Ad Hoc Networks:
Can Mobility help?

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Mario Gerla, CS Dept UCLA
gerla@cs.ucla.edu
www.cs.ucla.edu/NRL

The "curse" of mobility

- The design of ad hoc networks is difficult enough when nodes are static
- It becomes a nightmare when nodes move
- Motion creates problems in many areas:
  - Connectivity becomes "touch and go" because of fading and doppler effects
  - MAC protocols (scheduling) must be designed around mobility
  - Routing is much more difficult to manage
  - TCP connections break and go into time-out
  - TCP "capture" is more prevalent than in the static case
- Is there a way to take the "bull by the horns" and make ad hoc nets work well even with mobility?
- Even better, can we take advantage of mobility?

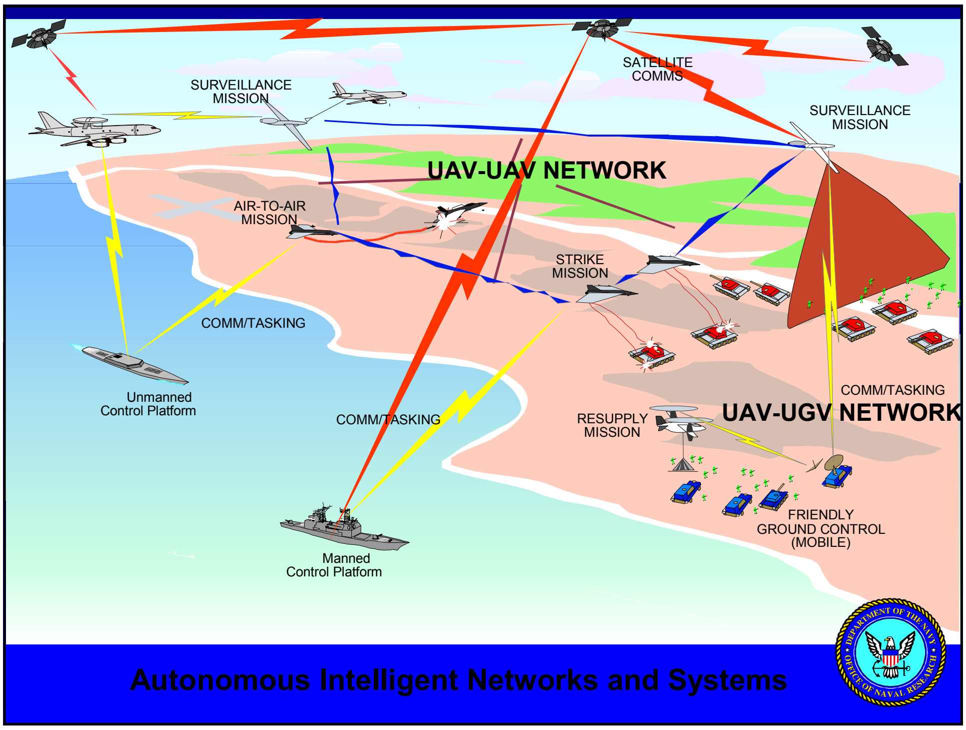
Mobility assisted protocols (How can mobility help?)

- Group oriented routing
- Group discovery/maintenance
- Backbone node relocation
- Team multicast
- Last encounter routing
- Distributed directory (C. Lindmann)

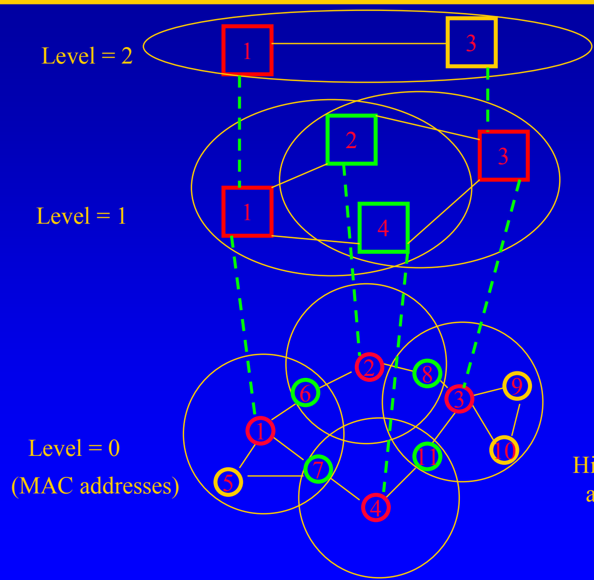
Ad Hoc Routing Techniques

- Proactive routing
- On demand routing
- Hierarchical routing
- Physical hierarchies
- Myopic routing (eg, Fisheye)
- Georouting
- Redundant broadcast reduction

- Some work better than others – but none are scalable to *large number and mobility combined*



HSR - physical multilevel partitions



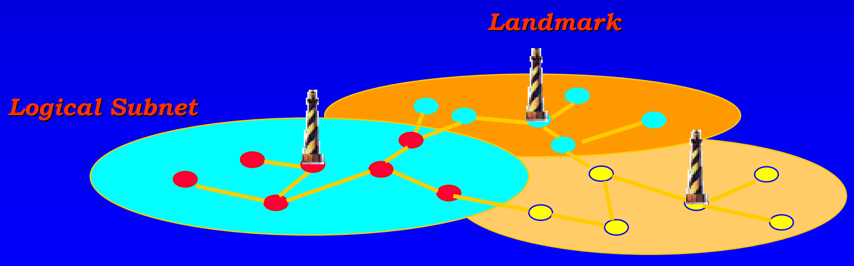
HSR table at node 5:

DestID	Path
1	5-1
6	5-1-6
7	5-7
<1-2->	5-1-6
<1-4->	5-7
<3-->	5-7

Hierarchical addresses { HID(5): <1-1-5>
HID(6): <3-2-6>

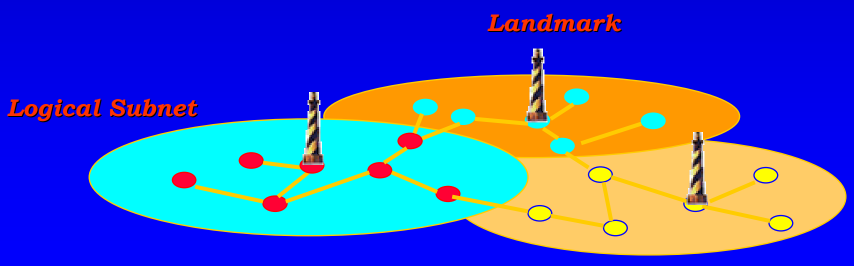
Landmark Routing (LANMAR)

- Key insight: nodes move in teams/swarms
- Each team is mapped into a logical subnet
- IP-like Node address = <subnet, host>
- Address compatible with IPv6
- Team leader (Landmark) elected in each group



LANMAR: key components

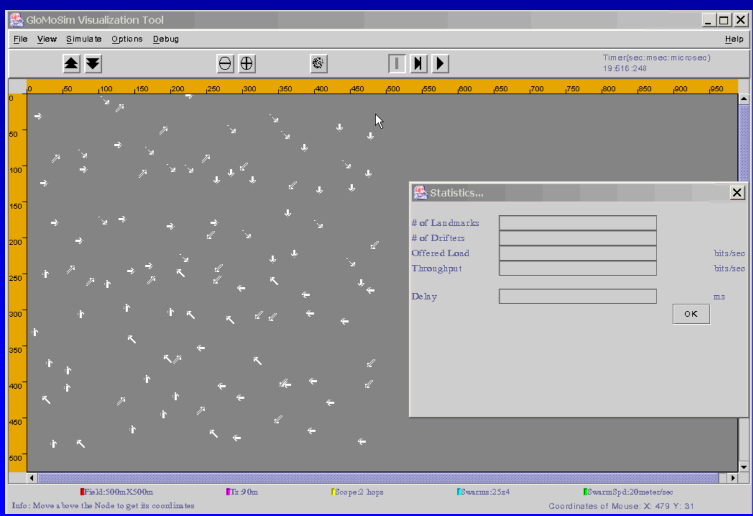
- Three main components in LANMAR:
  - (1) "local " routing algorithm that keeps accurate routes within local scope < k hops (e.g., Distance Vector)
  - (2) Landmark selection for each logical group
  - (3) Landmark routes advertised to all nodes



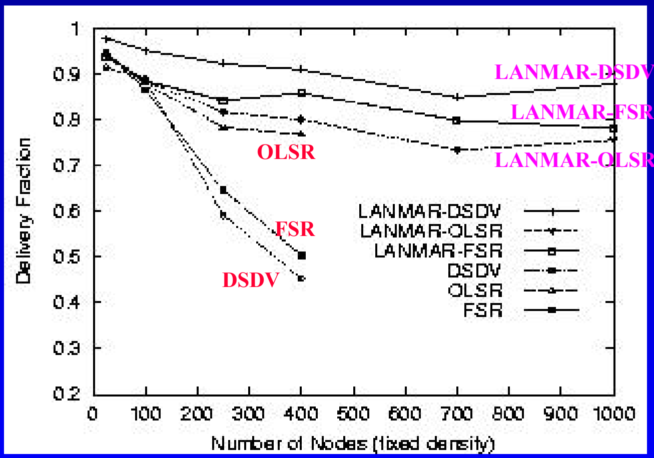
LANMAR operation

- Packet Forwarding:
  - A packet to "local" destination is routed directly using local tables
  - A packet to remote destination is routed to corresponding Landmark
  - Once the packet is "in sight" of Landmark, the direct route is found in local tables.
- Landmarks form a two level logical hierarchy that reduces routing O/H

Dynamic Team Discovery/Formation



Delivery Ratio



On Going Work

- **Currently, all Landmark nodes advertise**
- **This may introduce excessive O/H**
- **Not desirable in covert operations**
- **On-Demand LANMAR version :**
  - Destination is first found using flood-search
  - After the destination is found, advertising begins
- **Large, popular groups will advertise all the time**
- **Small groups will keep low profile**

Dealing with Group dynamics

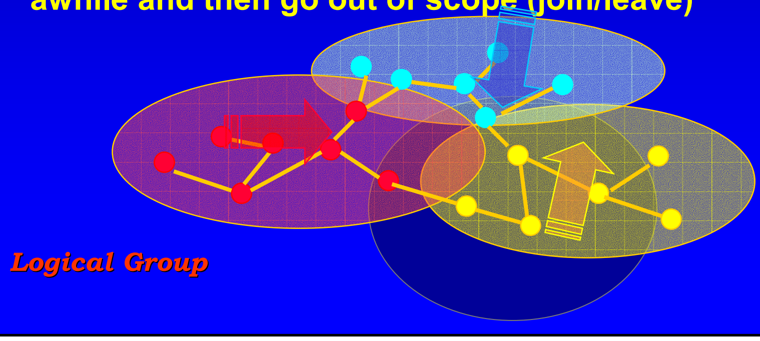
- What if the groups merge and split dynamically during the mission?
- New assumption: no a priori knowledge of groups – or, if it existed, it is lost
- Nodes still move as groups and this can be exploited.
- The network layer must discover now the groups automatically

Group discovery

- **Objective:**
  - Network layer "discovers" the groups automatically based on coordinated motion + mission related criteria (eg, equipped with a particular set of sensors)
- **Working assumptions:**
  - no information about location and velocity (ie, no GPS info)
  - only information collected at network layer

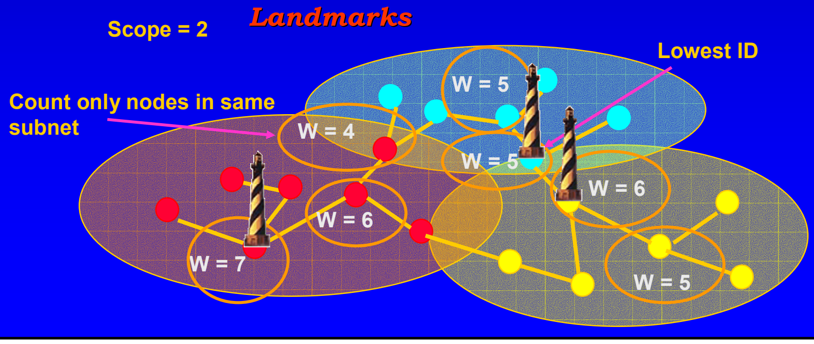
Dynamic Group Formation

- **Motion affinity criterion: nodes that are persistent in a node's scope are group member candidates**
- **Scope: local route hop range (eg, 3 hops)**
- **Motion affinity tracking done via local routing table inspection**
- **Nodes may dynamically enter into locality, stay for awhile and then go out of scope (join/leave)**

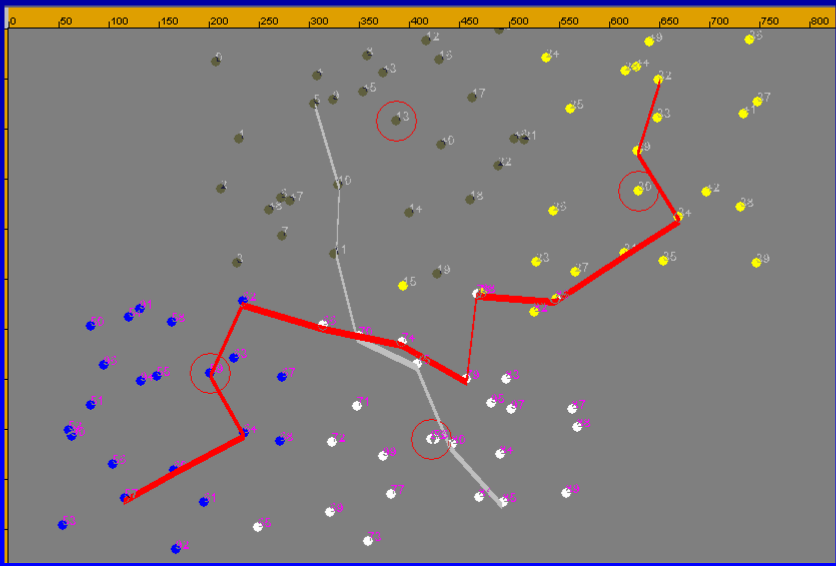


Dynamic Group Leader Election

- **Similar to clustering and cluster-head election**
- **Create groups and elect leaders at the same time**
  - Weights are calculated based on members within the local scope.
  - For each candidate group, the node with highest weight wins (lowest ID breaks tie)
  - The ID of the elected node is recognized as the "group ID" in LANMAR routing.



Example: 4 groups are discovered

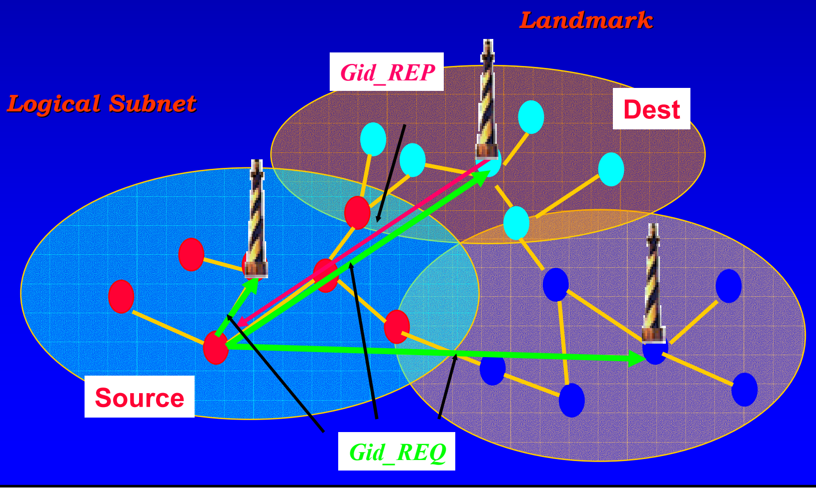


Request-Driven Group ID Retrieval

- How can the source find the “landmark” to destination?
  - Solution 1: Elected Landmark registers group members to :
    - centralized name server
    - distributed hashed based directory
  - Solution 2: Utilize underlying Landmark routing structure.
    - the landmark knows all the nodes in its group (in local table or registered as drifters) – it must know in order to carry out the “election”
    - the source queries all the landmarks
    - the landmark with the hit returns the landmark ID
  - Benefits:
    - Less search overhead than full broadcast search
    - Robust to re-election: the new Landmark is “ready to go”!

Request-Driven Group ID Retrieval

- The source queries all the landmarks (through multiple unicast)
- The destination or the landmark of the destination replies to the sender
- LANMAR routes used for response and for subsequent data packets



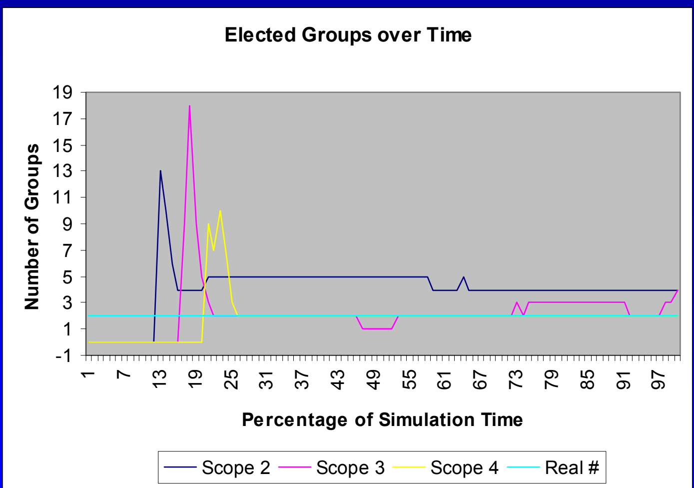
Request-Driven Group ID Retrieval (cont'd)

- **Group ID Caching**
  - nodes receiving ***Gid_REQ or Gid_REP*** cache source's and destination's group ID
  - cached ID info can be used to satisfy future queries
  - Caches will expire
- **Benefits:**
  - **Only generate a few unicast packets to Landmarks.**
  - **Less overhead than flood-search schemes (eg, AODV, DSR); search packets are sent only to landmarks, not flooded to entire network**
  - **Once the landmark is found, the route to the node is robust to mobility (Landmark route is frequently updated)**
  - **Caching for search overhead reduction**
- Can be extended to resource discovery/content addressing

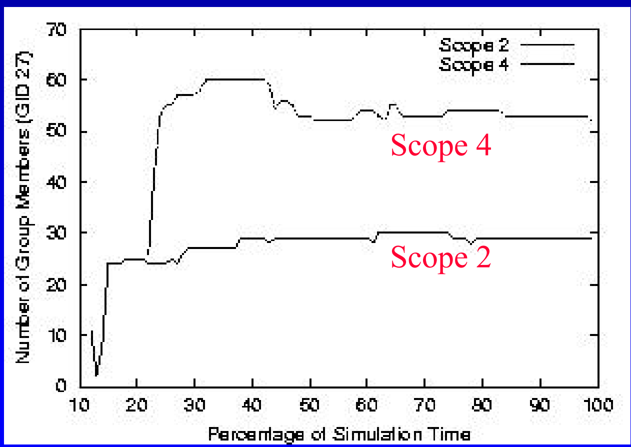
Group Stability Simulation

- Two motion groups (50 nodes each) in area 250m X 500m (tx 90m)
- The group "scopes" are larger then 4 hops
- Groups move in opposite directions, relative speed 10m/s
- Test scope = 2, 3,4
- The larger the scope, the larger the groups and the lesser the number of groups discovered

Stability: # of groups



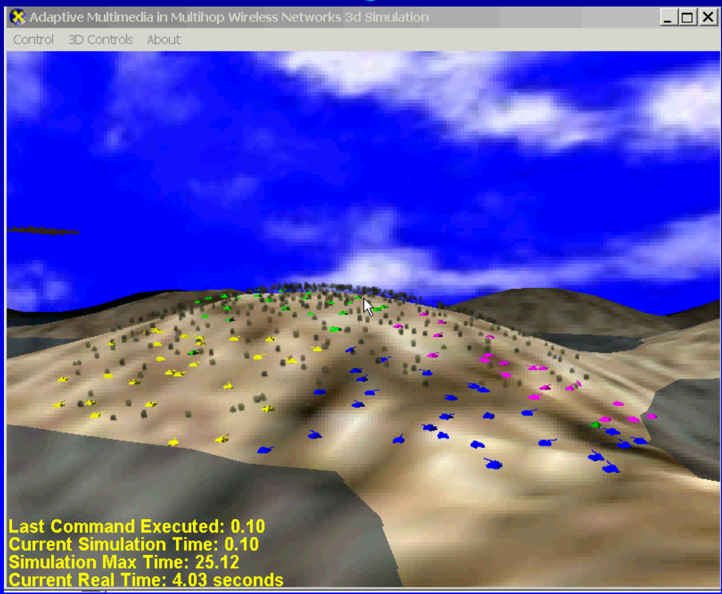
Stability: # of members



Exploit Mobility of Backbone Nodes

- **Why a Backbone "physical" hierarchy?**
  - To improve coverage, scalability and reduce hop delays
- **Backbone deployment**
  - automatic placement: Relocate backbone nodes from dense to sparse regions (using repulsive forces)
- **Routing: LANMAR automatically adjusts to Backbone**

Backbone routing with LANMAR



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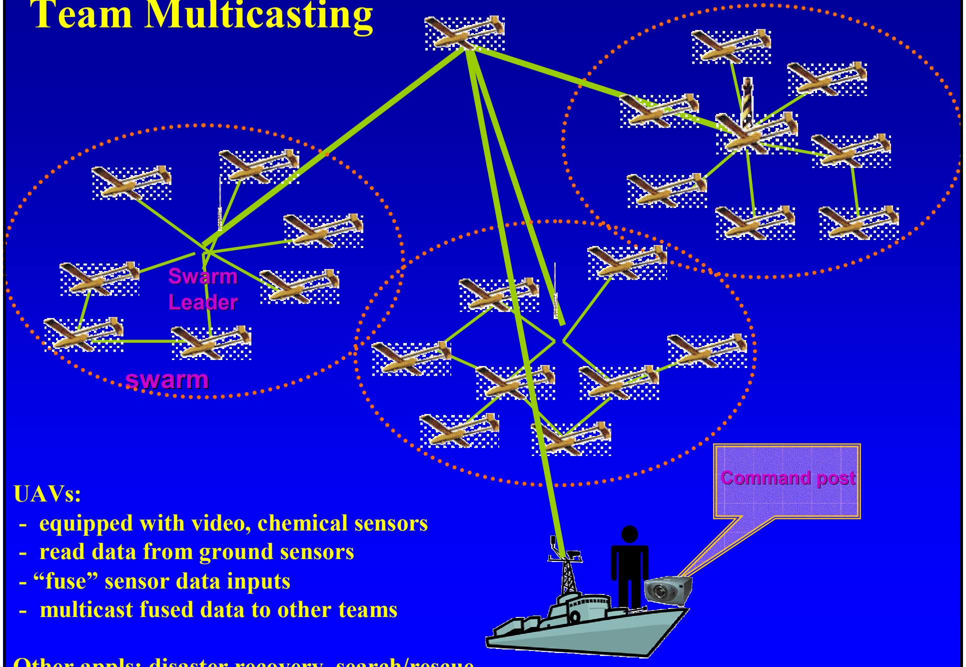
Scalable Ad hoc multicasting

- **Multicast (ie, transmit same message to all member of a group) critical in search/rescue missions**
- **Current ad hoc multicast solutions are limited**
  - multicast tree approach is "fragile" to mobility;
  - no congestion control; no reliable end to end delivery
- **Proposed multi-pronged approach:**
  - **ODMRP**: mesh type fabric (for robustness)
  - **TEAM Multicast**: enhanced scalability in group motion

Team Multicasting



UAVs:
- **equipped with video, chemical sensors**
- **read data from ground sensors**
- **"fuse" sensor data inputs**
- **multicast fused data to other teams**

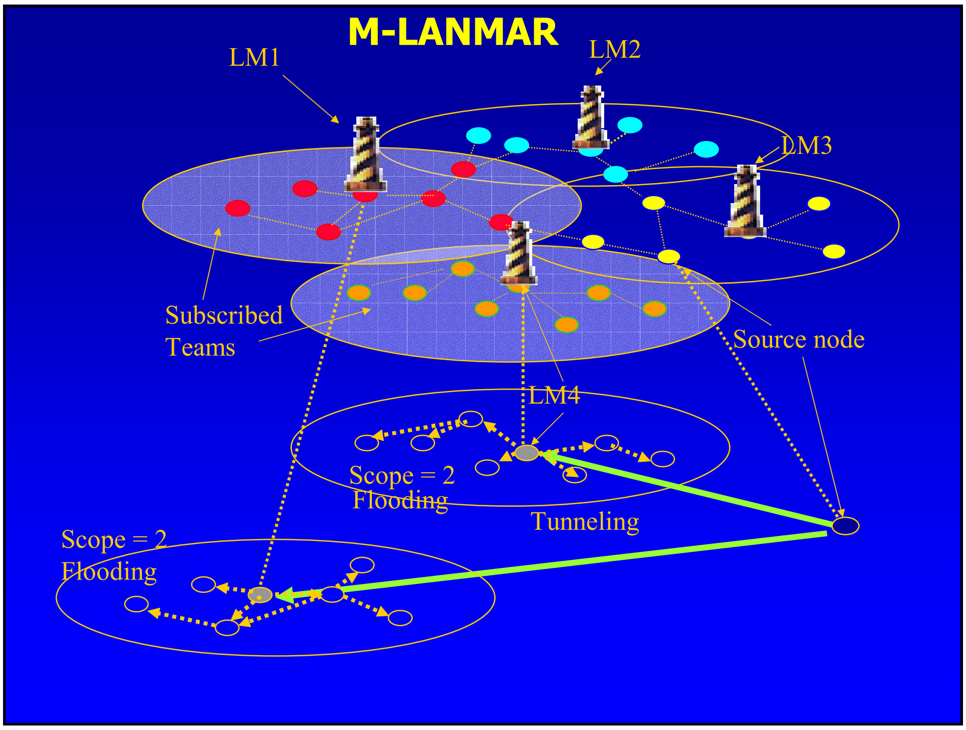
Other appls: disaster recovery, search/rescue

Key idea: exploit team coordinated motion!

- Each team moves as a group (coordinated motion)
- The team thus is a “stable” cluster => ideal building block of the network hierarchy
- Can use same strategy as in LANMAR

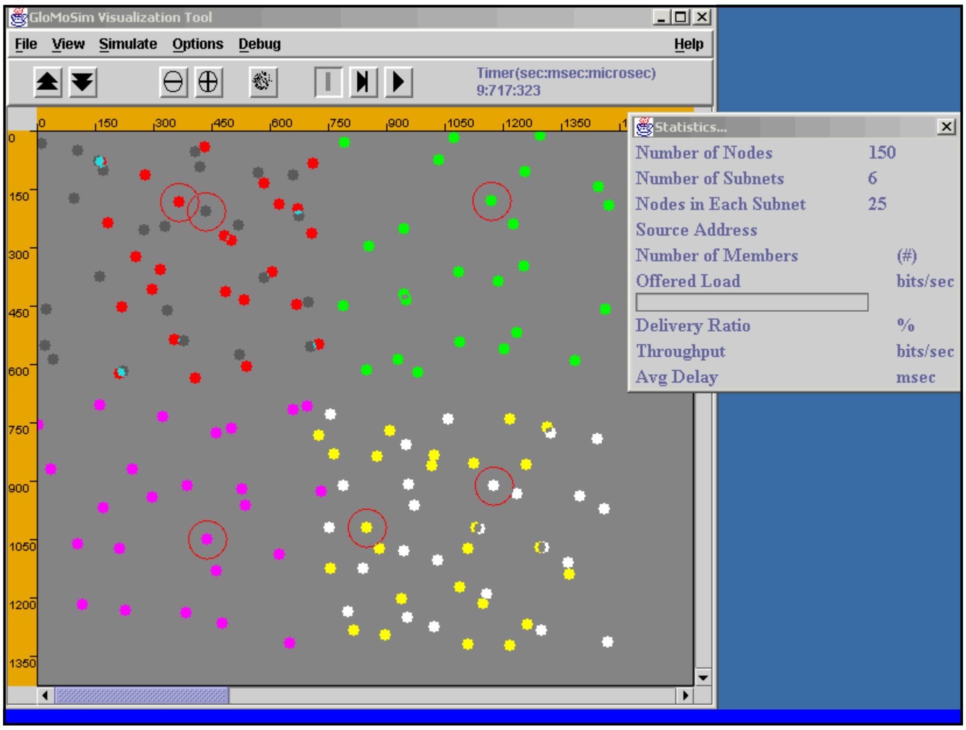
Multicast LANMAR (M-LANMAR)

- Approach:
  - **Unicast tunneling from the source to the Landmark of each “member” team**
  - **Scoped flooding within a team**



Advantages of M-LANMAR

- Reduced control traffic overhead
- Scalable to thousands of nodes
- Enhanced Congestion control and Reliability (because of TCP control on unicast tunnels)



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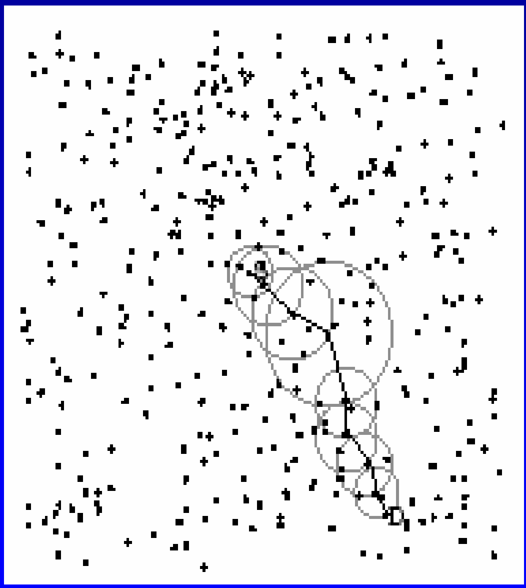
More help from mobility?

- Group mobility was helpful to scale the routing protocol
- Can mobility help also in other cases (eg, random instead of group motion)?
- (a) Mobility induced distributed route/directory tree
- (b) Using mobility prediction for efficient forwarding/transport

Epidemic Diffusion

- Imagine a roaming node “sniffs” the neighborhood and learns/stores neighbors’ IDs
- Roaming node carries around the info about nodes it saw before (epidemic diffusion)
- If nodes move randomly and uniformly in the field (and the network is dense), there is a trail of nodes – like pointers – tracing back to each node ID

Fresh algorithm – H. Dubois Ferriere, Mobihoc 2003



Last Encounter Routing

- The superposition of these trails is a tree – it is a routing tree (to send messages back to source); or a distributed directory system (to map ID to hierarchical routing header, or geo coordinates, for example)
- "Last encounter" routing: next hop is the node that last saw the destination

Epidemic Diffusion of "location based services"

- The roaming node can also "sniffs" contents and resources in the neighborhood
- Roaming node carries around this info and can be queried about it
- This is ideal to support location based services: eg, I can find uptodate directions to the closest coffee shop, newspaper vendor, pharmacy etc

Mobility induced, distributed embedded route/directory tree

Benefits:

- (a) avoid periodic advertising O/H (eg, Landmark routing)
- (b) reduce flood search O/H (to find ID, local service)
- (c) avoid registration to location server (to DNS, say)

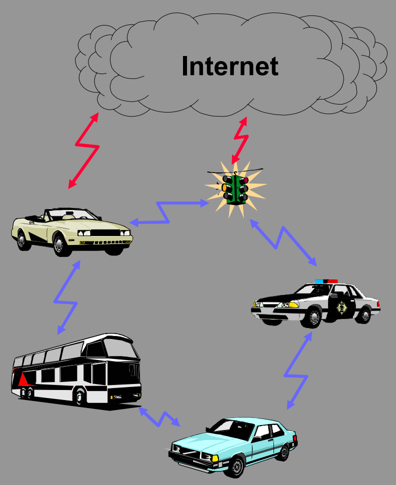
Issues:

- Sensitivity to motion pattern (localized movements vs random roaming)
- Latency and route obsolescence caused by slow moving "scouts"

Mobility increases network Capacity

- Example: highway info-station every 1000 m
- I am driving and I can predict the time when I will connect to the infostation. My intelligent router decides to wait to download a CD
- Latency vs control OH trade offs

Ad Hoc Networking for Car-to-Car App.



P2P Applications

- Information exchange on traffic jam, accident, icy road, etc.
- Download music, video games, road maps, etc. from info stations
- wireless charging of parking fees

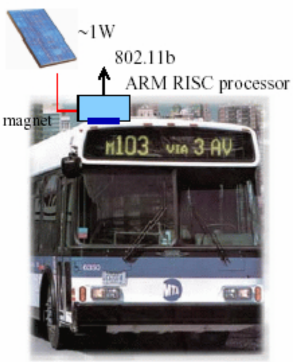
Challenges:

- Exploiting mobility for information dissemination
- Routing protocols for rapidly changing configurations

7DS: seven degrees of separation (Henning Schultzrinne)

- **The urban grid**
  - Ideally, a pedestrian can inject packets in the “urban grid” and expect them to be delivered to the Internet (via several car and light pole hops)
- **However:**
  - hot spots not ubiquitous
  - ad hoc networks don’t scale to full grid
  - brittle if spanning large areas
- **7DS proposal: use mobile nodes to carry data**
  - to and from infrastructure networks
  - Pedestrian transmits a large file in blocks to the passing cars, busses
  - The carriers deliver the blocks to the hot spot

Realization



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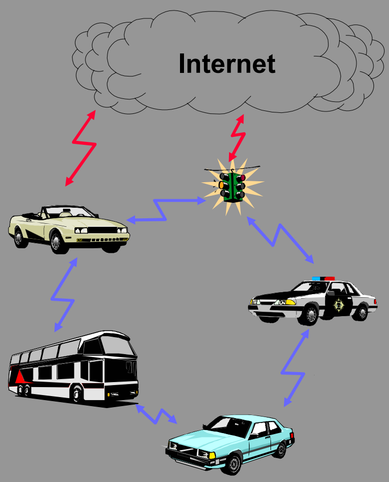
Passive Distributed Indexing: A Distributed Lookup Service Supporting Mobile Applications

Christoph Lindemann

Oliver P. Waldhorst

University of Dortmund
Department of Computer Science
August-Schmidt-Str. 12
44227 Dortmund
http://www4.cs.uni-dortmund.de/~Lindemann/

Ad Hoc Networking for Car-to-Car App.



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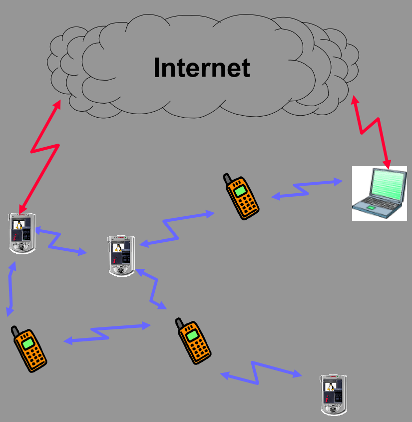
Mobile Ad Hoc Networks for Edutainment



P2P Applications

- File Sharing for mobile e-learning (e.g. “Notebook University”)
- Sharing of music clips, jingles, photos, etc.

Challenges:

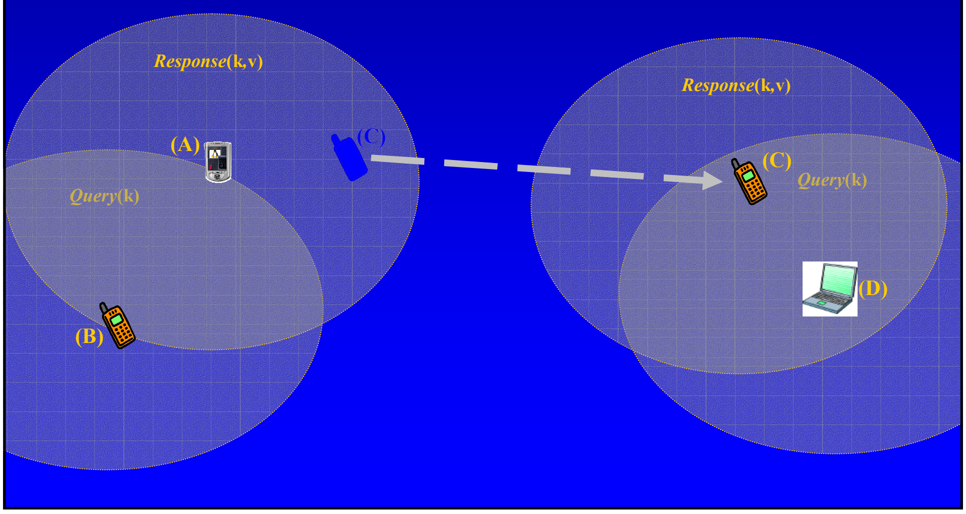
- Exploiting mobility for information dissemination
- Routing protocols for irregular movement
- QoS support for wireless links
- management for limited memory and power consumption

Passive Distributed Indexing (PDI)

- **General-purpose distributed lookup service for mobile applications**
- **Fundamental Ideas**
  - Epidemic dissemination of information
  - Caching responses to popular queries in index caches
  - Timeouts and invalidation caches for keeping index caches coherent
  - Many local broadcast, limited multihop relaying
  - Underlying network technology: IEEE 802.11

Illustration of PDI

- **Epidemic dissemination of information**



Building Blocks of PDI

- **Local Index**
  - Stores (key,value) pairs the local host contributes to the system
- **Index Cache**
  - Stores (key,value) pairs from remote nodes
  - Limited size, LRU replacement of pairs
  - Used to generate responses on behalf of other nodes
- **Local Broadcast Transmissions**
  - All messages are transmitted using (local) broadcast
  - Nodes overhear responses form other nodes and store results in the index cache

- **Problem: How to keep index caches coherent?** **see** http://www4.cs.uni-dortmund.de/~Lindemann/

Conclusions

- **Mobility in ad hoc nets can be exploited to :**
- **Achieve scalable routing:**
  - Using LANMAR for example (in case of group mobility)
  - Using "last encounter routing" in case of uniformly random routing
- **Assist in deploying mobile backbone nodes that "fill the gaps" and reduce hops**
- **Support "location based" services**
- **Increase network capacity by combined "mechanical" transport (eg Bus) and delivery to nearest hot spot**
- **Support distributed "epidemic" indexing (an ad hoc alternative to CAN and Chord)**

Next steps

- Develop systematic and representative models of mobility
- Evalaute the dependence of mobility assisted solutions to mobility models
- Explore other application areas (eg mobility based security)

The End

Thank You!