Ad Hoc On Demand Distance Vector (AODV) Routing

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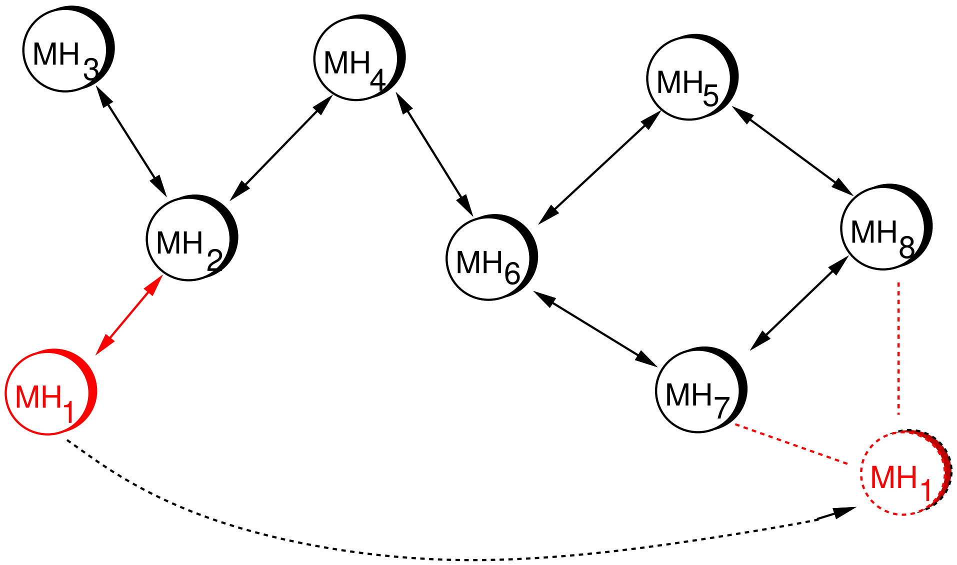
Ad-hoc mobile networking



Allow mobile nodes to create a network on demand, without base stations

Works with modified mobile-IP

- but foreign agent needs multi-hop routing paths to mobile nodes

Proposed model of operation

- Computers with unrelated IP addresses
- Limited range broadcast media
- Dynamic interconnection
- No "system administration" allowed
- Sleep mode not taken into account
- Links usually Symmetric *?*

Not yet considered – *Quality of Service*

Commercial Opportunities

- Conferencing
- Home networking
- Emergency services
  - ambulance
- Hospitals
- Embedded computing applications
  - computers everywhere with short-range interactions
- Liberate users from the subnet yoke
- Automotive/PC interaction

Other Envisioned applications for Ad-Hoc Networking

- Digital Battlefield Communications
- Movable base stations
- Many military applications
- Campus wireless access from quadrangles
- *Any* interpersonal communications

What is *networking* good for?

Technical/Market/Political hurdles

- Scalability
- Power budget vs. latency
- Protocol deployment
- Wireless data rates
- Obsoletes the client/server model
- ... and, thus, breaks a *lot* of protocols
- User education, acculturation
- Antenna inconvenience
- Higher bit-error-rate (BER)
- Additional security exposure
- Perceived dependence upon heavy, short-lived batteries
- Non-ubiquitous coverage
- Incompatible standards

Traditional Routing Methods

Advantages of using routing protocols:

- Self-Starting
- Multi-Hop
- Dynamic topology

Single metric: number of hops to destination

Link-State

- Complete topology stored
- OSPF (RFC 1583)

Distance Vector Algorithms

- One route-table entry per host per destination
- Berkeley routed implementation/RIP version 2 (RFC 1723)
- simple to program
- can be made loop free
- use less memory
- localized update operations
- Poisoned-Reverse/Split-Horizon
- Count to ∞ problem

Various Ad-Hoc Networking Proposals

- IETF (*manet* working group)
- AODV (refinement of DSDV)
- DSR (Dave Johnson, CMU)
- WINGs (JJ Garcia, UC Santa Cruz path-finding)
- WAMIS (Mario Gerla, UCLA)
- Torah/IMEP (Vincent Park, University of Maryland)
- Link Quality (Rohit Dube, University of Maryland)
- Hierarchical (Ian Akyildiz, Georgia Tech)
- Clustering (Texas A&M)
- Packet Radio (DARPA; Martha Steenstrup, BBN)
- ABR (C.K. Toh)
- ZRP (Zygmunt Haas, Cornell)

AODV Overall Description

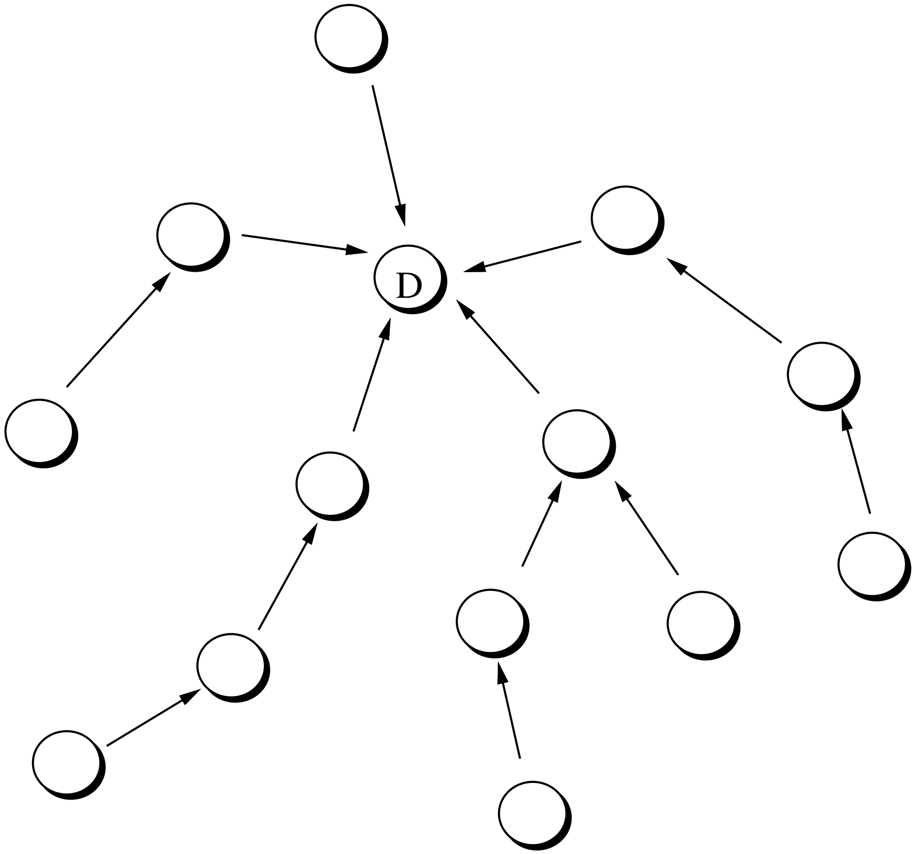
- Routes on demand
- Distance Vector, using node sequence numbers for route updates (on both forward and reverse paths)
- Route acquisition by broadcast RREQ, unicast RREP
- RREQ causes reverse path setup
- *Active* routes are cached by intermediate nodes
- *"hello"* used for neighbor discovery and to ensure symmetric links
- $< \infty, dest\_timestamp + 1 >$ RREP triggered by broken links
- Link breakage RREPs notify *active* upstream neighbors
- Two criteria for route selection
  - Sequence numbers guarantee maximal freshness
  - Metric comparison for lowest cost

Properties of the AODV Protocol

- Each mobile host is a router.
- Loop-free at all instants
- Dynamic, multi-hop, and self-starting
- Low memory requirements
- Quick convergence via triggered updates
- Routes available on demand
- Fast processing time
- Reasonable network load
- Minimal overhead for data traffic
- Minimal route thrashing
- Intended for operation with 500+ mobile nodes, depending on *mobility factor*
- Enables future aggregation computations

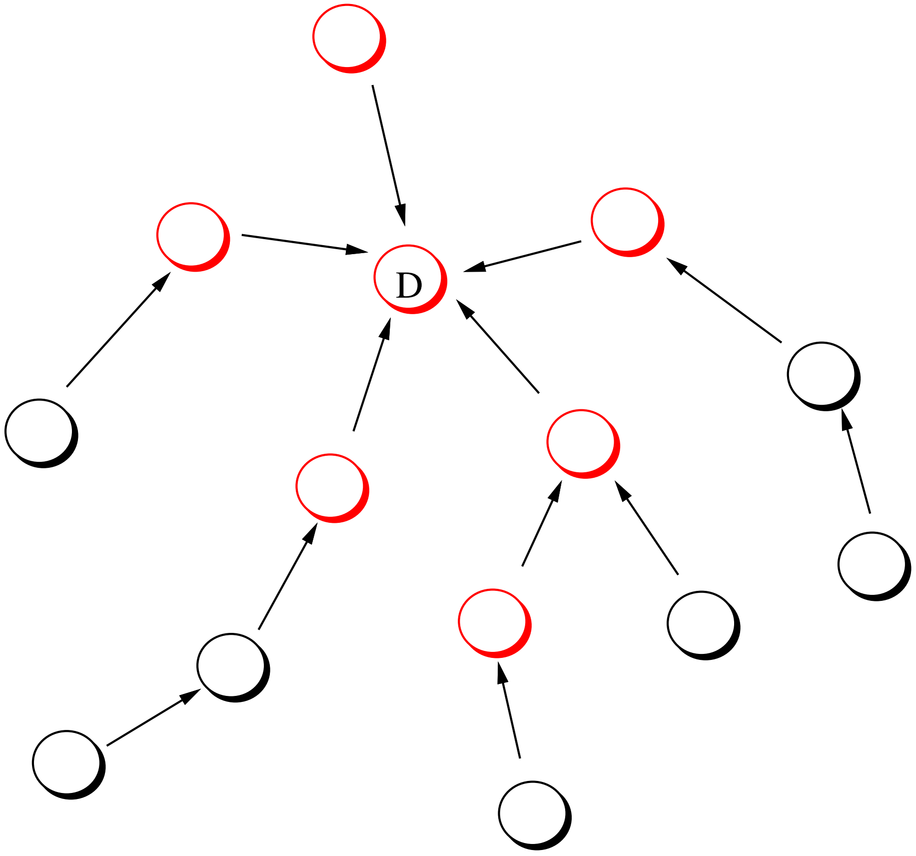
Loop Freedom by using DAGs

The ad-hoc network is a (time-dependent) forest of such rooted trees



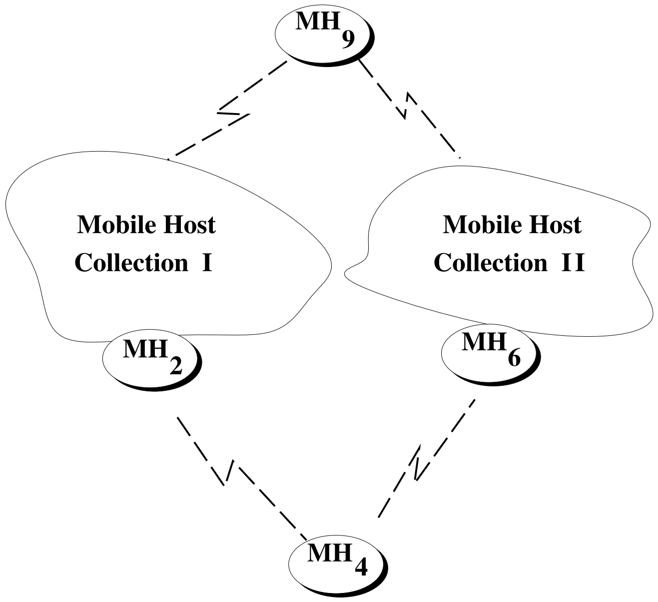
What happens when D issues a route update?

Sequence Number Propagation



loop-free paths to each destination at all instants

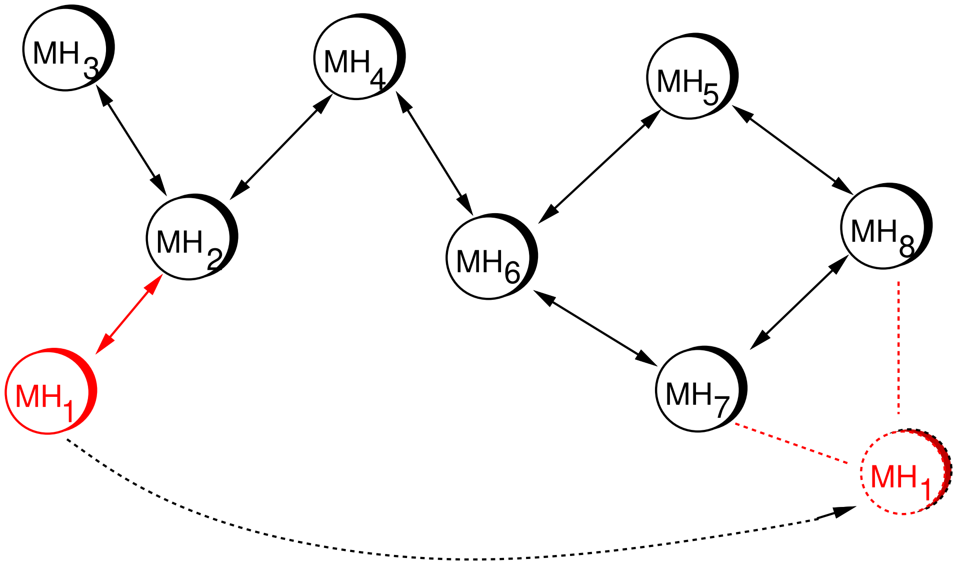
Need for Stabilization



Suppose sometimes MH_4 *sometimes* receives updates about MH_9 in the wrong order, introducing route instability. This would cause routes to be propagated needlessly downstream from MH_4. We allow MH_4 to delay its triggered updates and other advertisement depending upon past history.

Alternative: reduce strict dependence on number of hops

Ad-hoc Networking Example



Suppose MH_1 moves away from MH_2 towards MH_7, and has active sessions with MH_3 and MH_6. The following actions occur:

- MH_2 notices that its link to MH_1 is broken
- MH_2 checks its routing table, and finds that its link to MH_1 was actively in use by MH_3 and MH_4.

- MH_2 unicasts an ∞-metric route update, with an incremented destination sequence number, to MH_3 and MH_4. MH_3 may subsequently issue a new route request for MH_1.

- MH_4 also notes that its route to MH_1 was actively in use, and forwards the ∞-metric route update to MH_6.

- The ∞-metric route update for MH_1 may also be included in the next *hello* message issued by MH_2

- MH_6 may subsequently issue a new route request for MH_1

- Any subsequent route request for MH_1 which is satisfied by a route reply through MH_2 may cause MH_2 to update its route table

Destination sequencing maintains nice properties of loop-freeness, and eliminates Bellman-Ford "counting to infinity" problem.

What does Location Independence mean for ad-hoc networking?

Are *functions* independent of location? hostname?

Where do services reside?

- DNS?
- Obtaining Certificates?
- Foreign Agents for mobile IP?
- Directory Agents for Service Location?

One idea: a *grid* of well-known services, with new candidate servers dynamically appearing in order to preserve a minimum number of hops to the closest service (of, e.g., the abovementioned types)

Summary

- AODV supports reasonably sized (500+) ad-hoc networks
- Dynamic topology is supported by maximizing the number of routers
- Destination timestamping provides route freshness
- Incoming route updates selected based upon two metrics
- AODV is dynamic, self starting, and automatic – thus appropriate for the expected class of users
- Ad-hoc operation can be compatible with mobile-IP
- Many protocols are emerging

IETF information

Mailing Lists:

ad-hoc join: `manet-request@itd.nrl.navy.mil`

ad-hoc contribute: `manet@itd.nrl.navy.mil`

For more information, check out:

http://www.ietf.org/html.charters/manet-charter.html