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Ad Hoc Networking with AODV

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Outline of Presentation

- Ad Hoc Networks in general
- AODV in particular
- Recent results from manet
- Internet Gateways for ad hoc networks
- Address autoconfiguration
- Challenges for the future

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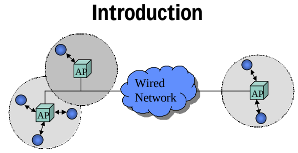
Introduction



- Infrastructured Wireless Networks
  - Fixed, wired backbone
  - Mobiles communicate directly with access points
  - Suitable for locations where access points can be placed

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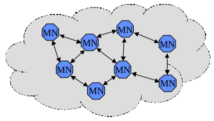
Introduction



- Infrastructureless Networks (Ad hoc networks)
  - No wired backbone
  - All nodes are capable of movement
  - All nodes serve as routers (multi-hop routes)
  - Reduced administrative cost
  - Ease of deployment

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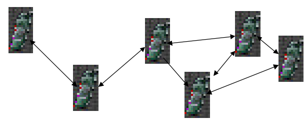
Ad Hoc Network characteristics



- peer-to-peer
- multihop
- dynamic

- zero-administration
- low power
- autonomous
- autoconfigured

But, most these have exceptions!

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Commercial Opportunities

- Conferencing
- Home networking
- Emergency services
  - Ambulance
  - Police
- Hospitals
- Embedded computing applications
  - Ubiquitous computers with short-range interactions
  - Automotive/PC interaction
- Enable computing where subnets do not exist

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Other Envisioned Applications

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

What is ***networking*** good for?

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Ad Hoc Networking Protocol initial goals

- Quick convergence
  - to enable faster mobility
- Scalability
- To enable larger networks (100? 1000? 10,000? 100,000?)
- Loop-freedom
- Unicast
- Bidirectional communications

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Next Ad Hoc Networking Protocol goals

- Multicast
- Security
- QoS
- Autoconfiguration
- More Scalability
- Unidirectional links
- Smooth Handovers
- Internet Gateway operation
- Service Discovery

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Various Ad Hoc Routing Projects

- DSR (Dave Johnson, CMU)
- WINGs (JJ Garcia/UCSC)
- ROAM (JJ Garcia/UCSC)
- WAMIS (Gerla/UCLA)
- ODMRP (Gerla et.al/UCLA)
- TRAVLR (Kleinrock/UCLA)
- Tora/IMEP (Park, Corson/UMD)
- Link Quality (Rohit Dube/UMD)
- LAR (Texas A&M)
- TBRPF (SRI)
- OLSR (Inria: Clausen./Jacquet)
- DSDV (Dest. Sequence #'s)
- AODV (refinement of DSDV)
- AOMDV (Multipath – Das/Marina)
- Hierarchical (Akyildiz/Georgia Tech)
- GPSR (Karp/Harvard)
- CBRP (Singapore)
- Terminodes (EPFL)
- MMWN (Steenstrup/BBN)
- ABR (C.K. Toh)
- STAR (JJ Garcia/UCSC)
- ZRP (Zygmunt Haas/Cornell)
- Fisheye/Hierarchical (UCLA)
- CEDAR (Urbana-Champaign)

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Traditional Routing Methods

- Advantages of using routing protocols:
  - Self-Starting
  - Multi-Hop
  - Dynamic topology

Single metric: number of hops to destination

- Link-State (*Dijkstra's algorithm*)
  - Complete topology stored
  - OSPF(RFC 1583)

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Distance Vector Routing Protocols

- Route table has (metric, next hop) – i.e., (distance, vector).
  - Other metrics (e.g., time) may be more useful in many cases
- “Distributed Bellman-Ford” algorithms
- Can be made loop-free
- Easy to program
- Low memory and processor utilization
- Localized update operations (*important* for ad hoc)
- Susceptible to *counting-to-infinity* problem
- Previous solutions (poison reverse/split-horizon) *must* be undone

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On-Demand Routing Protocols

- Downsides:
  - Latency
  - Route Discovery broadcasts
  - ICMP Unreachable only after Route Discovery attempt
- Eliminate route table updates for routes that are not used
- Fewer control packets:
  - → Better scalability
  - → Reduced congestion
  - → More robust protocol action
- Less frequent control packets → reduced processing requirement
- Even more localization for topology changes if distance vector
- Also can be made to work for link-state

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Overview of AODV

- Reactive routing protocol
- Route discovery cycle for route finding
- Maintenance of active routes
- Loop freedom achieved through sequence numbers
- No overhead or data packets
- Scalability shown to 10,000 nodes
  - performance suffers
- Works with subnets
  - *subnet leader* maintains sequence #
- Works as transit network
  - gateways run AODV as well as their infrastructure routing protocol
- Integrated multicast protocol (MAODV) specified
  - multiple next hops
  - *group leader* maintains sequence #
- QoS extension specified (undergoing revision)

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AODV Unicast message types

- Route Request (RREQ)
  - AODV Unicast Route Discovery Initiation
- Route Reply (RREP)
  - AODV Unicast Route Discovery Completion
- Route Error (RERR)
  - AODV Unicast Link Breakage Indication
- Route Reply Acknowledgement (RREP-Ack)
  - AODV unidirectional link invalidation

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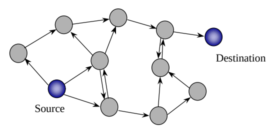
AODV Unicast Route Discovery Initiation

Route Request (RREQ) broadcast flood



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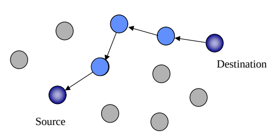
AODV Unicast Route Discovery Completion

Route Reply (RREP) propagation



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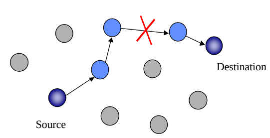
AODV Unicast Link Breakage Indication

Route Error (RERR) message

- Node upstream of break broadcasts RERR
- Neighboring nodes propagate if they use source of RERR as next hop for destination



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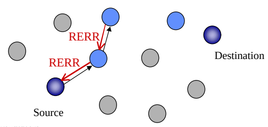
AODV Unicast Operation: RERR

Route Error (RERR) message
- Node upstream of break broadcasts RERR
- Neighboring nodes propagate if they use source of RERR as next hop for destination



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AODV Unicast Operation: RERR

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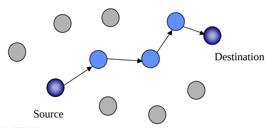

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AODV Interoperability testing

- At UCSB: 6 implementations from different organizations
  - we know there are many others that did not come…
- Implementers mailing list (currently almost 100 members):
  - aodvimpl-public@lists.sourceforge.net
  - https://lists.sourceforge.net/lists/listinfo/aodvimpl-public
- Linux freeware implementations: http://moment.cs.ucsb.edu/AODV/aodv.html#Implementations
- Possibly AODV-6 release upcoming (Ryuji Wakikawa)
- AODV workshop held immediately preceding MobiHOC 2002 in Lausanne, Switzerland

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Why do we need two types of wireless networks?

i.e., why can't they be integrated?

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Motivation for Mobile IP integration

- Growth deployment of wireless LANs
- Maintaining connectivity while roaming is desirable
- Mobile IP is a solution for enabling roaming, but it has limitations…
  - Expensive in terms of hardware, configuration
  - Dead zones (distance, multipath, fading, obstacles...)
  - Mobile nodes must be in direct transmission range of HA and FA
- Multi-hop Internet connectivity for mobile nodes solves these problems

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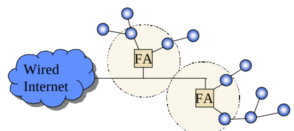
Objective



- Enable mobile nodes with multi-hop connectivity to foreign agents to obtain Internet connectivity
  - Use Mobile IP for obtaining care-of addresses, home agent registrations
  - Use AODV for route discovery and maintenance in ad hoc network

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Internet Gateways for Ad Hoc Networks

- Our model: do not inject per-host routes into Internet
- Good start: ad hoc nodes use gateway as default router
  - but it could be multiple hops away
  - plus, the ad hoc nodes need to know its IP address
  - Router solicitation/advertisement "work", with changes
- Gateway should be "protocol-agnostic" (for any manet protocol)
- Gateway needs a host route for each manet node
- Host ID in range advertised by Internet Gateway can be CoA
- Mobile IP{v4,v6} needed for movement to/from Internet
- Q: do all intermediate nodes *also* acquire default route?

M ←→ a ←→ b ←→ ... ←→ IG ←→...

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Mobile IP / AODV Cooperation

- Agent advertisement and foreign agent discovery
- Registration with foreign agent
- Route discovery
- Issues with multiple foreign agents

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Agent Advertisement

- FA operation
  - Periodic Agent Advertisements
- Mobile Node operation
  - Update the Foreign Agent List
  - Update route to FA
  - Rebroadcast beacon messages (added seq# to avoid duplicate beacons)
- Increase beacon interval to reduce flooding

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Proactive Foreign Agent Discovery

- Mobile broadcasts RREQ for FA
  - Dest IP address = 224.0.0.11 ("All Mobility Agents" multicast group address)
  - RREP sent by FA or mobile with route to FA
    - Foreign Agent extension used to indicate FA IP address
  - Agent Solicitation unicast to FA from mobile node
  - Agent Advertisement unicast to mobile node
- Registration with the Foreign Agent
  - Registration Request
  - Registration Reply
- Note: Nodes not needing Internet connectivity do not need to register

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Route Discovery

- Node location is unknown
  - In the ad hoc network?
  - In the outside network (wired or wireless)?
- Route Request for destination
- Mobile nodes respond to RREQ by rebroadcasting RREQ or creating RREP
- RREP from mobile node indicates the destination is within the ad hoc network

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FA Operation on RREQ Reception

- Check if the destination is on its registered mobile node list
  - If it is, normal RREQ processing applies
  - Otherwise, unicast FA-RREP to source
    - Indicates FA believes destination is outside ad hoc network
    - Use a big metric so local routes will prevail

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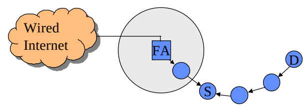
Mobile Node Operation

- Upon reception of FA-RREP
  - Store the route from the FA in route table
  - Wait for RREP from other nodes
  - Up to RREQ_RETRIES discovery attempts
  - Use the route from FA as default route
  - Note: tunneling is *not* needed



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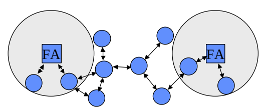
Multiple Foreign Agents



- Handoff between foreign agents
  - Modified version of MMCS (MIPMANET Cell Switching) [Jonsson '00]
  - Nodes must be two hops closer to new FA to handoff

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Digression on Address Autoconfiguration...

- Nodes in networks need IP addresses
  - Ad hoc networks are no exception!
  - Autoconfiguration would also aid in obtaining co-located care-of addresses
- Previously ignored problem

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Selecting an IP Address

- A node selects two addresses:
  - Permanent address candidate
    - 169.254/16 + unique host ID (2048 ... (2^{16}- 1))
    - Network prefix + unique host ID
  - Temporary address
    - 169.254/16 + (0 ... 2047)
    - Network prefix + (0 ... 2047)

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Obtaining a Unique IP Address

- *With reactive routing protocols...*
  - *Address Request* (AREQ) issued on permanent address candidate
    - Temporary IP address is source address of AREQ
  - Nodes receiving AREQ set up reverse route to source, check for address match
    - Rebroadcast AREQ if do not have same address
    - Unicast *Address Reply* (AREP) if address match
  - Node issuing AREQ waits for reply
    - If no reply after max retries, obtains address
    - If AREP is received, select new candidate address and start again

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Obtaining a Unique IP Address

- *With proactive routing protocols...*
  - Take advantage of routing table information of neighbors
    - Issue address request to neighboring node
    - Neighbor indicates whether address is already taken
  - No network flood is needed

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Address Authorities

- One primary, one or more backup authorities
- Maintain list of registered IP addresses for network
- Maintain address leases for address reuse
- Periodically broadcast Authority Advertisement
- Merge detection…
  - Network Identifiers used to uniquely identify network
  - Network merge detected when Advertisement from new network received
  - Authorities exchange IP address lists and resolve duplicates

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Conclusions

- Mobile IP & AODV can work together to create a hybrid wireless network that enables mobile nodes to gain Internet connectivity
- AODV is utilized for route discovery and maintenance of routes within ad hoc network
- Mobile IP is used for COA assignment and registration with HA
- Address autoconfiguration can be used to obtain co-located COA
- Simulation results are promising
- To be done…
  - Continue experiments with more foreign agents
  - Multi-hop paths to gateways in non-Mobile IP networks
  - Continue refinement of address autoconfiguration protocols

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Thanks Elizabeth!

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Client/Server vs. ad-hoc networking

Are *functions* independent of location? hostname?

Where do *services* reside?

- DNS?
- DHCP Server?
- Certificate Authority?
- Foreign Agents?
- Directory Agents?

Possibility: modification of DHCP to fit ad hoc; use DHCP options 78 and 79 to enable Service Location Protocol (SLP).

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Challenges for the Future

- QoS – and don't forget layer 2!
- Multipath routing vs. route caching
- Getting to Standard!
- Route Repair vs. multihop context transfer
- Re-examine the "client-server" paradigm
- Multicast/Anycast
- Security (e.g., route repair!)
- Scalability: overcoming the 1/sqrt(N) capacity limit
  - NOTE: The Internet is an "ad hoc" network…!
- Backbone formation and maintenance
  - Is worth it, most likely!
- Using positional hints (for some apps, definitely worth it!)

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Summary and Conclusions

- Ad Hoc Networking is well-established as a viable research area
- Infrastructureless operation has many applications
- Distance Vector can be made loop free
- On-demand protocols offer many advantages
- AODV makes use of advantges from both Distance-Vector and On-demand
- AODV has good chances for standardization
- Ad hoc networks can be glued to the Internet and then provide wireless extension domains
- Mobile IP provides addressability between every ad hoc node to and from every globally addressable Internet node
- Address autoconfiguration techniques have been adapted