join(50) to node 15
- Node 44: returns node 58
- Node 50 updates its successor to 58



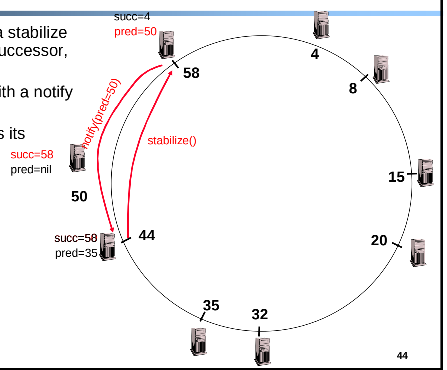
Joining Operation

- Node 50: send stabilize() to node 58
- Node 58:
  - update predecessor to 50
  - send notify() back



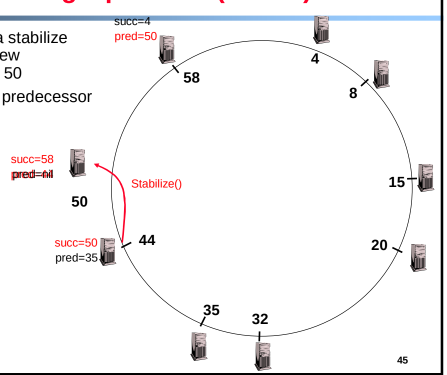
Joining Operation (cont'd)

- Node 44 sends a stabilize message to its successor, node 58
- Node 58 reply with a notify message
- Node 44 updates its successor to 50



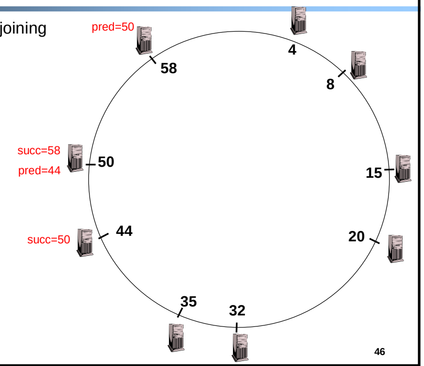
Joining Operation (cont'd)

- Node 44 sends a stabilize message to its new successor, node 50
- Node 50 sets its predecessor to node 44



Joining Operation (cont'd)

- This completes the joining operation!

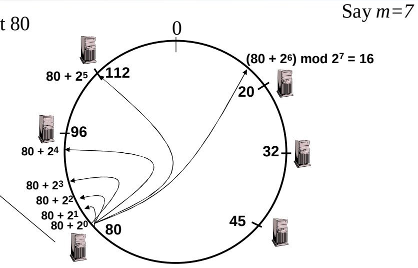


Achieving Efficiency: *finger tables*

Say *m=7*

Finger Table at 80

i	*ft[i]*
0	96
1	96
2	96
3	96
4	96
5	112
6	20



*i*th entry at peer with id *n* is first peer with id >= $n + 2^i \pmod{2^m}$

Achieving Robustness

- To improve robustness each node maintains the k (> 1) immediate successors instead of only one successor
- In the notify() message, node A can send its k-1 successors to its predecessor B
- Upon receiving notify() message, B can update its successor list by concatenating the successor list received from A with A itself

Discussion

- Query can be implemented
  - Iteratively
  - Recursively

- Performance: routing in the overlay network can be more expensive than in the underlying network
  - Because usually there is no correlation between node ids and their locality; a query can repeatedly jump from Europe to North America, though both the initiator and the node that store the item are in Europe!
  - Solutions: Tapestry takes care of this implicitly; CAN and Chord maintain multiple copies for each entry in their routing tables and choose the closest in terms of network distance

Conclusions

- The key challenge of building wide area P2P systems is a scalable and robust directory service

- Solutions covered in this lecture
  - Naptser: centralized location service
  - Gnutella: broadcast-based decentralized location service
  - CAN, Chord, Tapestry, Pastry: intelligent-routing decentralized solution
    - Guarantee correctness
    - Tapestry, Pastry provide efficient routing, but more complex