Ad Hoc Networks, IETF, Social Networks

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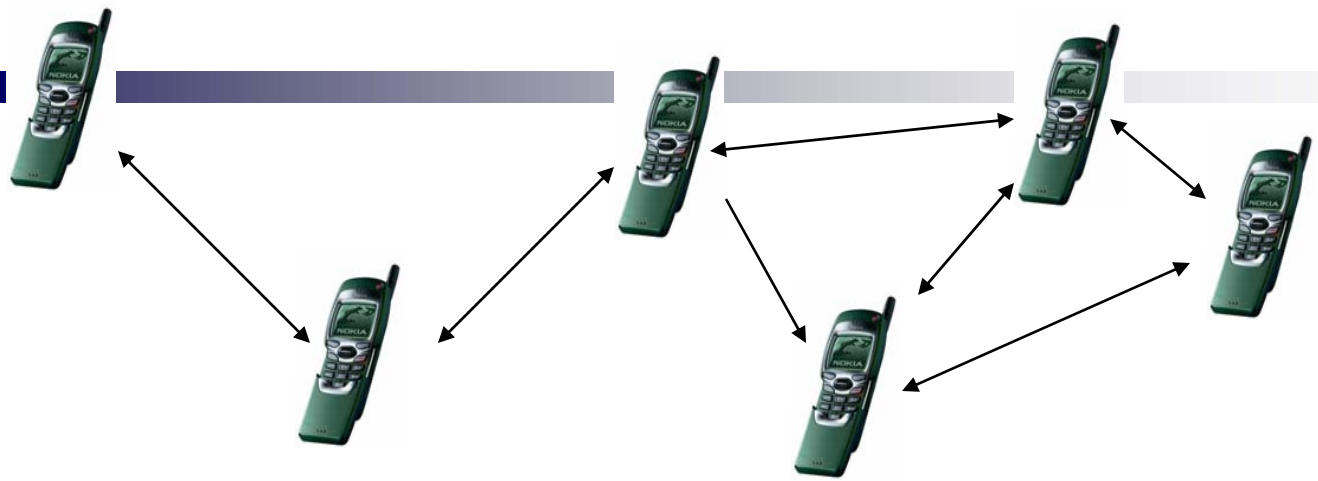
Outline of Presentation

- Ad Hoc Networks in general
- IETF structure and relevant working groups
- Performance observations
- Flooding – a potential modular component
- Convergence – parameterized modular components

Ad Hoc Network characteristics



- peer-to-peer
- multihop
- dynamic
- *Really* "anytime, anywhere"

- zero-administration
- low power
- autonomous
- autoconfigured

But, most of these have exceptions!

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Commercial Opportunities

- Conferencing
- Home networking / Community (mesh) networking
- Emergency services
  - Ambulance, Police
  - Disasters (natural or man-made)
- Hospitals
- Embedded computing applications
  - Ubiquitous computers with short-range interactions
  - Automotive/PC interaction (numerous “devices”)!
  - What if wireless computers are *everywhere*?

Other Envisioned Applications

- Digital Battlefield Communications
  - Including sensor networks
- Movable base stations
  - Many military applications
- Campus wireless access from quadrangles
- Immediate, interpersonal communications
- Range extension for cellular telephones
- Enable computing where subnets do not exist
- Some people still ask “What is Ad Hoc Networking good for?”.
    - I ask them, “What is ***networking*** good for?”

Sensor Network Characteristics

- Less dynamic than other ad hoc networks
- Large network sizes (more need for IPv6)
- Battery power truly at a premium
- Congestion less of an issue
- What about latency?!
- Identity of individual nodes less important
  - Affects even concepts of addressability
  - Increases need for multicast/anycast/geocast?

Mesh Networks

- At NRC, view mesh as a special kind of ad hoc network
  - Some designated stable points (+power)
  - Wireless ad hoc nodes freely moving
- Mesh points *may* be Internet gateways
  - Or, mesh may be completely disconnected
- Mesh points are natural clusterheads

Traditional Routing Methods

- Advantages of using routing protocols:
  - Self-Starting
  - Multi-Hop
  - Dynamic topology
- Link-State (*Dijkstra's* shortest-path algorithm)
  - Complete topology stored
  - OSPF (RFC 1583)
- Distance-Vector protocols (*Bellman-Ford*)
- Source Routing

Ad Hoc Routing Projects

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

More Ad Hoc Routing Projects

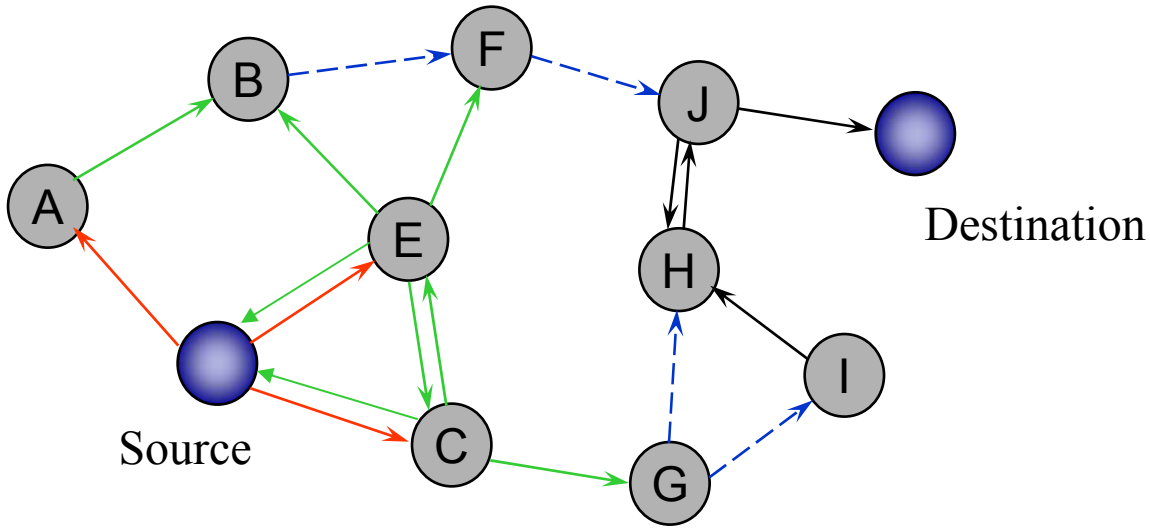
- FRESH (latest encounter)
- ANTS(*swarm intelligence*)
- Ariadne
- Cryptographic Threshhold
- Insignia [QoS] (Columbia)
- AODV6
- FLR [“Feasible”] (UCSC)
- GPS/Geographic
- SHARP
- DMAC (Directional)
- Pulse
- TDR (Trigger based Distributive)
- DREAM
- SAODV (Guerrera)
- LDR (Mosko/Garcia …/Perkins)
- AODVjr(Chakeres/Klein-Berndt)
- WRP
- Minimum-energy approaches
- Compow
- Face Routing (GOAFR+,…)
- XTC (Topology Control)
- *Many* more…

On-Demand Routing Protocols

- Eliminate route table updates for unused routes
- Fewer control packets:
  - → Better scalability
  - → Reduced congestion
  - → More robust protocol action
  - → Reduced processing
- Also can be made to work for link-state
- Downsides:
  - Traditional IP would signal "ICMP Unreachable"
  - Discovery latency → longer application launch times
  - Route Discovery broadcasts
  - Hard to assign value for *ACTIVE_ROUTE_TIMEOUT*

On-Demand Unicast Route Discovery Initiation

Route Request (RREQ) broadcast flood



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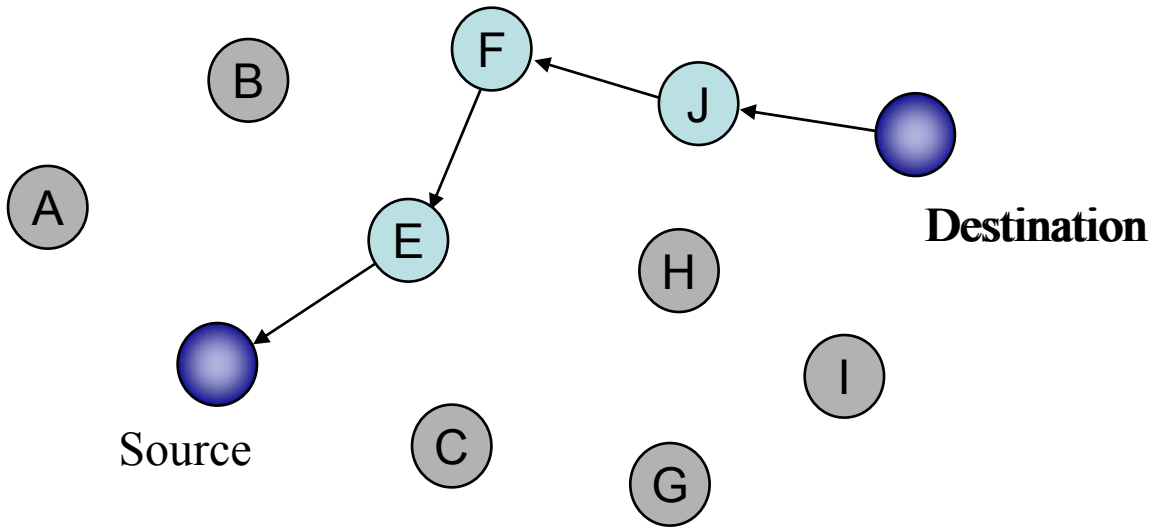
On-Demand Unicast Route Discovery Completion

Route Reply (RREP) propagation



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IETF structure

IETF has Areas and Area Directors (ADs)

IETF has over 100 working groups:

- General Area (AD is IETF chair)
- Applications Area
- Internet Area (most mobility groups here)
- Operations and Management Area
- Routing Area ([manet] is here!)
- Security Area
- Transport Area

IETF mantra

Rough consensus and running code

Consensus requires team building and persistence.
Running code requires, well, you know…
(but including interoperability too!)

Relevant IETF working groups

- Mobile Ad hoc Networks [manet]
- Network Mobility [nemo]
- Address autoconfiguration [autoconf]
  - Charter is IPv6 only

Mobile Ad Hoc Networking (*manet*)

- AODV: *on-demand*, and *distance-vector*
  - Interoperability testing
  - Experimental RFC 3561
- Other *on-demand* protocol is (DSR)
- Two link-state, *table-driven* | *proactive* protocols
  - RFC 3626: Optimized Link-State Routing (OLSR)
  - RFC 3684: Topology-Based Reverse Path Forwarding (TBRPF)
- DSR recently published as Experimental
- Many other protocols have been considered!
  - For instance, quite a few of the previous list

[autoconf]

- Address assignment, as needed
  - Disconnected/isolated network case
  - Connected to Internet via a gateway
- Gateway provides routable address prefix
  - Allows packets to reach manet nodes
- Nodes can use permanent address with new care-of address in manet

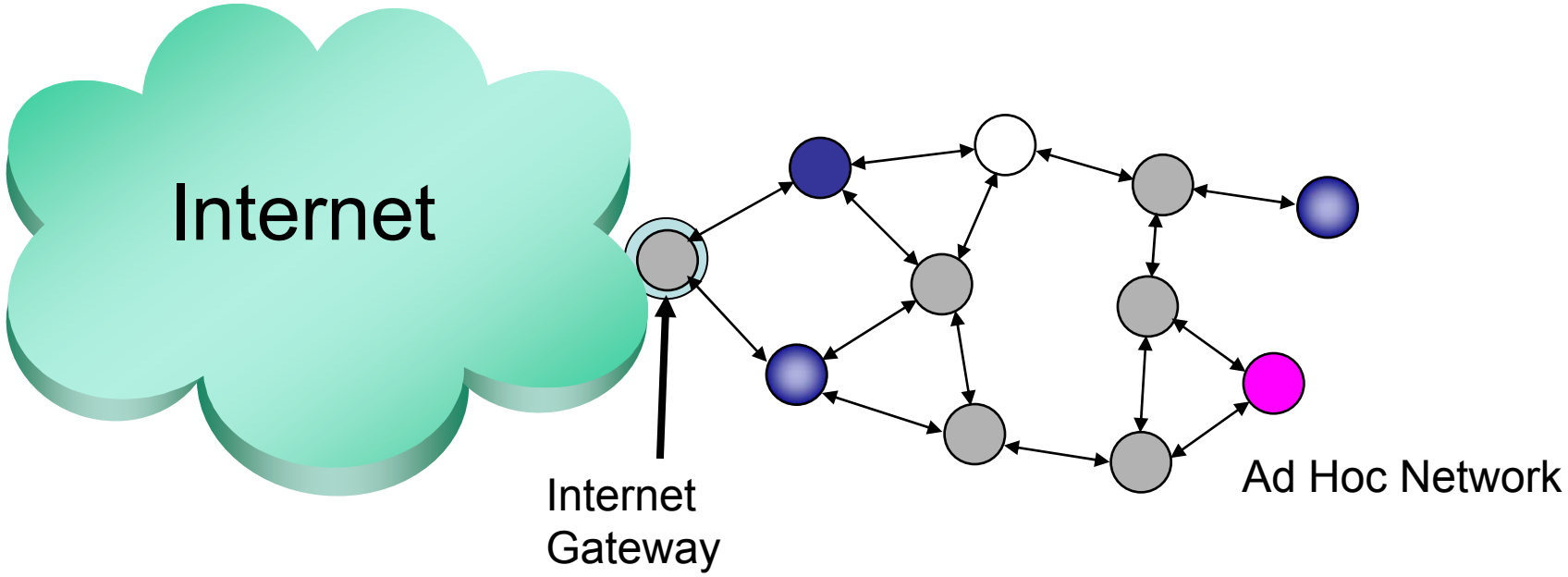
Strategies for address allocation

- Random (works well with IPv6)
- Constructed from MAC address (also works well with IPv6)
- Address pool/subdivision (likewise!)
- Problem: network partition/remerge

Assured Address Uniqueness

- IPv6 => reliable address uniqueness!
  - By construction from MAC address
  - By random selection
  - Optimistic DAD, e.g.
- This eliminates complexity and signaling
- Even more important for wireless
  - And even more so for sensor nets!
  - Better energy use:1 bit = 10,000+ CPU cycles

Ad Hoc Stub Networks



- If any node has access to the Internet, then all nodes can have access.

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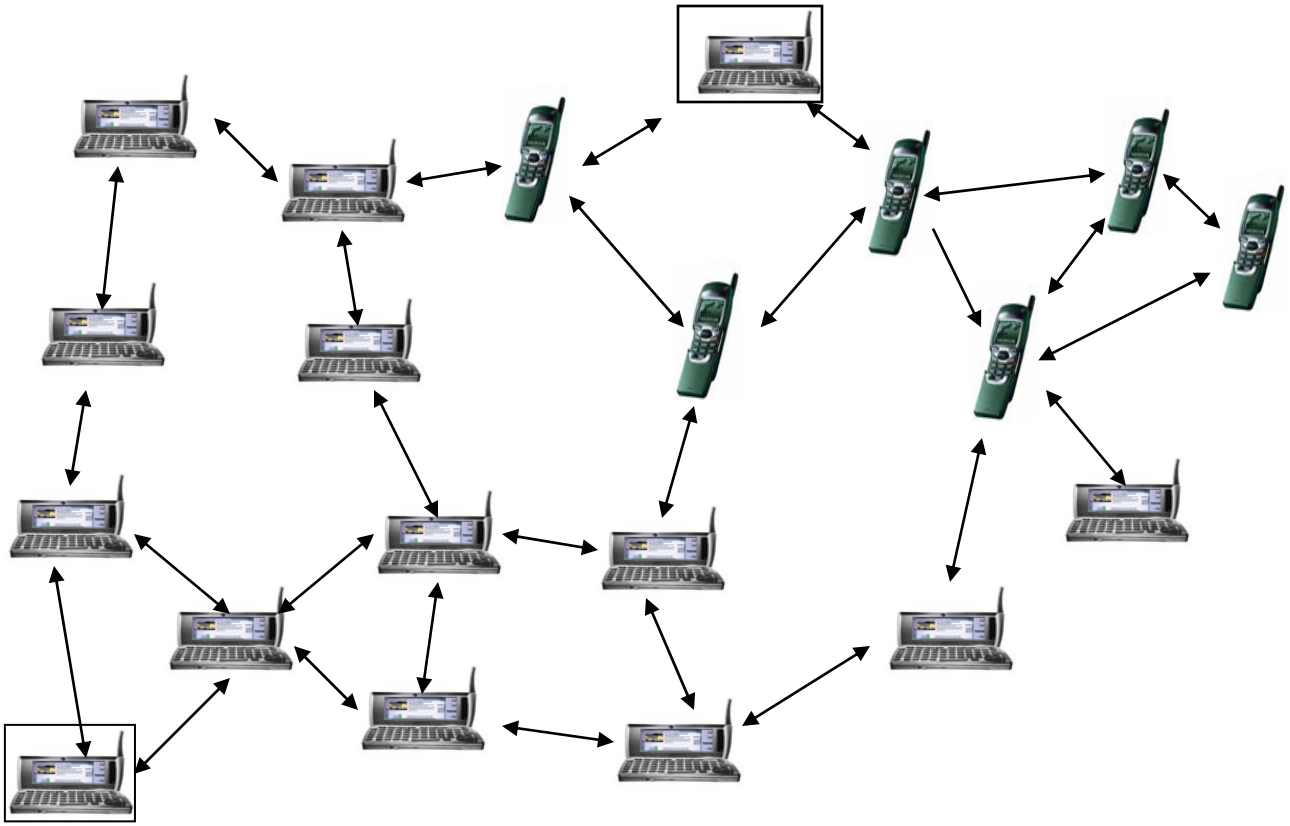
Distance Vector Characteristics

- Very suitable for *on-demand* operation
- Remote movement less likely to propagate
  - i.e., mobility has more localized effects
- Natural fit for IP route table operation
  - e.g., OLSR and TBRPF use a shortest-path algorithm to fill route table with distance-vector entries
- To handle multipath, sort by metric

Is Distance Vector *better* than Link-State?



Some general performance observations

- When two protocols both lose almost all packets, maybe it doesn't matter which one is "better"
- Flooding → congestion, *and* flooding is unreliable
  - Problematic for creating OSPF extensions!
- At low node populations, what choices matter?
- High hop count increases fragility, latency
- N.B.: minimum hop count can be a *lousy* metric
- On-demand increases startup latency
- Table-driven tends to increase congestion
- Simulation times grow quadr. w/node population

Simulation performance results

- Old AODV at 10,000 nodes performs poorly
  - 25% packet deliveries in the best of circumstances
  - Even worse without local repair and expanding-ring
- AODV vs. DSR with limited node populations
  - DSR works better under conditions of low mobility
  - Node movement favors AODV's route management
- MAODV has been tested under ns-2, and shows performance difficulties even at low populations
- Gün Shirer at Cornell offers the *Staged Network Simulator* (SNS) using ns-2 for big simulations

More performance results

- # RREQs ~ linearly with the node population
- Line's slope changes depending on strategy
- At 10,000 nodes, most packets are control traffic (in one case, ratio was 5000 to 1)
- End-to-end delay wasn't outrageously terrible (150ms) even at high node populations
- AODV w/expanding ring has the longest latency
- Query localization seems not to work (?why?)
- Should be similar for other on-demand protocols

Ways to produce convergence

- Modularize features, new and old (not easy!)
  - Flooding
  - Expanding rings search/fisheye routing
  - QoS routing
  - Pulsar/clusterhead/hierarchical/…
  - Internet Gateway operation
  - Multipath, address allocation, etc., etc., …
- Apply new advances to each routing protocol…
- Eventually, common part may dominate!

Merging Proactive and On-Demand

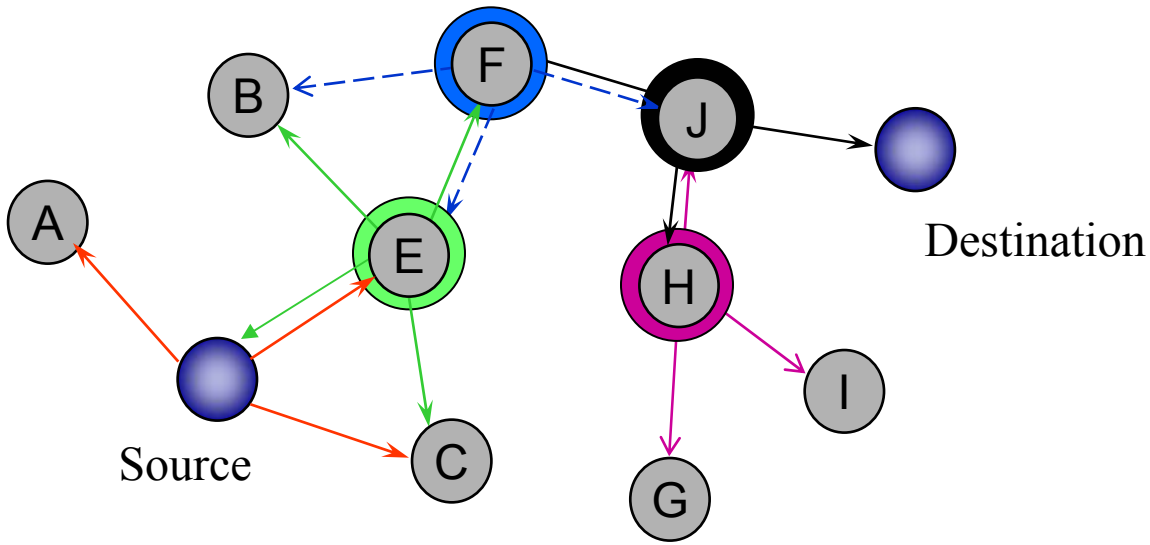
- Key parameter: *ACTIVE_ROUTE_TIMEOUT*
- If *ACTIVE_ROUTE_TIMEOUT* >> 0, route repair will maintain routes
  - Example: Internet Gateways
- Special case solution: multi-hop Route Advertisement
- Helpful: frequent topology updates
  - potentially via "rich" Route Discovery

Flooding: Needed for *discovery*

- "Application" flooding vs. "IP-level" flooding
  - TTL = 1 vs. TTL = network-diameter++ vs. ...
- Multicast vs. Broadcast vs. ???
  - No multicast tree needed
  - 255.255.255.255 isn't right
  - No subnet broadcast
  - Wanted: *manet-local* flooding
- Our goal: ***Many*** fewer packet retransmissions
- Technique: Fewer nodes retransmitting
  - E.g., by picking a set of multipoint relays (MPRs)
- Needed: unique identification for flooded packets

Fewer broadcast retransmitters

Example: Route Request (RREQ) flood



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Connected dominating set (CDS)

- A dominating set *covers* the whole network
- Simpler forwarding if dominating set is *connected*
- Example: the set of all non-leaf nodes
- Reducing the size of the CDS, using a distributed algorithm, is a very active research area

Known Issues

- Broadcast unreliability (problem for OSPF)
- Dependence on last hop?
  - If so, how do receivers detect sender's identity?
- ICMP vs. UDP vs. IP vs. ??
- *Bundling* for multiple simultaneous messages?
- Fewer relays → non-optimal routing!
- Relay nodes in all routes → reduced lifetime!
- May be unnecessary for some networks

Flooding comparisons (a few results)

- We can show nice pictures for the nodes that become part of the broadcast skeleton
- Minimal broadcast *does* reduce PDR
- At 1,000 nodes, TBRPF took all weekend to simulate 3 seconds
- At 1,000 nodes, AODV & reduced broadcast method took 30 min. to simulate 900 seconds
- We also have ideas for further improving the simulator (SNS)
- MUCH work needs to be done!!

Convergence ideas

- DYMO := AODV + DSR; OLSR with TBRPF
  - All *could* use the same flooding protocol
- Distance Vector with Link State
- On Demand with Proactive
- Modular, Constructible approach
- Adaptive/Hybrid approach
- Simulation Results
  - http://lsewww.epfl.ch/Documents/acrobat/CSA02b.pdf
  - "Simplified Simulation Models for Indoor MANET Evaluation Are Not Robust" (Secon 2004)

Service Discovery

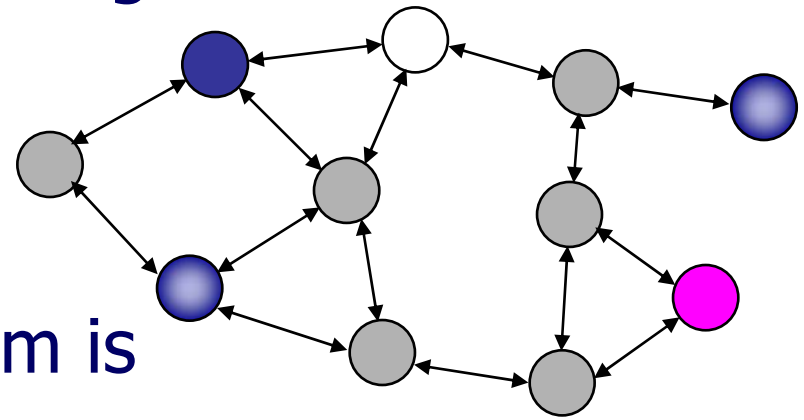
- Needs same sort of "flooding" operation
- But, instead of an "IP address", a service is needed which meets some desired service criteria (name & attributes)
- Allow a service to be identified by the application *port number*
- Alternatively, use SLP *service descriptors*
  - Others exist

Ad Hoc Quality of Service

- Add QoS constraint to link descriptor
  - RREQ for on-demand
  - Topology updates for proactive
- Nodes only forward RREQ if they can possibly meet constraint
- Need ICMP for links that "fail"
- NP complete problems abound, due to congestion management, scheduling

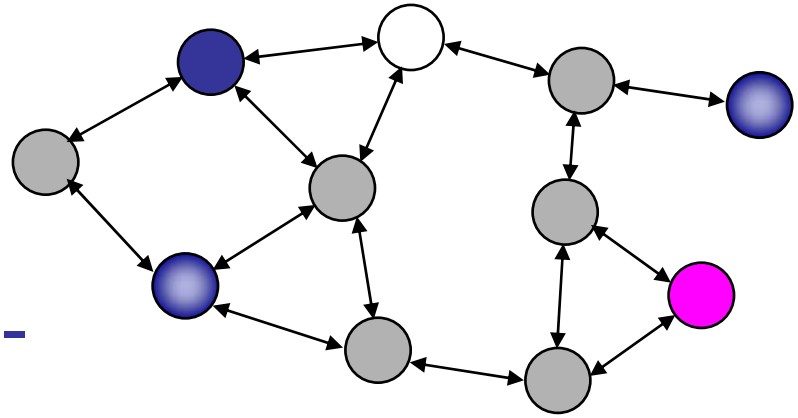
Social Networking

- Friends often provide interesting leads
  - Music
  - Blogosphere
  - Other new friends
- The smartest guy in the room is everybody…
  - "The Wisdom of Crowds" (James Surowiecki)
  - Flickr often (?usually?) gets first pictures of breaking news



Personal Ecosystem

- Opportunity: Make an ecosystem where social interaction is a big win-win
  - So that your friends *empower* you (and, vice-versa)
  - You become further enmeshed and invested



Opportunity!

- Social network can drive acceptance of ad hoc networks
- How can one organize the knowledge of the social community
- How can proximity of ad hoc network fuel new social network applications?
  - For example, locality can improve high performance, video streaming, interactivity, …

More Current Research Areas

- Topology control/power control
- Incentives for Forwarding
- Cognitive Radio
- Message Ferries
- Security
- 802.11s and Mesh Networking

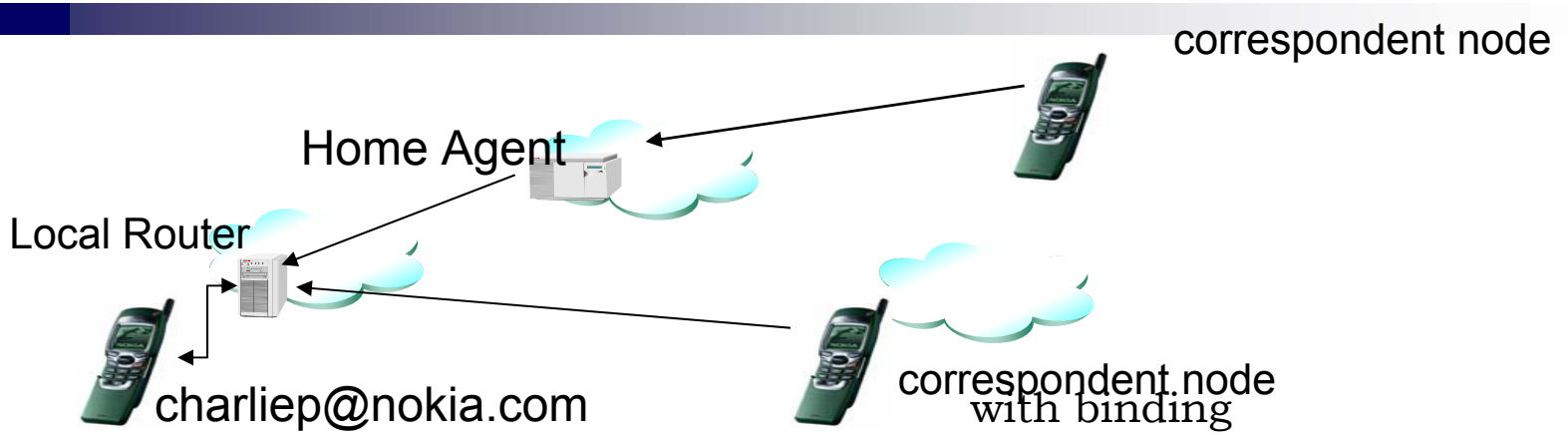
Challenges for the Future

- Getting to Standard!
- Multicast/Anycast/Geocast/Mobicast
- Security (e.g., route repair!)
- Scalability: the 1/sqrt(N) capacity limit per node
  - Backbone formation and maintenance
- QoS – and don't forget layer 2!
- Multipath routing "vs." route caching
- Route Repair vs. multihop context transfer
- Re-examine the "client-server" paradigm
- Using positional hints (for sensors, worth it!)

Summary and Conclusions

- IETF *manet* working group working to converge
- Distance Vector can be made loop free, and localizes the effect of topology changes
- On-demand protocols offer many advantages
- Creating modular components aids convergence
- Convergence aids getting to standard
- Ad Hoc Networking is a great research area
  - Can be applied whenever *infrastructureless*
  - Related fields: sensor networks, graph theory, …

Mobile IP protocol overview



- Routing Prefix from local Router Advertisement
- *Seamless Roaming*: Mobile Node appears "*always on*" home network
- Address autoconfiguration → care-of address
- Binding Updates → home agent & correspondent nodes
  - (home address, care-of address, binding lifetime)

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Backup slides start here…

- In case of specific questions, or if more presentation time is available