CS 294-7: Advanced Routing in Packet Radio Networks

Professor Randy H. Katz
CS Division
University of California, Berkeley
Berkeley, CA 94720-1776

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Large Network Routing Algorithms

- **Large Network Issues**
  - Increasing number of node, with fixed density of nodes, yields increase in average number of hops ($N^{0.5}$)
    - » Bandwidth per user goes down by $N^{0.5}$
  - One solution: Backbone links needed to insure that route length grows more slowly with network size
  - Standard protocols simply don't work
    - » Time for routing updates to propagate through the network grows with $N^{0.5}$
    - » This means that routing updates must be transmitted more frequently as network grows, yielding too much traffic
    - » Event-driven routing doesn't help: beyond some upper limit, all network bandwidth is dedicated to routing updates

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Some Feasible Approaches

- Hide details of distant parts of the network
  - Next hop decisions only depends on local region
  - Motivates hierarchical algorithms
- Send out information about distant parts less frequently
  - Next hop route unlikely to change dramatically if distant part of the network undergoes topology changes
  - Prioritized tier connectivity information exchange algorithm: use up-to-date information as paket gets near destination
- Send information only to nodes that need it
  - Threshold distance vector routing algorithm: if changes don’t change the quality of the route too much, don’t report the changes

Hierarchical Algorithms

- Hide details via clustering of nodes
- Clusters can also be aggregated into superclusters
  - Between superclusters: intersupercluster router
  - Between clusters: intercluster router
- Hierarchical algorithms depend on:
  - How clusters and superclusters are formed
  - How address of destination node is determined
  - How routes are computed
  - How packets are forwarded

Hierarchical Algorithms

- Supercluster/cluster hierarchy
  - Dynamic determination of neighbors
  - Election algorithms for choosing (super)cluster heads
  - Nodes join the nearest (super)cluster heads
- Hierarchical addressing
  - Address servers keep track of address of specific nodes
  - Any node must be able to find an appropriate address server
    - » Address server sends query to other address server to determine if the destination is in that cluster
    - » Address servers send updates to other servers when cluster membership changes
    - » Information about a cluster's membership is returned along with an answer to a query and cached

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Hierarchical Algorithms

- Hierarchical Routing
  - Quasi-hierarchical
    - » Use shortest path to the destination supercluster
    - » Then shortest path within the destination cluster
  - Strict hierarchical
    - » Routing through a sequence of intermediate superclusters
    - » Within each supercluster, packet is routed through a sequence of intermediate clusters
    - » Within destination supercluster, routed to destination cluster, then destination node

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Hierarchical Routing

- **Quasi-Hierarchical**
  - Extension of tier-routing algorithm
  - PROPs report shortest paths within clusters, to other clusters in supercluster, to other superclusters
  - Border Packet Radios
    - » Neighboring (super)clusters are reported as one hop away—each PR's path to a super(cluster) is shortest path to border PR
    - » Neighboring (super)clusters reported as S hops away, where S is average distance to the (super) cluster border plus average distance from border to members of the cluster
  - Requires periodic routing update broadcasts Order (# nodes in cluster, # clusters in supercluster, # clusters)
  - Simple, but poor responsiveness to routing changes

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Hierarchical Algorithms

- **Strict Hierarchical**
  - Clusterheads which compute hierarchical routing tables (HRTs)
    - » Specify next cluster to traverse to reach given dst cluster
    - » CHs distribute this routing info to PRs in their cluster
    - » Once destination cluster is reached, flat routing schemes are used to deliver packet to destination
  - Event-driven routing for intercluster: intercluster connectivity likely to change slowly, but can react quickly when topology changes do occur
  - Reduces amount of information necessary for a node to make routing decisions
  - Weakness is the clusterhead: hot standby mechanisms needed for robust routing

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Hierarchical Algorithms

- **Landmark Routing**
  - Variation on quasi-hierarchical routing
  - Distance vector used to compute routes to other nodes BUT destinations dropped from tier table if too far away
    - » Top of hierarchy: mentioned in every route update—"Global landmark"
    - » Leaves of hierarchy: only included in updates to nearby nodes
    - » Address of node is sequence of landmarks: global landmark to destination node's parent
    - » Routing done by forwarding packet to lowest level landmark visible to the forwarding node
  - Similar advantages and disadvantages to the quasi-hierarchical routing algorithm

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Non-Hierarchical Algorithms

- **Prioritized Tier Connectivity Information Exchange**
  - Routes characterized by priority based on rate of change
  - Single distance vector routing update per period
  - Rapidly changing routes transmitted frequently
  - Infrequently changing routes transmitted infrequently
- **Threshold Distance Vector Routing Algorithm**
  - Reduces the distance over which routing updates are propagated
  - $d_j + c_j \leq d \leq d_j + \alpha\, c_j$
    - » d is distance to destination
    - » j is next node on path
    - » c is cost of using link to j
    - » if α is increased, fewer update messages are transmitted and path lengths increase slightly

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ARPA Packet Radio

- **Strict Hierarchical Routing**
  - Used in ARPA PR program because quasi-hierarchical algorithms were shown to be unstable in highly dynamic networks
  - Intracluster algorithm: the existing tier algorithm is used
  - Intercluster algorithm: event-driven link-state algorithm
    - » Participate in two clusters at a time: current cluster and previous or next cluster
    - » Each PROP includes routes to all PRs in all clusters it has joined
  - Cluster partitions
    - » PR cannot route to its cluster's clusterhead
    - » PR must leave the cluster as soon as possible

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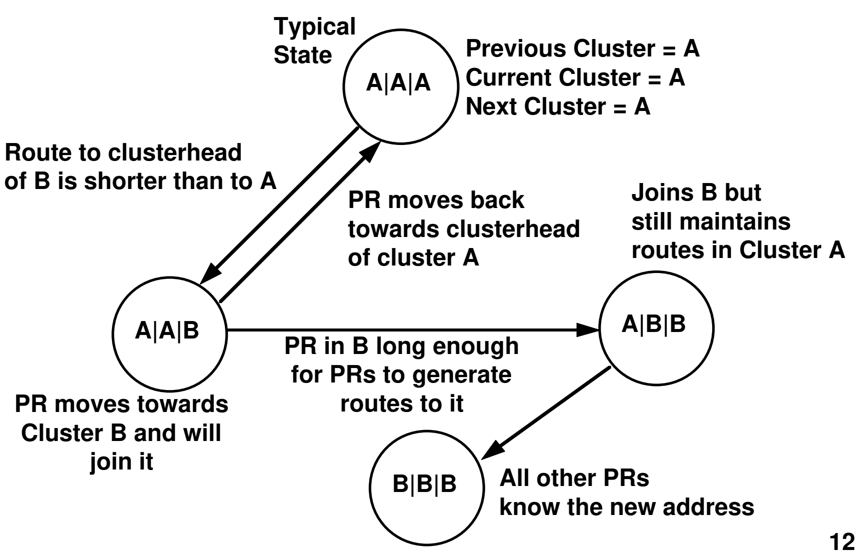
ARPA Packet Radio



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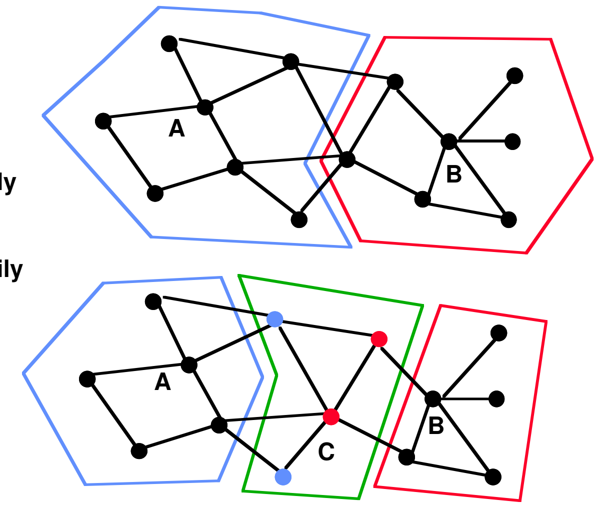
ARPA PacketRadio

Cluster birth disturbs original routes

Red nodes are temporarily in clusters B, C

Blue nodes are temporarily in clusters A, C

Makes it possible to establish A<-->C, C<-->B before dropping A<-->B



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ARPA Packet Radio

- A <--> B link is Previous/Current/Next
- A <--> C, B <--> C links come up as N links
  - Used to exchange clusterhead information
- A <--> B links becomes PC
- A <--> C, B <--> C links become CN
- A <--> B link becomes P
  - Only used when no C link exists
- A <--> C, B <--> C links become PCN
- A <--> B link is erased

Note that current links are preferred to previous links

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Receiver Directed Protocols

- **Advantage:**
  - Radio spends less time receiving unwanted packets
  - Increases probability that radio will be available to receive desired transmissions
  - 5X throughputs have been reported
- **Protocol Changes**
  - Routing updates changed from broadcast to unicast distribution
  - Alternative routing via broadcast cannot be used
  - Passive ACKs no longer available; active ACKs must be used
  - Overheard techniques can't be used anymore
  - Updating routing tables via overheard traffic can't be used
  - Overheard transmission can't be used to determine congestion

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ARPA Packet Radio: SURAN Program

- **LPR's could use broadcast or receiver-directed transmissions**
  - PROPs are broadcast
  - Active ACKs, including routing updates, are broadcast
  - Distance vector routing is used
  - Updating routing tables based on overheard traffic is eliminated
  - Packets sent via receiver-directed transmission unless being alternate routed
  - Active ACKs used for all packets
  - Uses channel access protocol that gives priority to ACKs
  - New link up/down protocol--overheard traffic not available
  - Congestion control algorithms modified since no more passive ACKs

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ARPA Packet Radio: SURAN Program

- Least Interference Routing
  - Min cost route where link cost measures distructive interference caused by PR transmissions
    - » Nodes determine potential destructive interference associated with sending packet over link
    - » Compute shortest path with respect to interference metric
  - Interference = # of neighbors that can receive a transmission
  - Preference given for “short” links--yields better spatial reuse

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ARPA Packet Radio: SURAN Program

- Subclass Routing
  - Link gain: power, data rate, FEC, etc. set to improve delivery probabilities
  - Uses link gain information for the routing algorithm: choose minimum link gain to assure successful forwarding
  - Minimizes the maximum link gain used on a given route
    - » Tends to choose longer routes
    - » But effectively reduces interference, thereby improving network throughput

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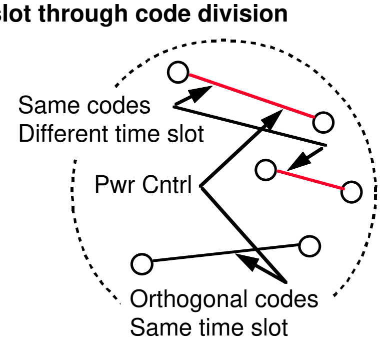
Summary

- **Large Scale PR Networks**
  - Total bandwidth grows with network size, but average number of hops also increases, and end user bandwidth decreases
  - Hierarchical Routing
    - » Hierarchy defined dynamically
    - » Routing adapts to changes in hierarchical connectivity
    - » Nodes must be able to determine hierarchical address of destination
  - Overlapping clusters help, but cluster birth and death complicate routing

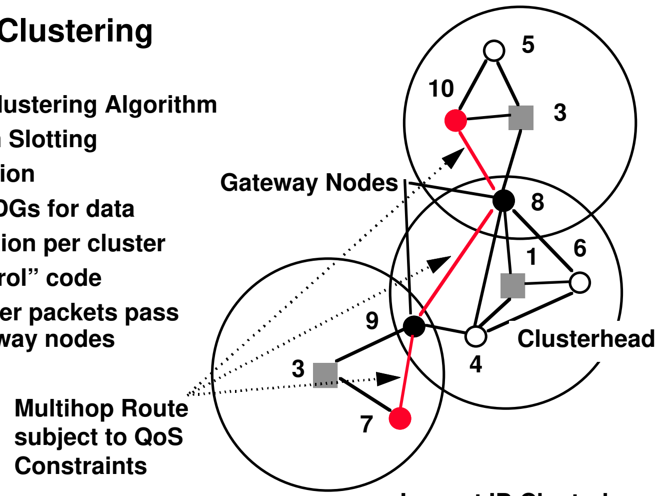
UCLA WAMIS Project

- **Media Access**
  - Cluster-Based CDMA/PRMA (UCLA)
    - » Packet reservation techniques for slots
    - » Multiple conversations per slot through code division
- **Link Establishment**
  - Code and slot assignment to minimize interference
  - Power control
  - Support for upper layer QoS requirements based on lower layer SIR constraints



UCLA WAMIS Project

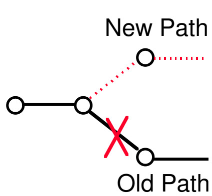
- **Hierarchical Clustering Algorithm**
  - Distributed Clustering Algorithm
  - Time Division Slotting
  - Slot Reservation
  - VCs for R/T; DGs for data
  - Code Separation per cluster
  - Shared "control" code
  - All inter-cluster packets pass through gateway nodes



Lowest ID Clustering

UCLA WAMIS Project

- **Dynamic Topology Reconfiguration**
  - Cluster merge/split under mobility
  - VC reconfiguration in presence of mobility
    - » **Fast Reservation** Scheme



- R/T packets follow shortest path
- Rate adjustment based on advertised QoS
- First packet reserves slot on path
- First packet competes for slot on new path
- May be dropped if no path
- Low priority voice/video components dropped during switchover
- Reservation released if slot unused