The Evolving Wireless Landscape: Convergence to 4G

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The three wireless “waves”

- **Wave #1: cellular telephony (late 80’s)**
  - Still, biggest profit maker
  - Has evolved to provide mobile Internet access
  - 2.5G (GPRS, 1XRTT): Internet data
  - 3G (UMTS): Internet multimedia
- **Wave #2 : wireless Internet access (mid 90s)**
  - Born as wireless Ethernet
  - Most Internet access on US campuses is via W-LANs
  - Hot spots are rapidly proliferating in the US; Europe and Asia to follow soon
  - Urban Mesh networks
- **Wave #3: ad hoc wireless nets (now)**
  - Set up in an area with NO infrastructure; to respond to a specific, time limited need
  - Sensor networks and Personal Area Networks (eg Bluetooth) may be seen as extensions of the ad hoc network concept

Convergence to the Fourth Generation Wireless networks: 4G

- **What is 4G?**
- **Mainly, the synergy of all the existing wireless network architectures**
  - We have given up the idea of a universal wireless network standard (eg, UMTS) that works for all situations
  - A more efficient solution is the interworking of "locally" optimal technologies
- **3G cellular and WiFi are converging to 4G**
  - Both infrastructure based
  - Both promote wireless Internet access
  - They have different areas of competence (indoor vs outdoor; voice vs data, etc)
  - Several projects underway, both in Industry and academia
  - Always Best Connected (ABC) project at UCSD
  - Seamless music download (UCLA)

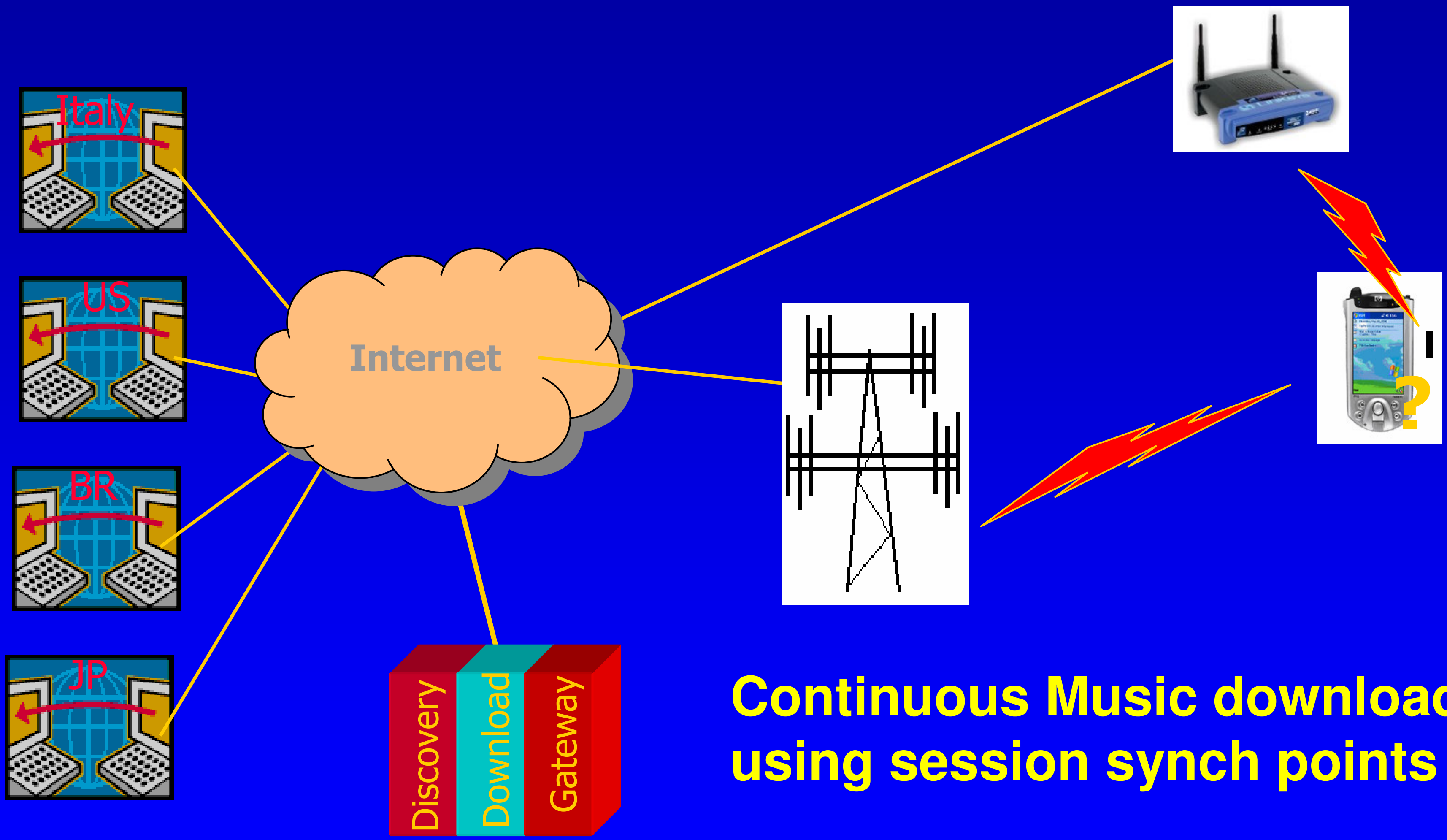
The convergence of cellular and 802.11

- **Doctors:** moving from hospital ward (Bluetooth) to labs (802.11) to the building across the street (cellular)
- **Field repairmen**: download web instructions via 802.11 (indoor) or via cellular (outdoor)
- **Car passengers**: connect to urban Hot Spots, or to the cellular network to play internet games

Choosing the best option

- **Portables have multiple radio interfaces**
  - 802.11, Bluetooth and 1xRTT supported on PDAs
- **Each alternative has unique properties**
- **Selection criteria :**
  - Lowest connection charge
  - Best reception
  - Best power budget (must save battery power)
  - QoS support
  - Location based services support
- **Challenges:**
  - Seamless handoff (network, session)
  - Rate content adaptation if data rates are different

UCLA Research Project, 2003
"Switching between 802.11 and 1XRTT"



Continuous Music download using session synch points

Downoading music

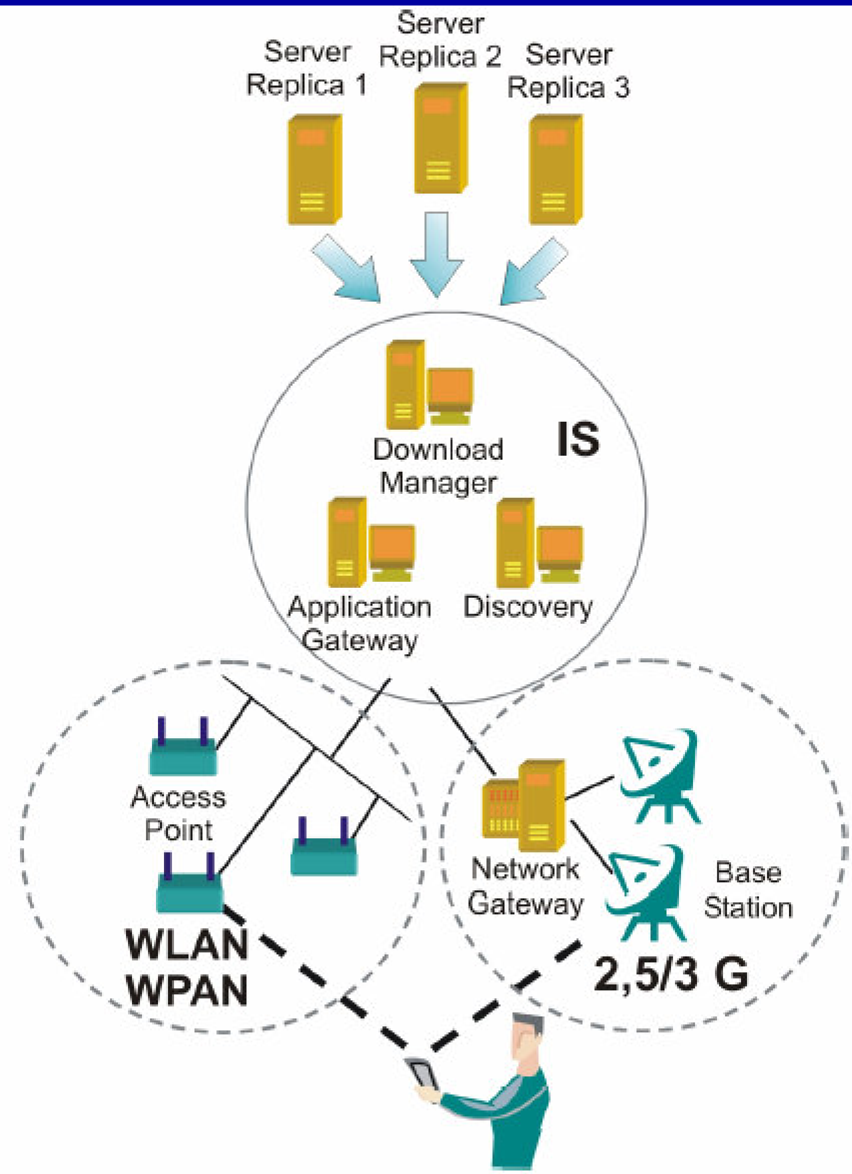


Figure 1. System Architecture

Figure 7: The HP iPAQ H5450 with three wireless interfaces installed

The UCLA experimental environment

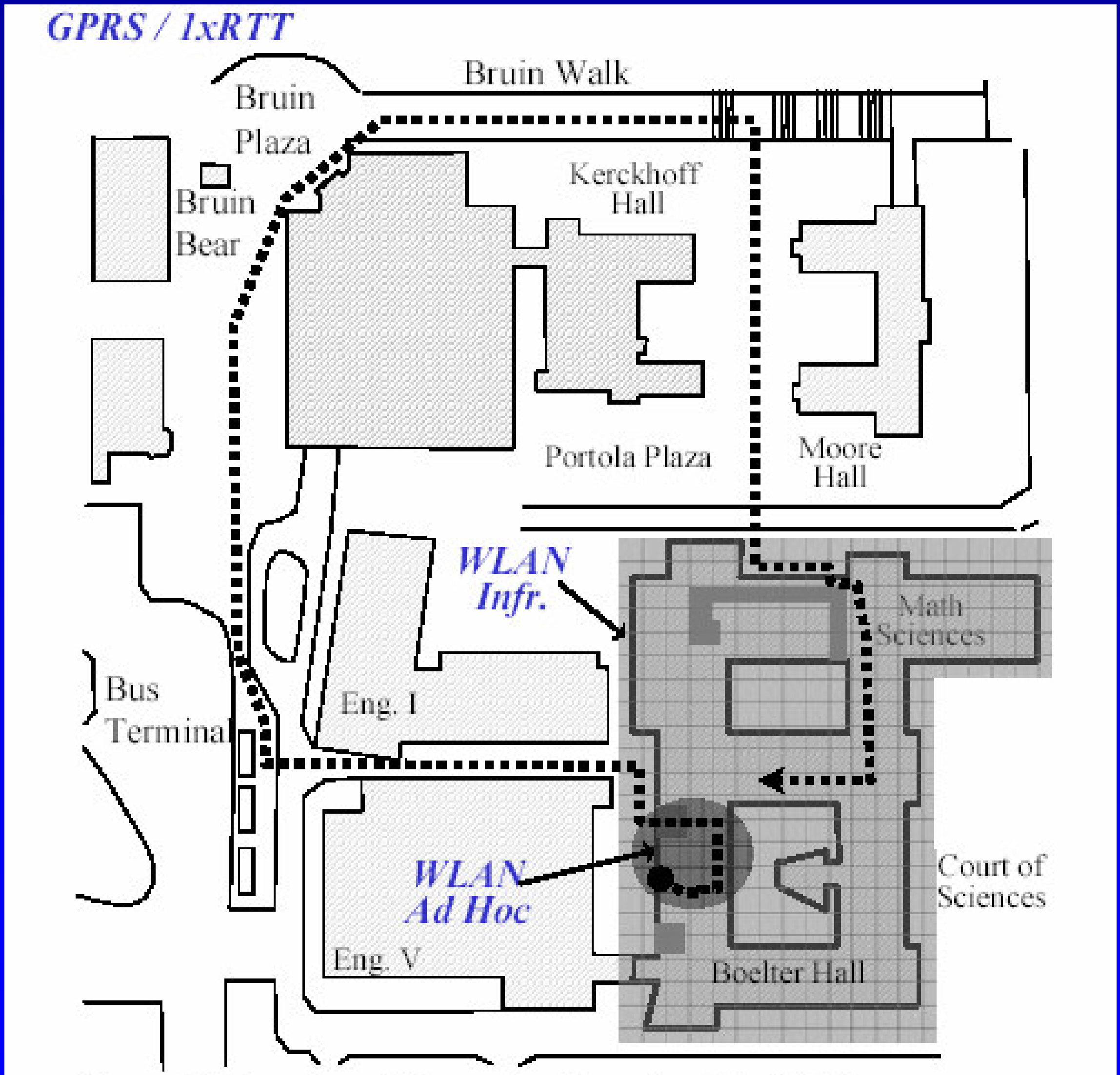
- 

Figure 14: Experiment #1: moving throughout the UCLA campus

Is Ad Hoc converging to 4G?

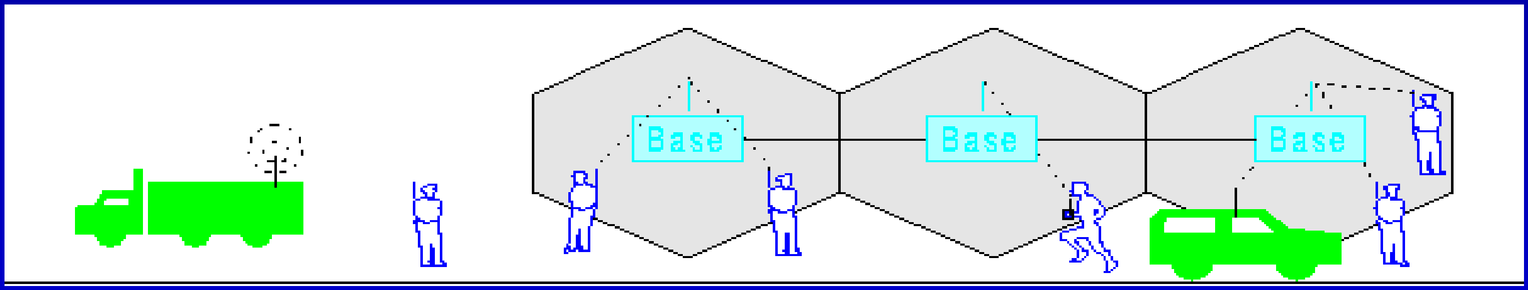
- **The convergence of cellular and 802.11 wireless LAN technologies is well on its way**
- **What about the convergence of the ad hoc network technology?**
  - Much slower to come about
  - Ad Hoc networks were originally developed for networks WITHOUT infrastructure
  - Must find an efficient way to fit them in the infrastructure
  - There is still a lack of compelling commercial applications

Outline of this talk

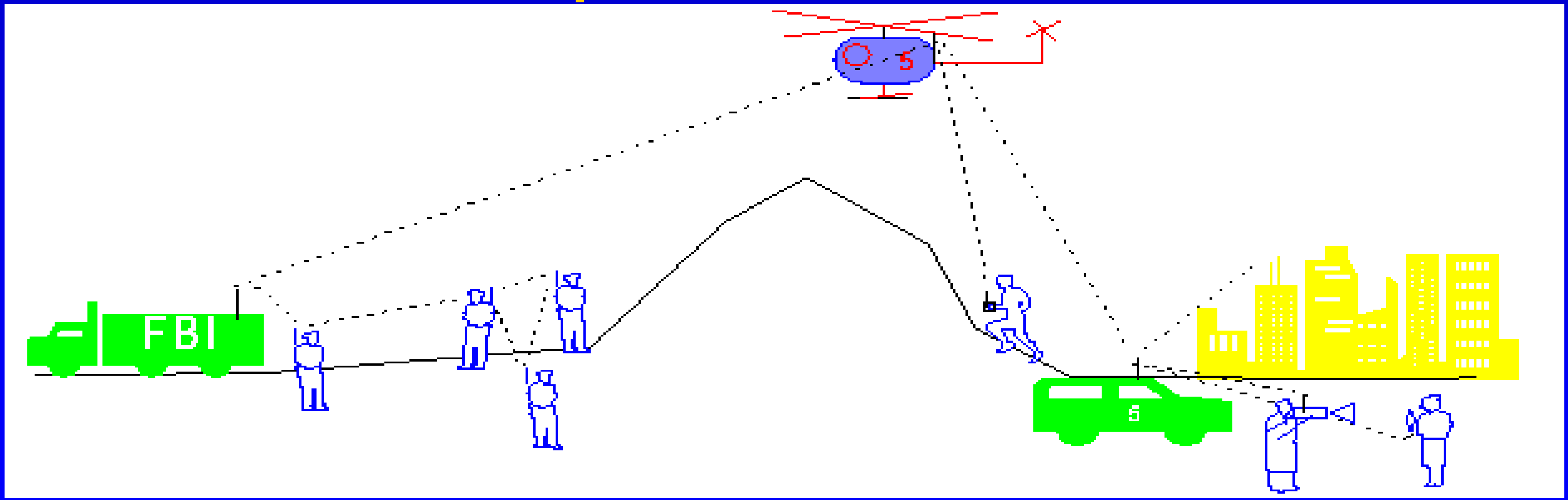
- **What is an Ad Hoc Network**
- **The scalable ad hoc wireless projects at UCLA**
  - The ONR Minuteman project
  - The NSF WHYNET project
- **Scalable routing protocols**
- **Bringing ad hoc networks to market**
- **4G convergence in the vehicular grid**
- **The future of "commercial" ad hoc networking**

The 3rd Wave: Infrastructure vs Ad Hoc

Infrastructure Network (cellular or Hot spot)



Ad Hoc, Multihop wireless Network



General Ad Hoc Network Characteristics

- Instantly deployable, re-configurable (no fixed infrastructure)
- Created to satisfy a “temporary” need
- Node portability (eg sensors), mobility
- Limited battery power
- Multi-hopping (to save power, overcome obstacles, enhance spatial spectrum reuse, etc.)

Ad Hoc Network Applications

Military

– Automated battlefield

Civilian

– Disaster Recovery (flood, fire, earthquakes etc)
– Law enforcement (crowd control)
– Search and rescue in remote areas
– Environment monitoring (sensors)
– Space/planet exploration

Ad Hoc Network Applications (cont)

Commercial

- Sport events, festivals, conventions
- Patient monitoring
- Ad hoc collaborative computing (Bluetooth)
- Sensors on cars (car navigation safety)
- Networked video games at amusement parks, etc

Commercial Killer Application?

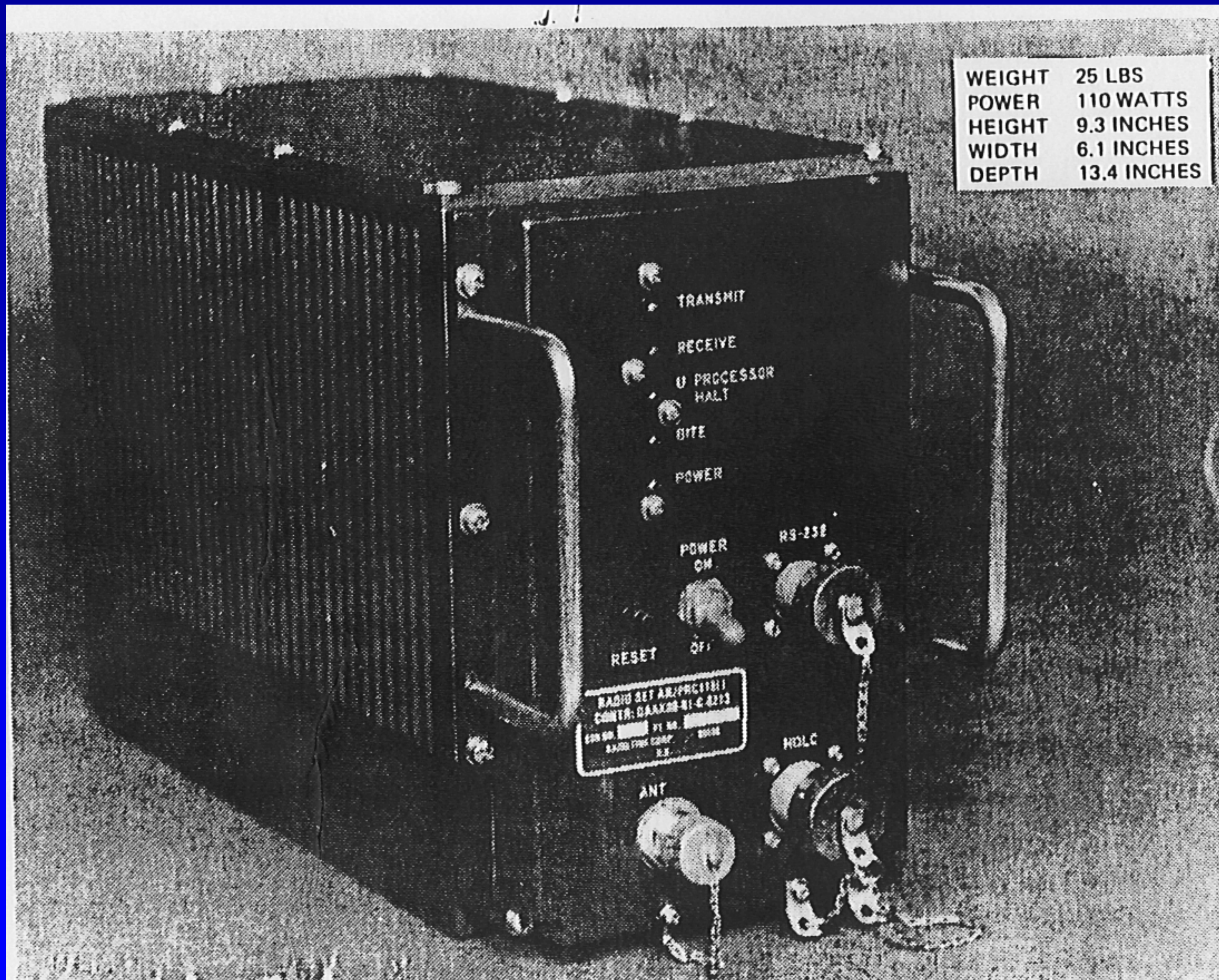
….stay tuned!

The Battlefield

- DoD was quick to understand the value of ad hoc networks for battlefield from very beginning
- In 1971 (two years after ARPANET) DARPA starts the Packet Radio project
- Since 1971, several DARPA, Army and Navy programs have funded ad hoc net research, bringing the technology to high sophistication
- Government has been the main funding source: battlefield is the “killer” application.

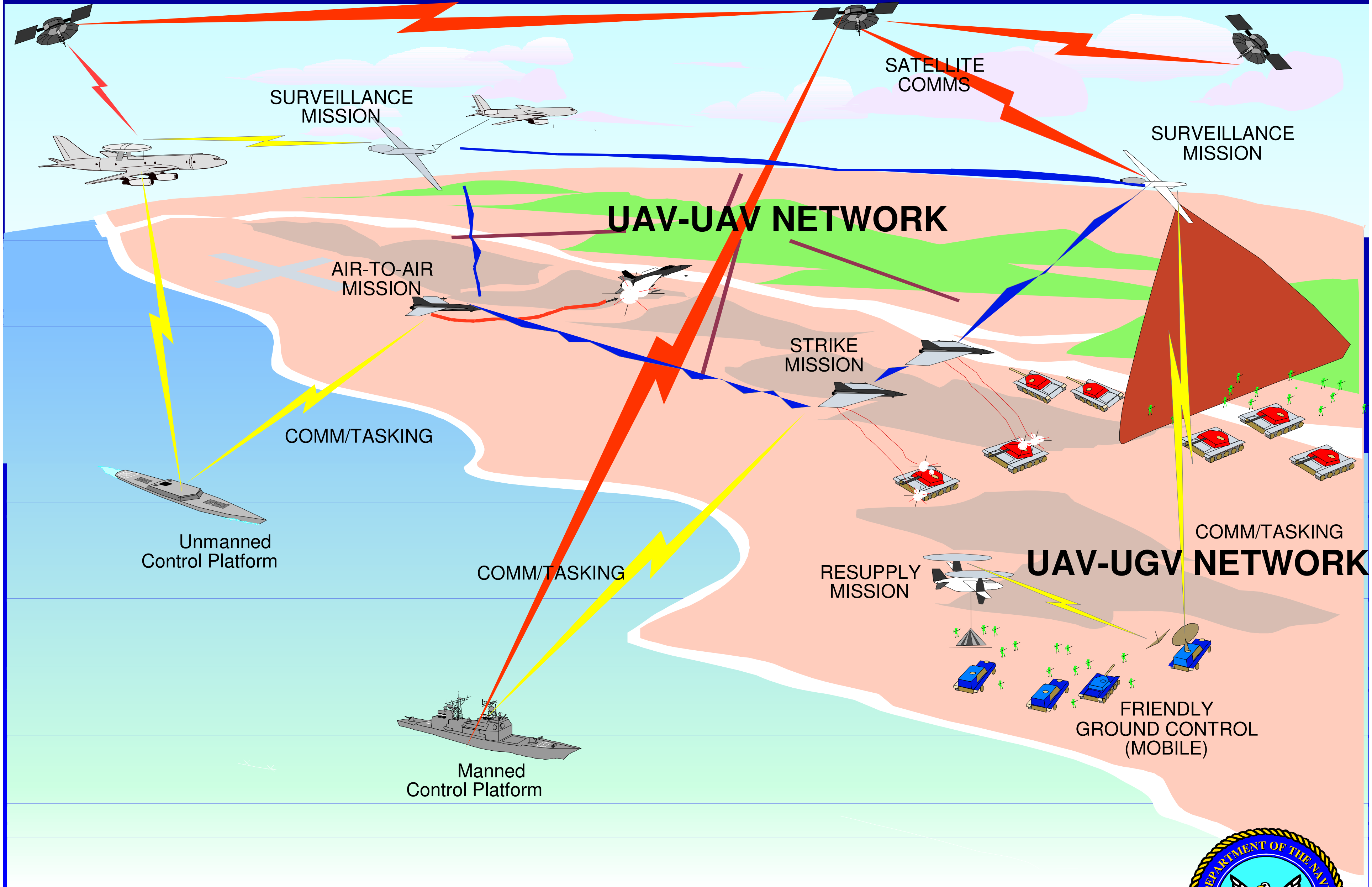
DARPA Packet Radio Project (1971-1985)

- **Goals:**
  - extend P/S to mobile environment
  - provide network access to mobile terminals
  - quick (re) deployment
- **Fully distributed design philosophy:**
  - self initialization
  - dynamic reconfiguration
  - dynamic routing
  - automated network management


WEIGHT 25 LBS
POWER 110 WATTS
HEIGHT 9.3 INCHES
WIDTH 6.1 INCHES
DEPTH 13.4 INCHES
TRANSMIT
RECEIVE
U PROCESSOR HALT
BITE
POWER
POWER ON
OFF
RESET
RS-232
HDLC
ANT

The AINS (Autonomous Intelligent Networked Systems) Program at UCLA

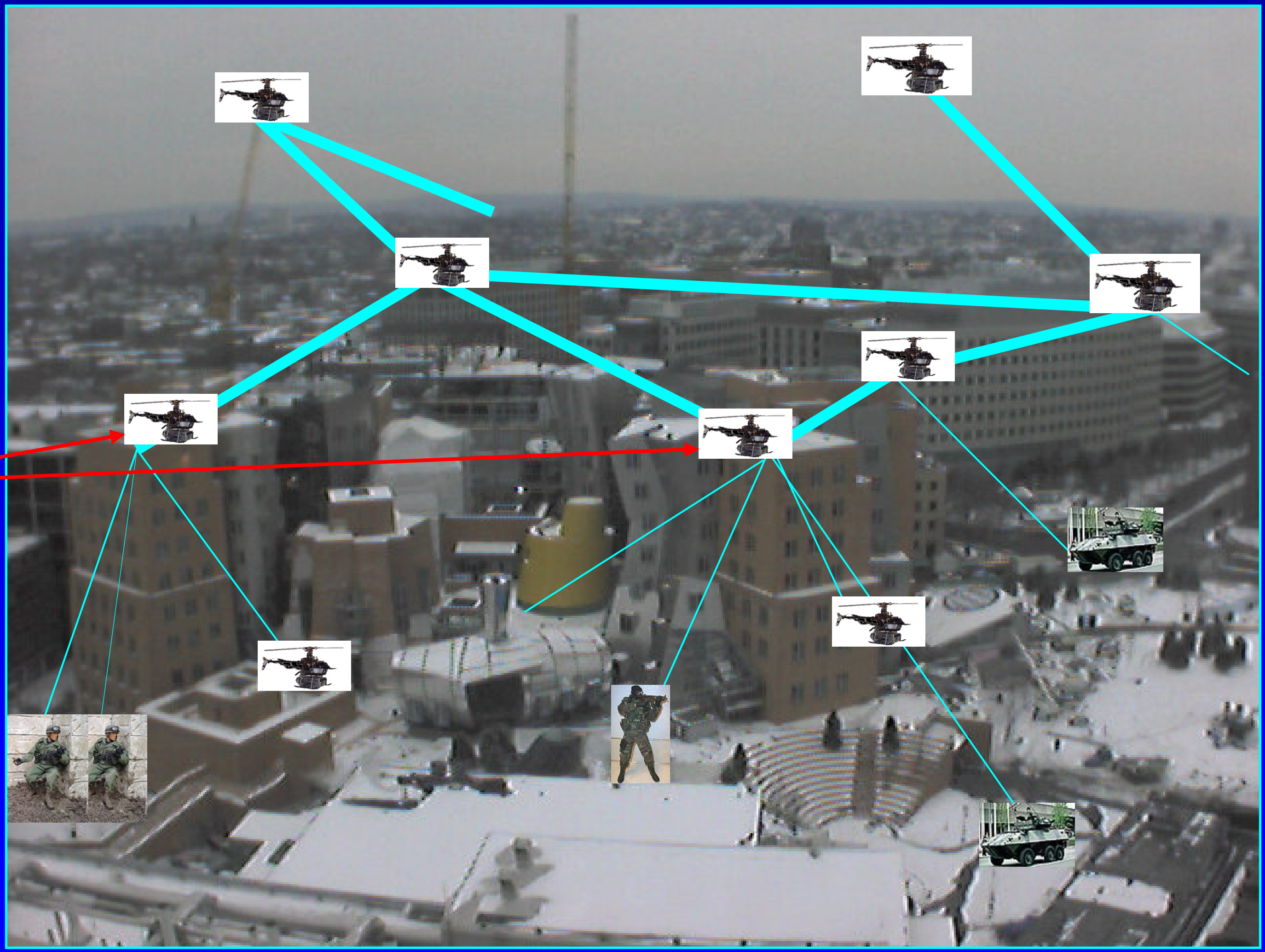
- 5 year research program (Dec 2000 – Dec 2005) sponsored by ONR
- 7 Faculty Participants: 3 in CS Dept, 4 in EE Dept
- Goal: design a robust, self-configurable, scalable network architecture for intelligent, autonomous mobile agents



Algorithms and Protocols for a Network of Autonomous Agents

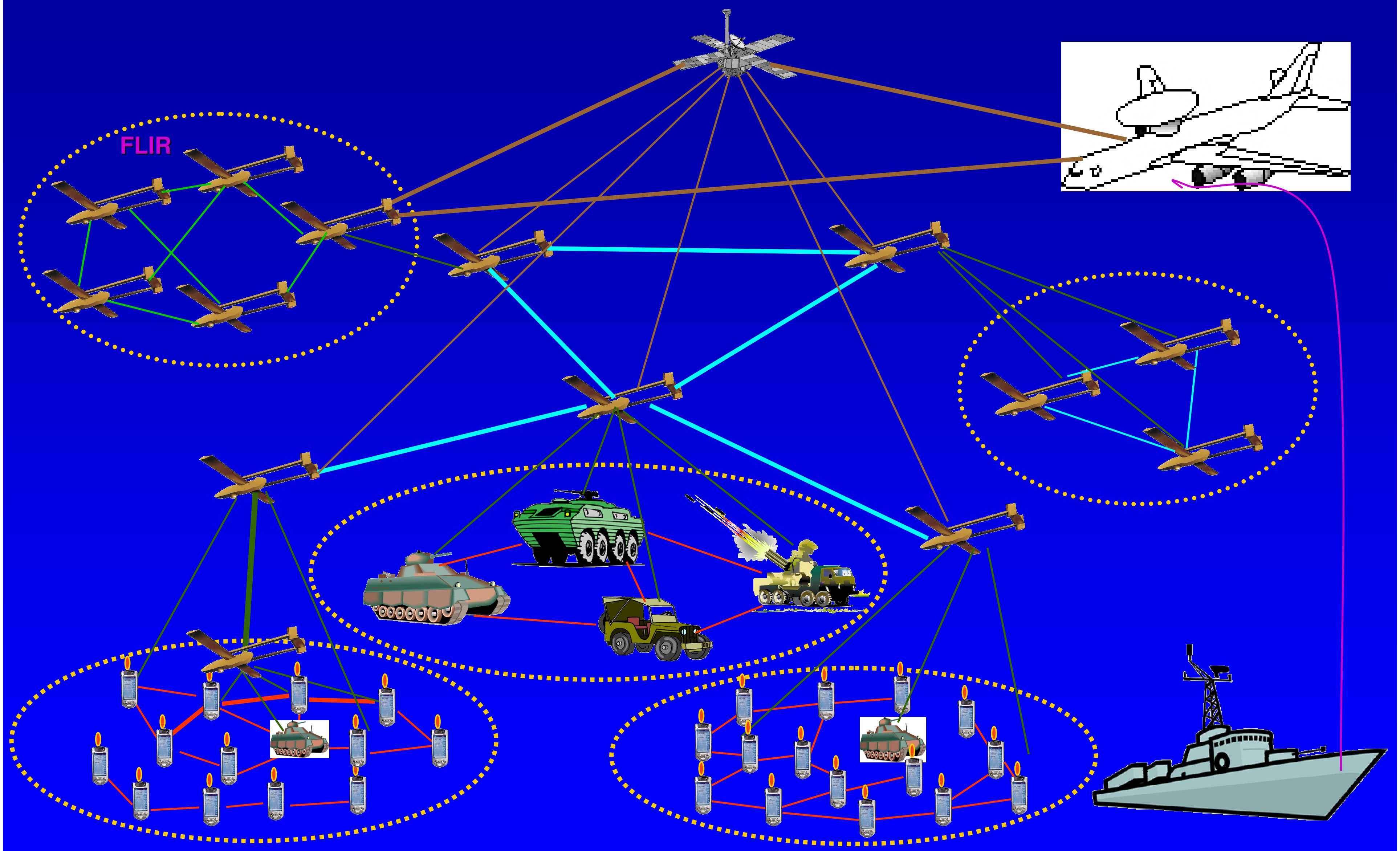
DEPARTMENT OF THE NAVY
OFFICE OF NAVAL RESEARCH

SWARM-enabled communications network

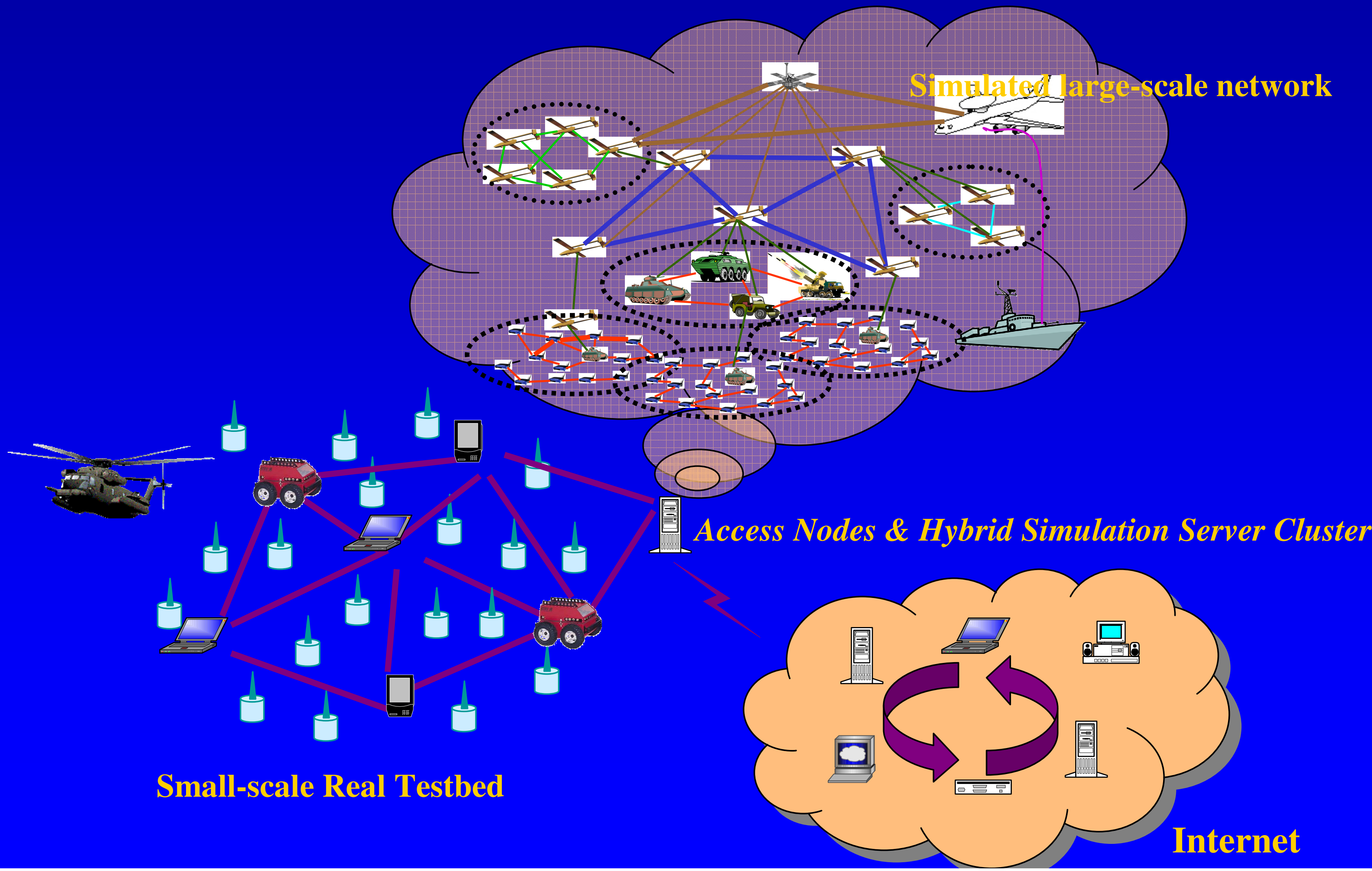


Autonomous Perching

Central AINS theme: networking



Testing the solutions: Hybrid Simulation testbed



WHYNET - Network Testbed at UCLA

- **Wireless Hybrid Networked Testbed**
- **Sponsored by NSF (2003 to 2007)**
- **A "consortium" of seven Universities (UCLA, USC, UCB, UCD, UCR, UCSD, U-Delaware)**
- **Main Goal: develop test environments/tools:**
  - Radios (MIMO, OFDM, UWB, sensor radios, etc)
  - MAC protocols (directional antennae)
  - Sensor (low energy protocols)
  - Network protocols (QoS, Scalability, interconnection)
  - Security
- **Approach: share results/code/platforms**
- **Center piece: hybrid emulation environment**

Sample WHYNET projects

- Transport layer and SCTP
- Securing Mobile Wireless Networks
- QoS in ad hoc and federated networks
- Team oriented routing and multicast
- Cross layer techniques for power management and smart antennas

UCLA Field Test May 2004

The UCLA Field Demo

- **Goals**

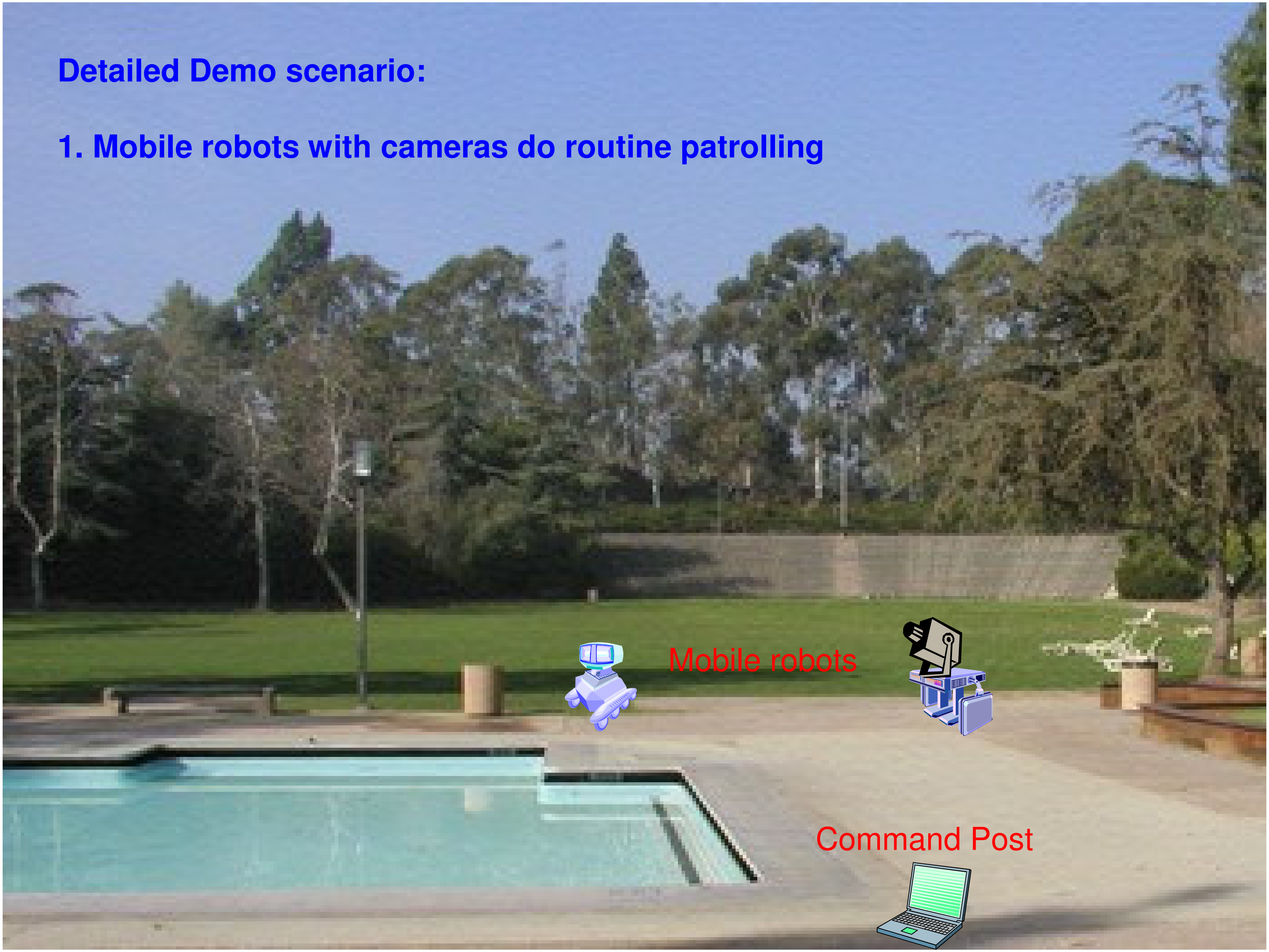
  - Demonstrate a real ad hoc network
  - Apply ODMRP (On Demand Multicast Routing Protocol) to a realistic scenario

- **Approach**

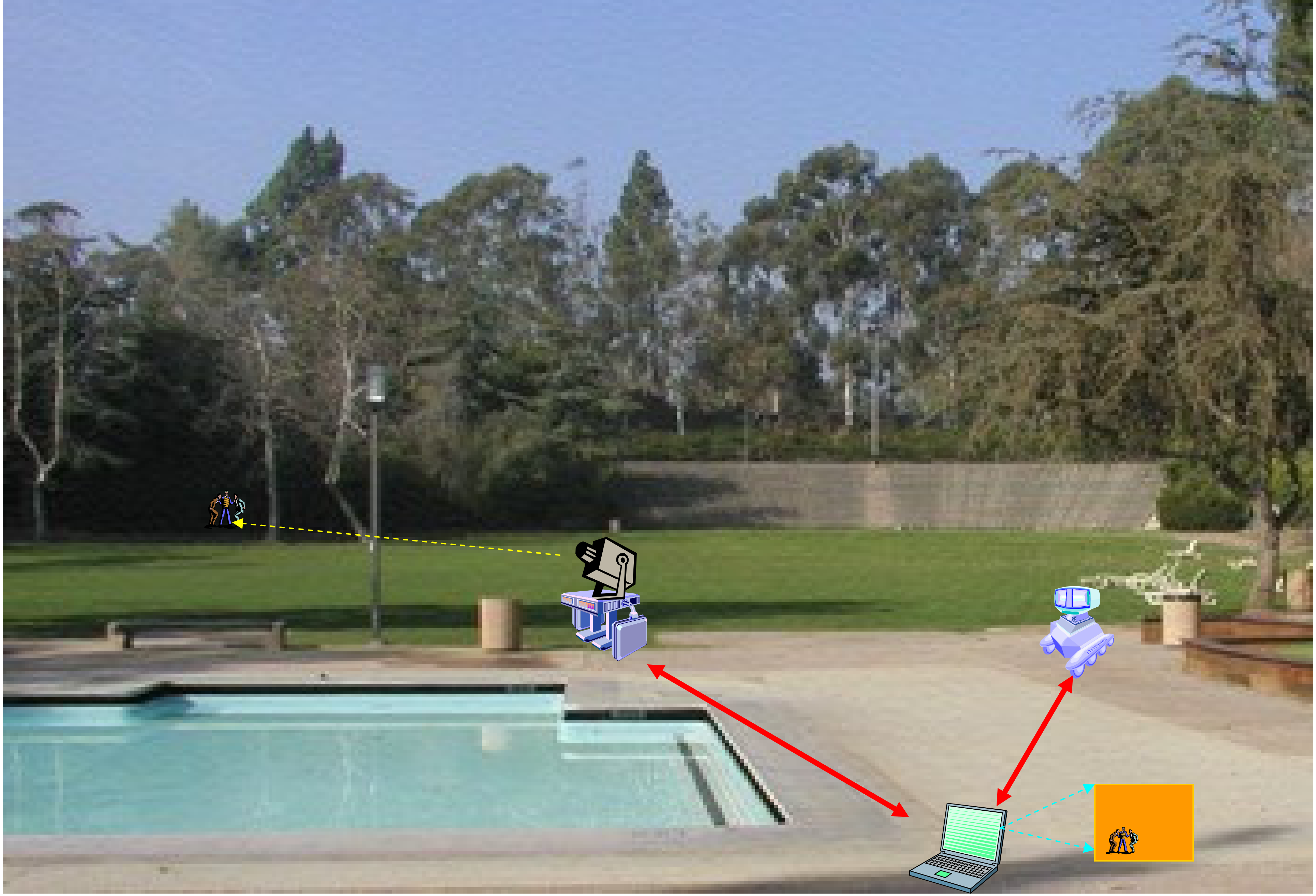
  - Aerial nodes: Blimps with laptops
  - Mobile ground nodes: men/robots carrying laptops
  - Routing protocol: ODMRP
  - Scenario: cooperative surveillance of a large area

Detailed Demo scenario:

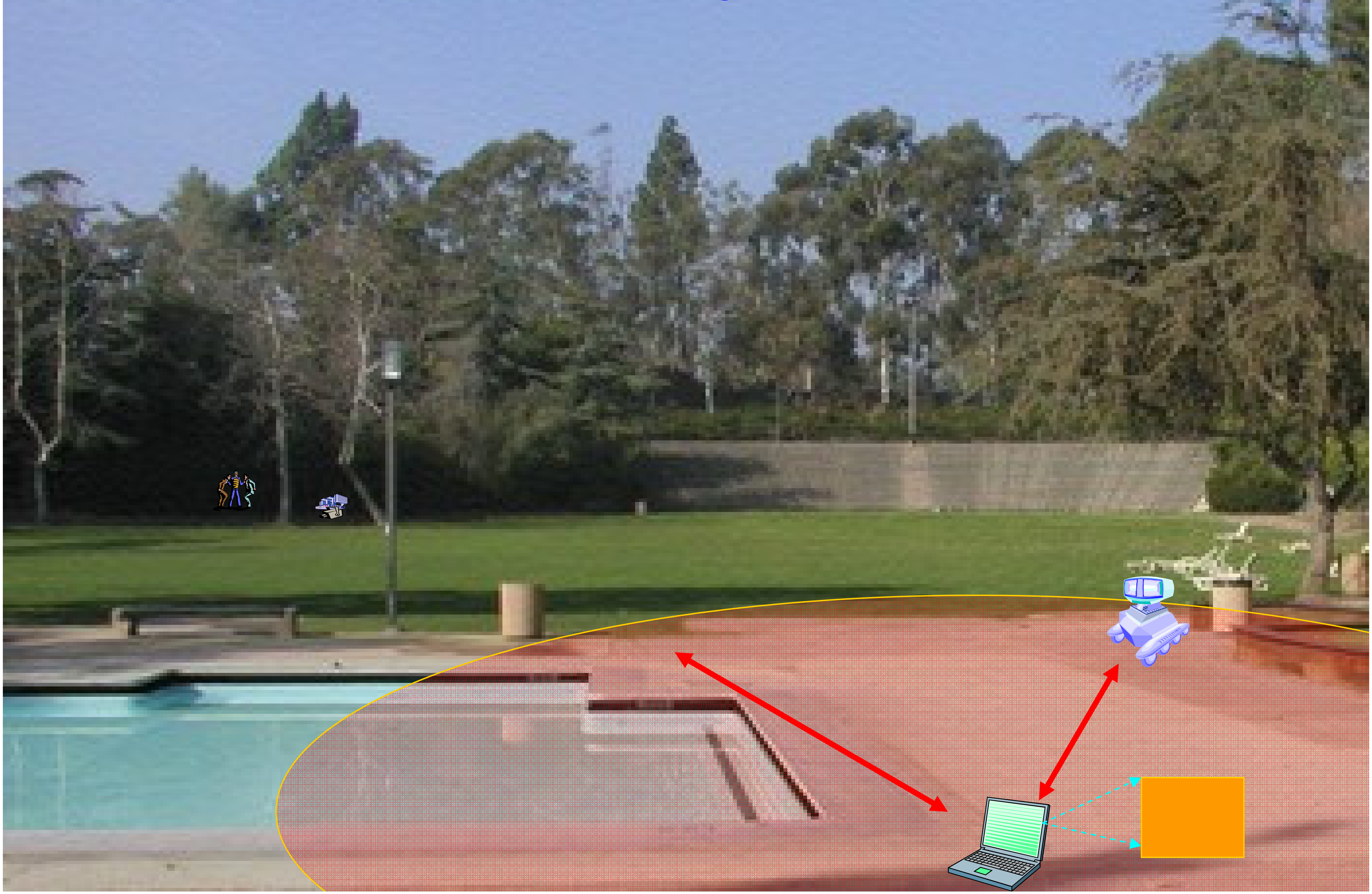
1. Mobile robots with cameras do routine patrolling



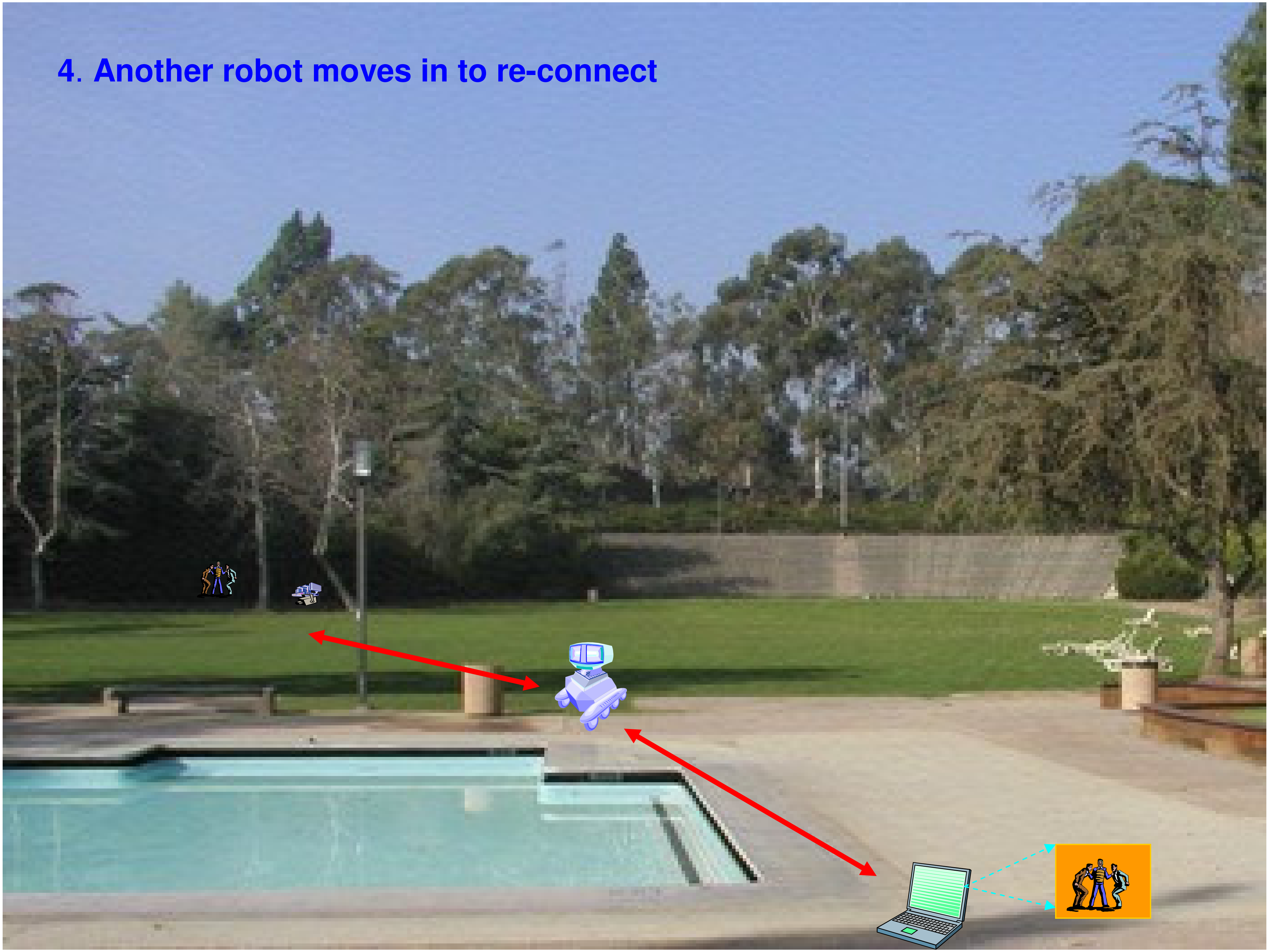
2. Command post (CP) detects an irregular activity far away



3. CP sends out a mobile robot for a closer investigation; it becomes disconnected due to the short radio range

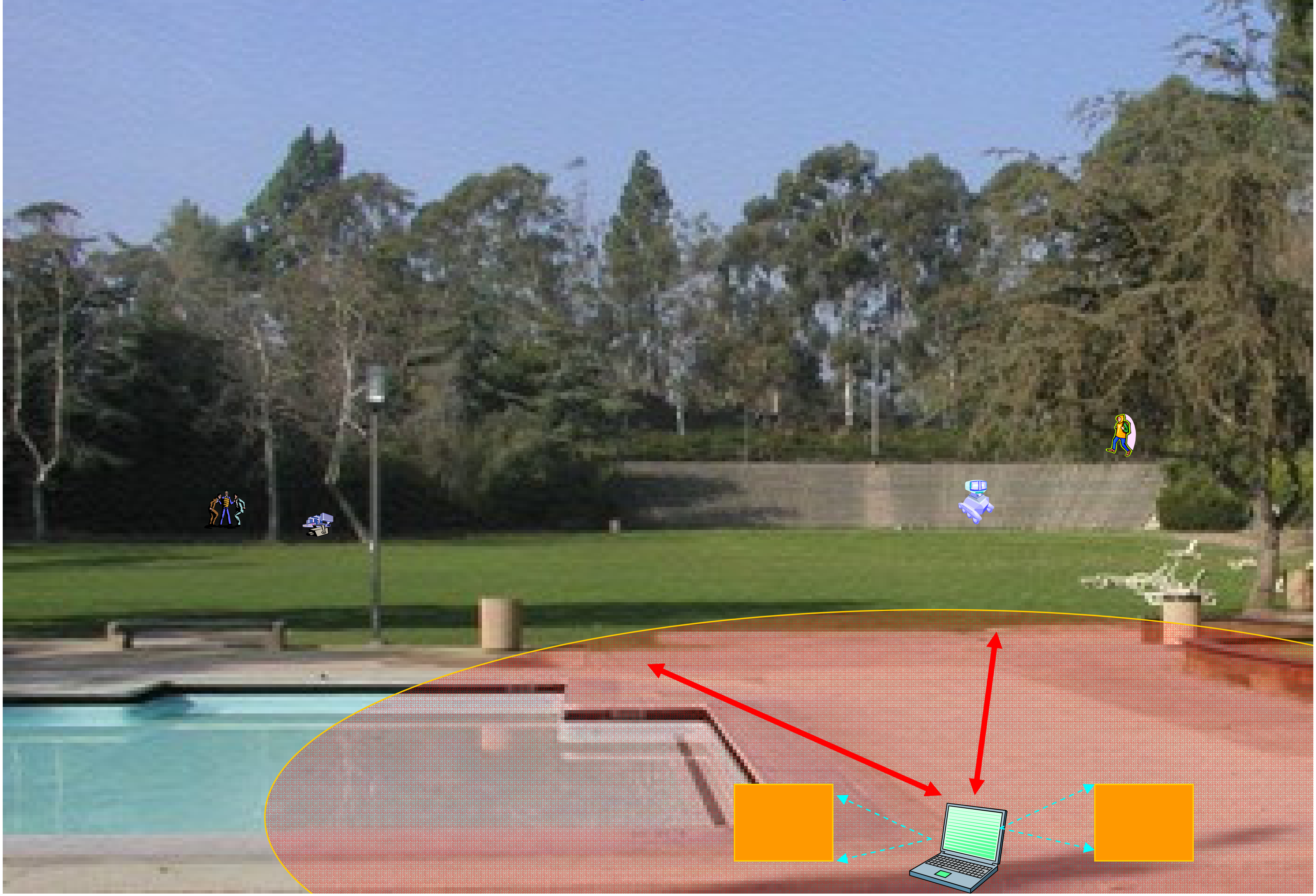


4. Another robot moves in to re-connect



5. **Another suspect activity detected**

6. Second robot moves out to investigate, breaking the network



Bring in the Blimp to reconnect

View From the Blimp

QuickTime™ and a
TechSmith EnSharpen decompressor
are needed to see this picture.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Challenge: Ad Hoc Scalable routing

- Tens of thousands of nodes
- Nodes move in various patterns
- QoS communications requirements
- Hostile environment – jamming

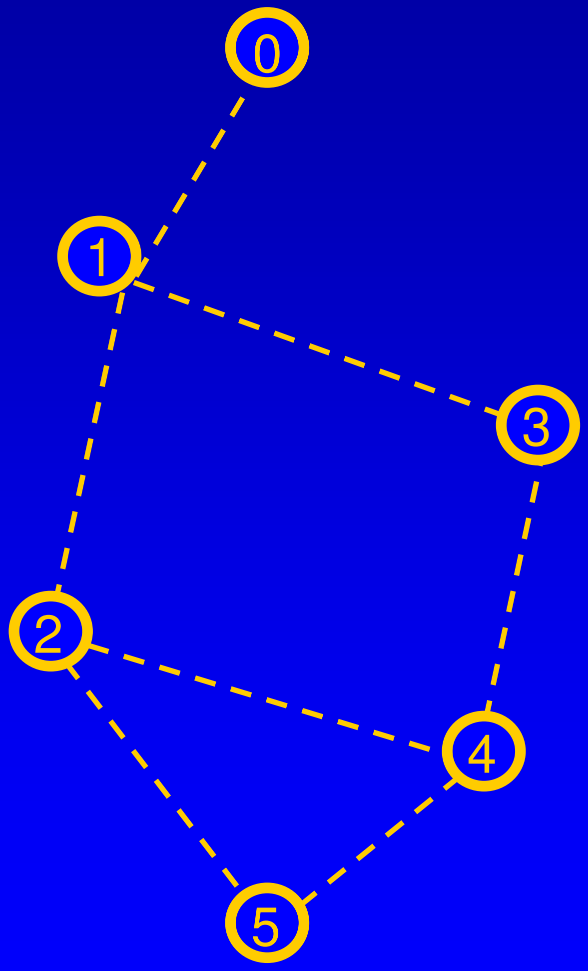
Current ad hoc routing solutions

- Proactive routing (eg, DSDV, Optimal Links State Routing - OLSR)
- On demand routing (DSR, AODV)
- Explicit hierarchical routing

Distance Vector (DV)

Routing table at node 5 :

Destination	Next Hop	Distance
0	2	3
1	2	2
É	É	É



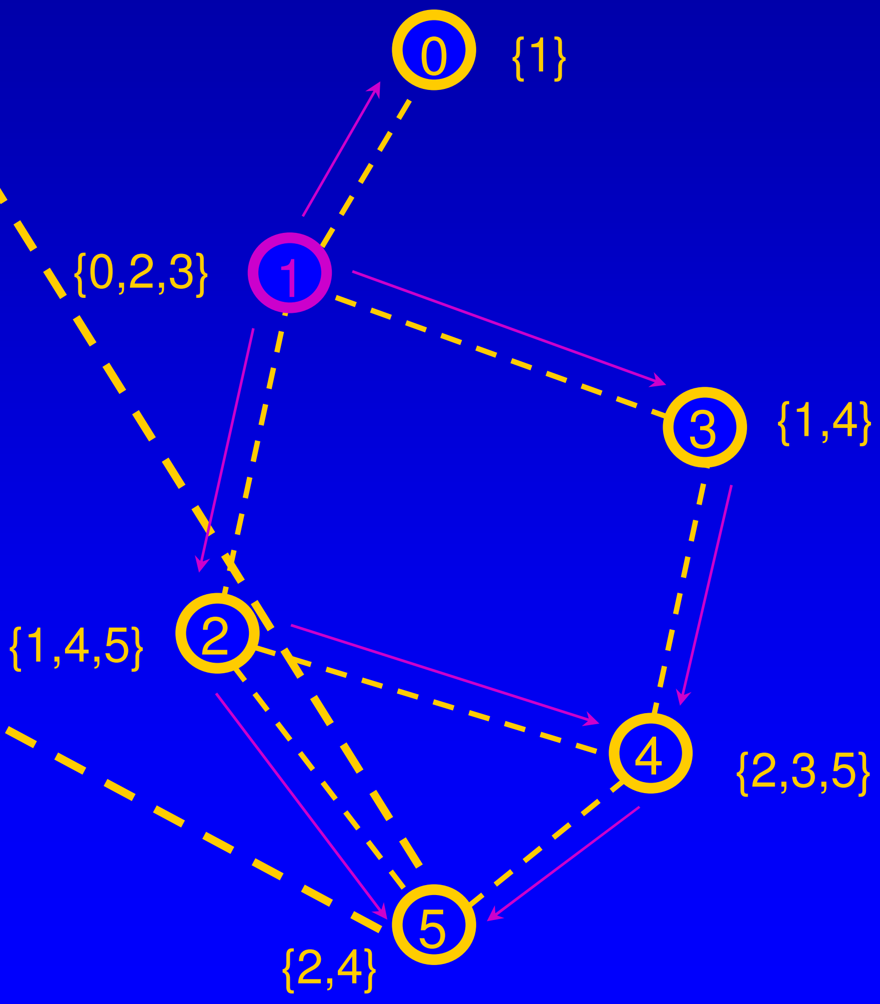
Tables grow linearly with # nodes

Control O/H grows with mobility and size

Link State Routing (OSPF)

- At node 5, based on the link state pkts, topology table is constructed:

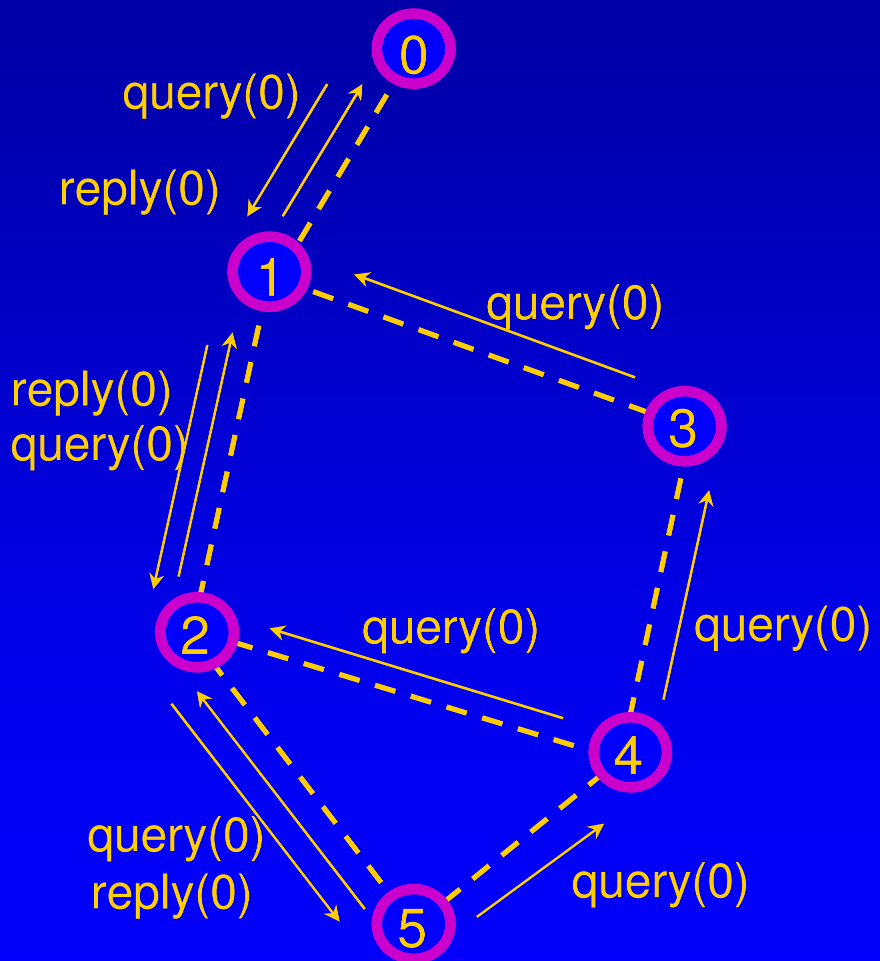
	0	1	2	3	4	5
0	1	1	0	0	0	0
1	1	1	1	1	0	0
2	0	1	1	0	1	1
3	0	1	0	1	1	0
4	0	0	1	1	1	1
5	0	0	1	0	1	1



- Dijkstra's Algorithm can then be used for the shortest path

O/H grows linear with N

On-demand Routing



Advantages:

- no periodic routing O/H

- no large routing tables

Limitations:

-**mobility and calls trigger flood-searches**

-**does not scale to large networks**

Approach #1: Making Link State "more" scalable

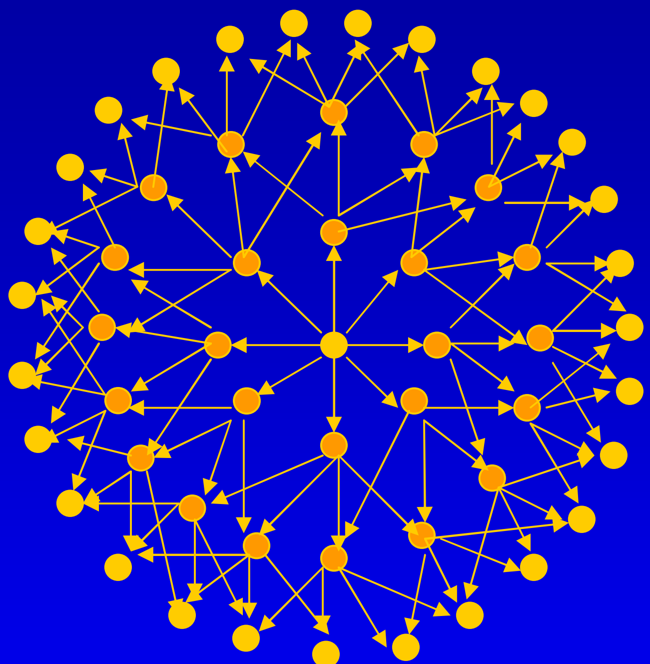
- **Link State explodes because of Link State update overhead**
- **Question: how can we reduce the O/H?**
- **Answer: "Topology reduction"**
  - (1) if the network is "dense", use fewer forwarding nodes
  - (2) if the network is dense, advertise only a subset of the links

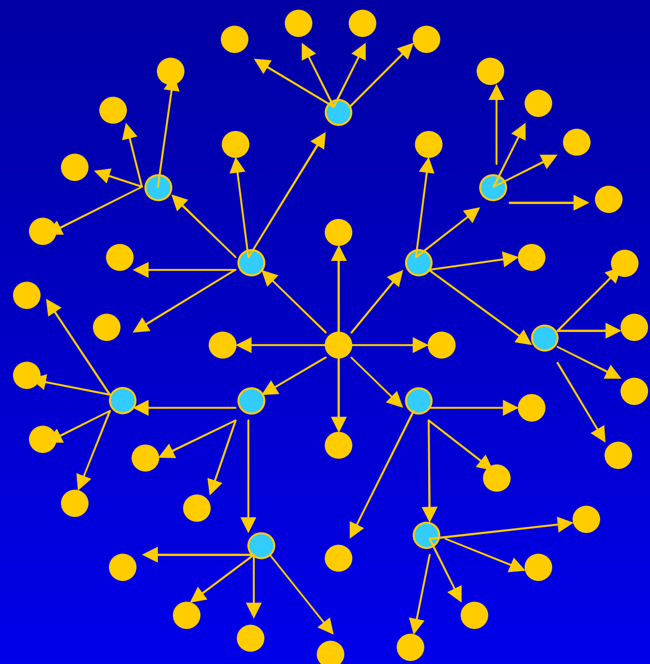
- **Result: IETF MANET OLSR : Optimal Link State Routing**

OLSR Overview

- **In LSR protocol a lot of control messages unnecessarily duplicated**
- **In OLSR only a subset of neighbors (*Multipoint Relay Selectors)* retransmit control messages**
  - Reduce flooding overhead
- **OLSR retains all the advantages of LSR:**
  - Does not depend upon any central entity;
  - Tolerates loss of control messages;

Optimized Link state routing (OLSR)





24 retransmissions to diffuse a message up to 3 hops

11 retransmission to diffuse a message up to 3 hops

Retransmission node

Retransmission node

Multipoint Relays (MPR) cont.

- Every node keeps a table of routes to all known destination through its MPR nodes
- Every node periodically broadcasts list of its MPR Selectors (Reduced Link State list)
- Upon receipt of MPR information each node recalculates and updates routes to each known destination
- Route is a sequence of hops through MPR's from source to destination
- All the routes are bidirectional

Neighbor sensing

- **Each node periodically broadcasts Hello message:**
  - List of neighbors with bidirectional link
  - List of other known neighbors. (If node sees itself in this list it adds the sender to neighbors with bidirectional link)
- **Hello messages permit each node to learn topology up to 2 hops**
- **Based on Hello messages each node selects its set of MPR's**

Example of neighbor table

One-hop neighbors

Neighbor's id	State of Link
2	Bidirectional
3	Unidirectional
4	MPR
…	…

Two-hop neighbors

Neighbor's id	Access through
6	2
7	1
15	3
…	…

Also every entry in the table has a timestamp, after which the entry in not valid

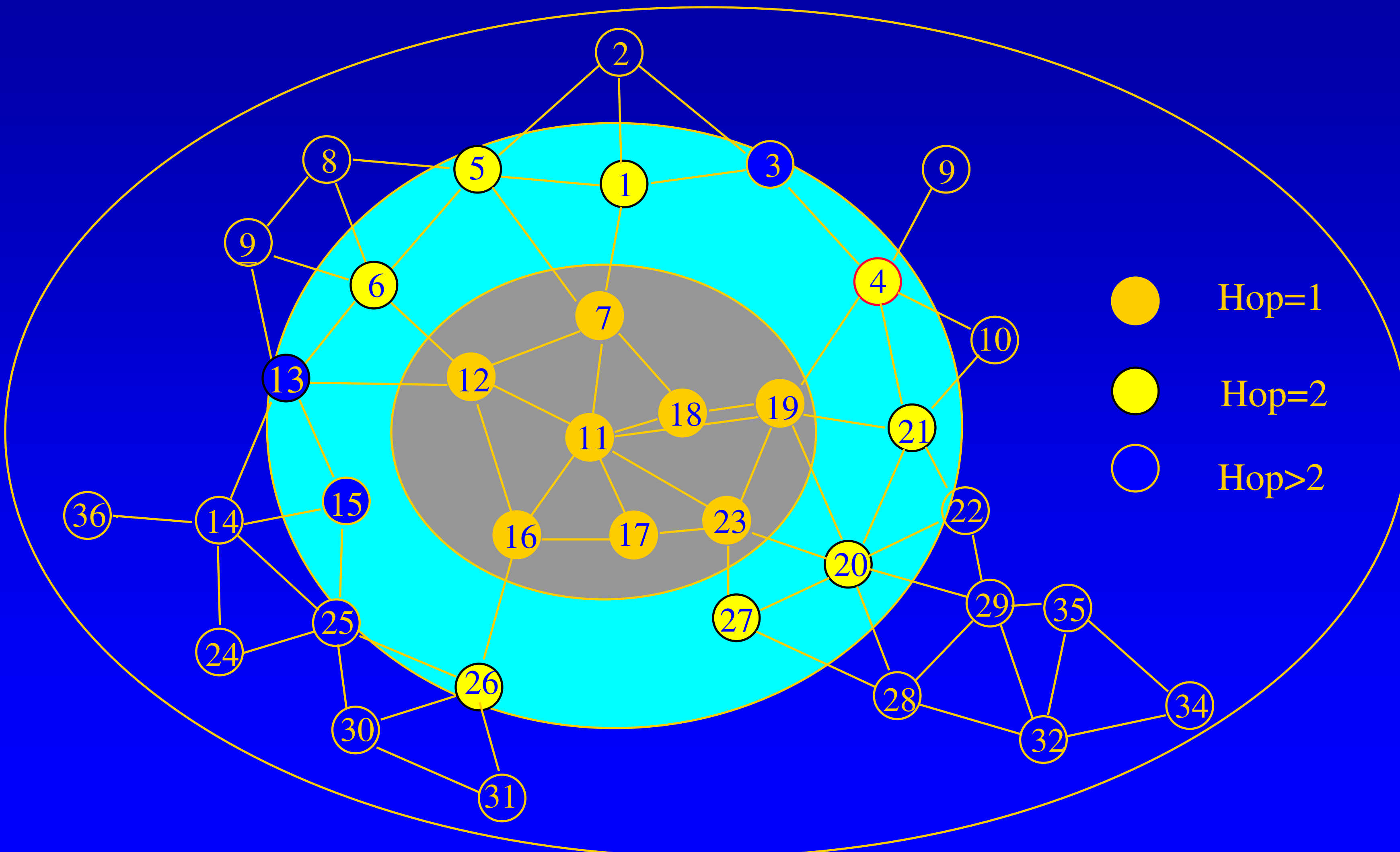
MPR Selection

- **MPR set need not to be optimal**
  - hard problem to find an optimal set
- **Greedy heuristic:**
  - select node with best 2-hop cover increment
- **MPR is recalculated after a change in one-hop or two-hops neighborhood topology**

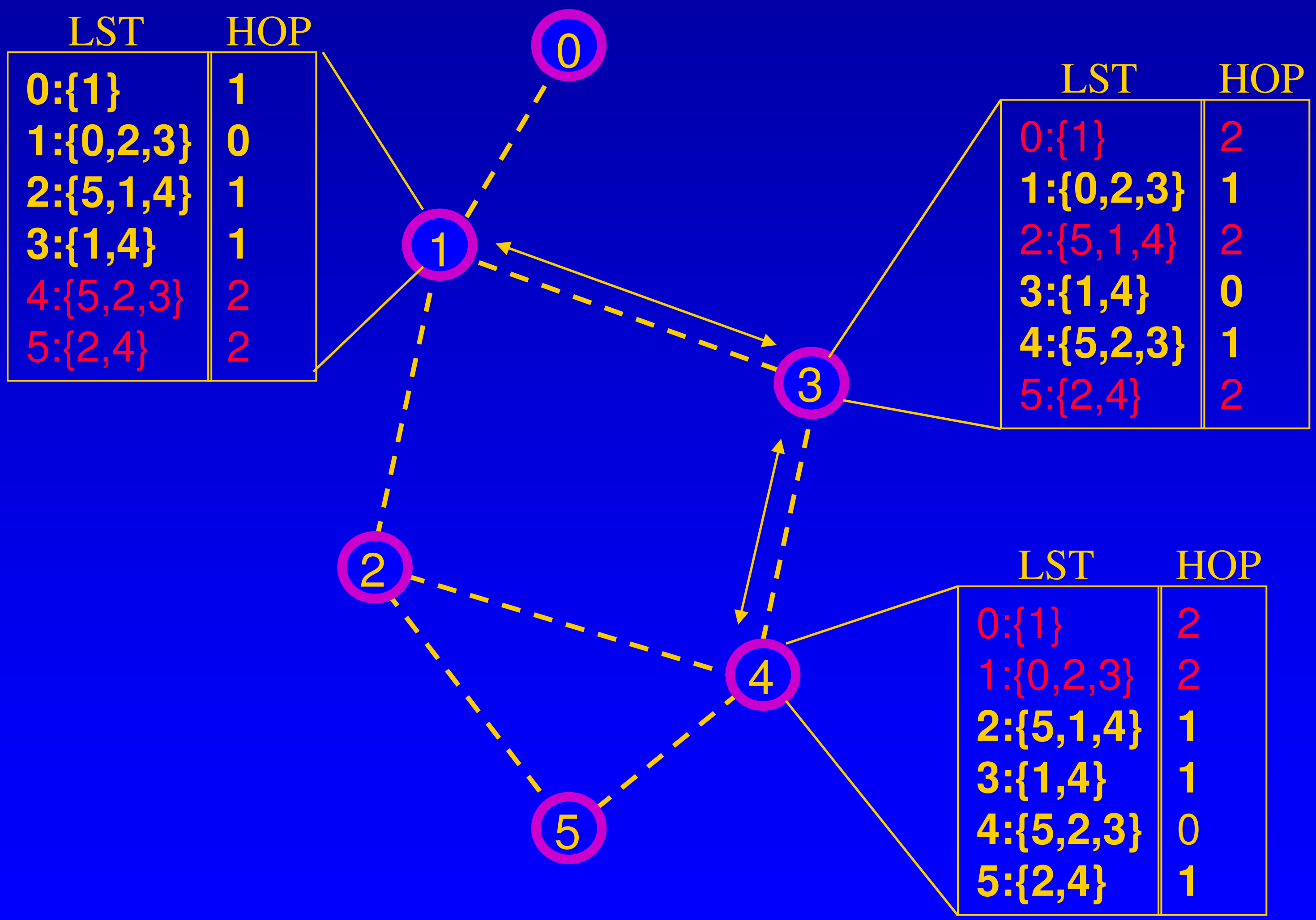
Another approach: Fisheye State Routing

- **Topology data base at each node**
  - similar to link state (e.g., OLSR)
- **Routing update frequency decreases with distance to destination**
  - Higher frequency updates within a close zone and lower frequency updates to a remote zone
  - Highly accurate routing information about the immediate neighborhood of a node; progressively less detail for areas further away from the node

Scope of Fisheye



Message Reduction in FSR



Where do we stand?

- OLSR can dramatically reduce the “state” sent out on update messages
- It effectively reduces the “working topology” in “dense” networks.
- Fisheye concept can further reduce update O/H
- However, the state still grows with O(N)
- We cannot handle large scale nets in the thousands of nodes

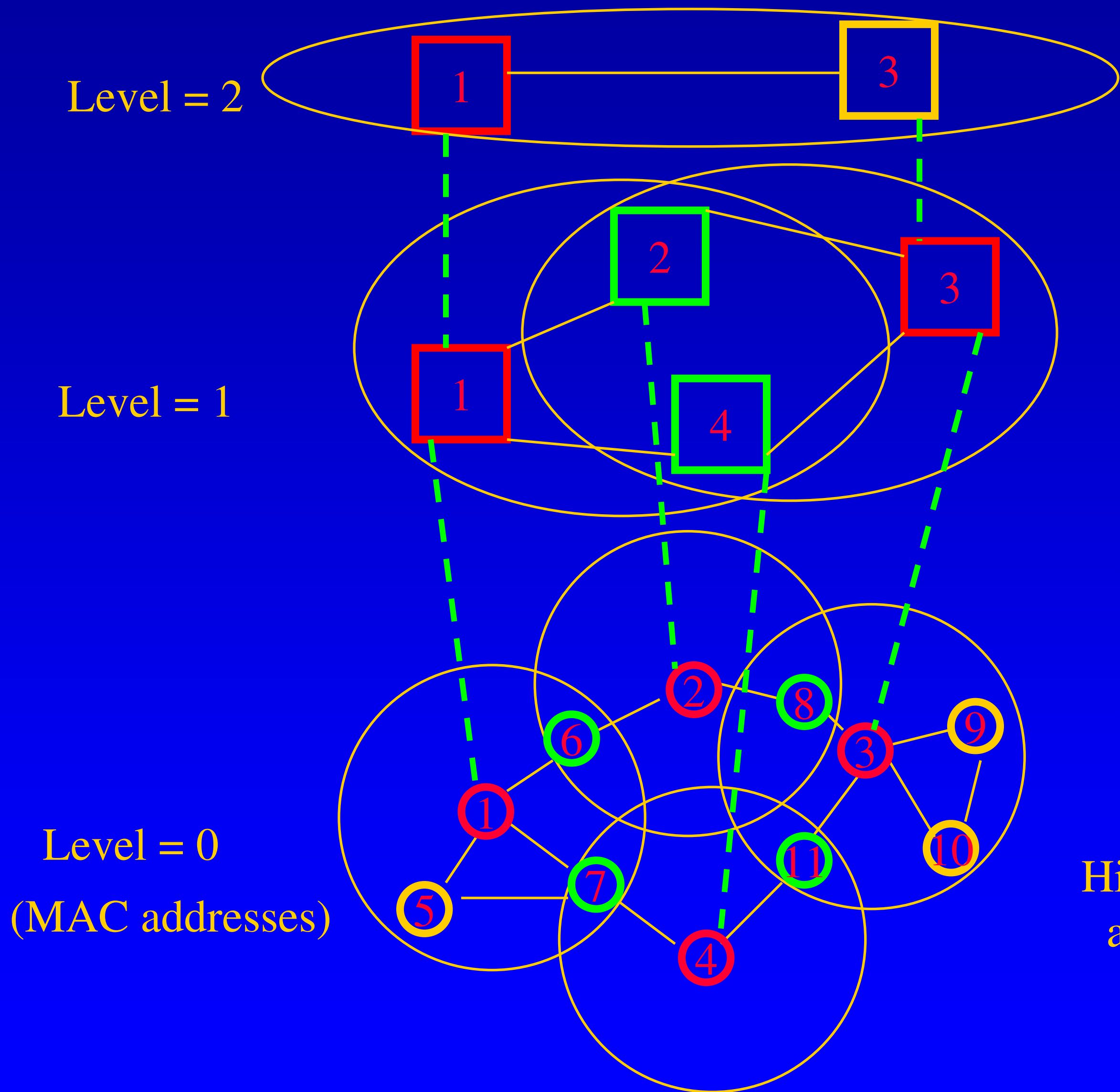
- What to do?

APPROACH: use hierarchical routing to reduce BOTH table size and table update overhead

Hierarchical State Routing (HSR)

- **Loose hierarchical routing in Internet**
- **Main challenge in ad hoc nets: maintain/update the hierarchical partitions in the face of mobility**
- **Solution: distinguish between "physical" partitions and "logical" grouping**
  - physical partitions are based on geographical proximity
  - logical grouping is based on functional affinity between nodes (e.g., tanks of same battalion, students of same class)
- **Physical partitions enable reduction of routing overhead**
- **Logical groupings enable efficient location management strategies using Home Agent concepts**

Hierarchical Routing - 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>

HSR - logical partitions and location management

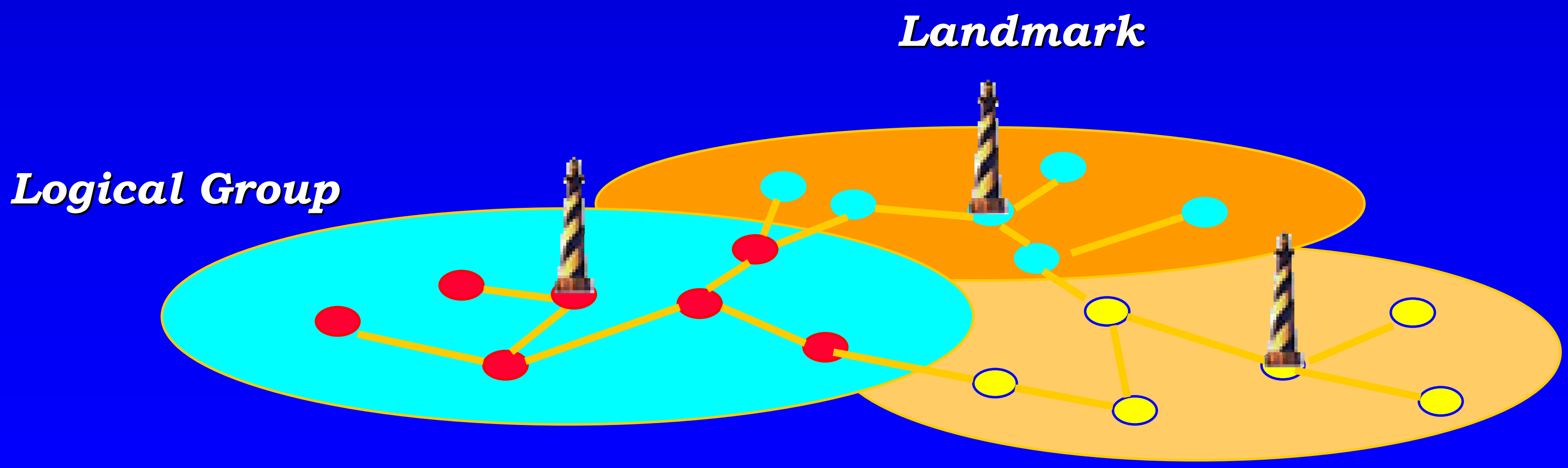
- **Logical (IP like) type address** <*subnet,host*>
  - Each subnet corresponds to a particular user group (e.g., tank battalion in the battlefield, search team in a search and rescue operation, etc)
  - logical subnet spans several physical clusters
  - Nodes in same subnet tend to have common mobility characteristic (i.e., locality)
  - logical address is totally distinct from MAC address

HSR - logical partitions and location management (cont'd)

- **Each subnetwork has at least one Home Agent to manage membership**
- **Each member of the subnet registers its own hierarchical address with Home Agent**
  - periodical/event driven registration; stale addresses are timed out by Home Agent
- **Home Agent hierarchical addresses propagated via routing tables; or queried at a Name Server**
- **After the source learns the destination's hierarchical address, it uses it in future packets**

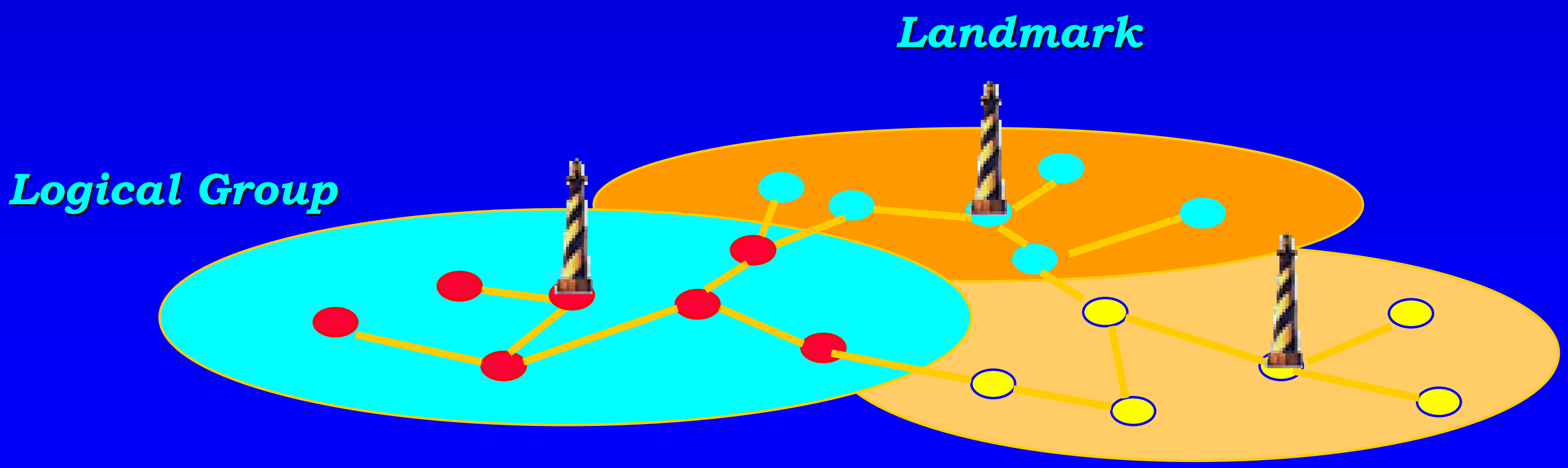
Our Approach: don't fight mobility - use it!

- Main assumption: nodes move in groups
  - Groups are predefined or dynamically recognized
  - Node address = < group ID , Host address>
  - Landmark elected in each group
  - Landmarks advertisements maintain the landmark overlay



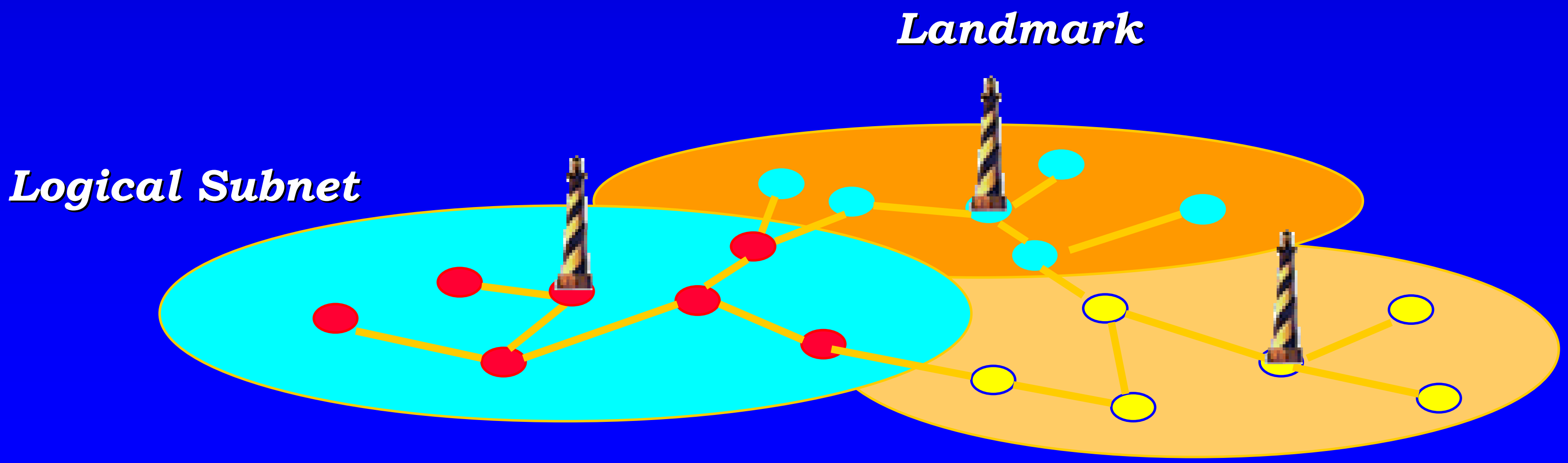
LANMAR Routing

- **Builds upon existing MANET protocols**
  - **(1) "local " routing algorithm that keeps accurate routes within local scope < k hops (e.g., OLSR)**
  - **(2) Landmark routes advertised to all mobiles using DSDV**



Landmark Routing In action

- **Packet Forwarding:**
  - A packet to "local" destination is routed directly using local tables
  - A packet to remote destination is routed to Landmark corresponding to logical addr.
  - Once the landmark is "in sight", the direct route to destination is found in local tables.
- **Benefits: low storage, low update traffic O/H**



Dynamic Group Formation

QuickTime™ and a
Microsoft Video 1 decompressor
are needed to see this picture.

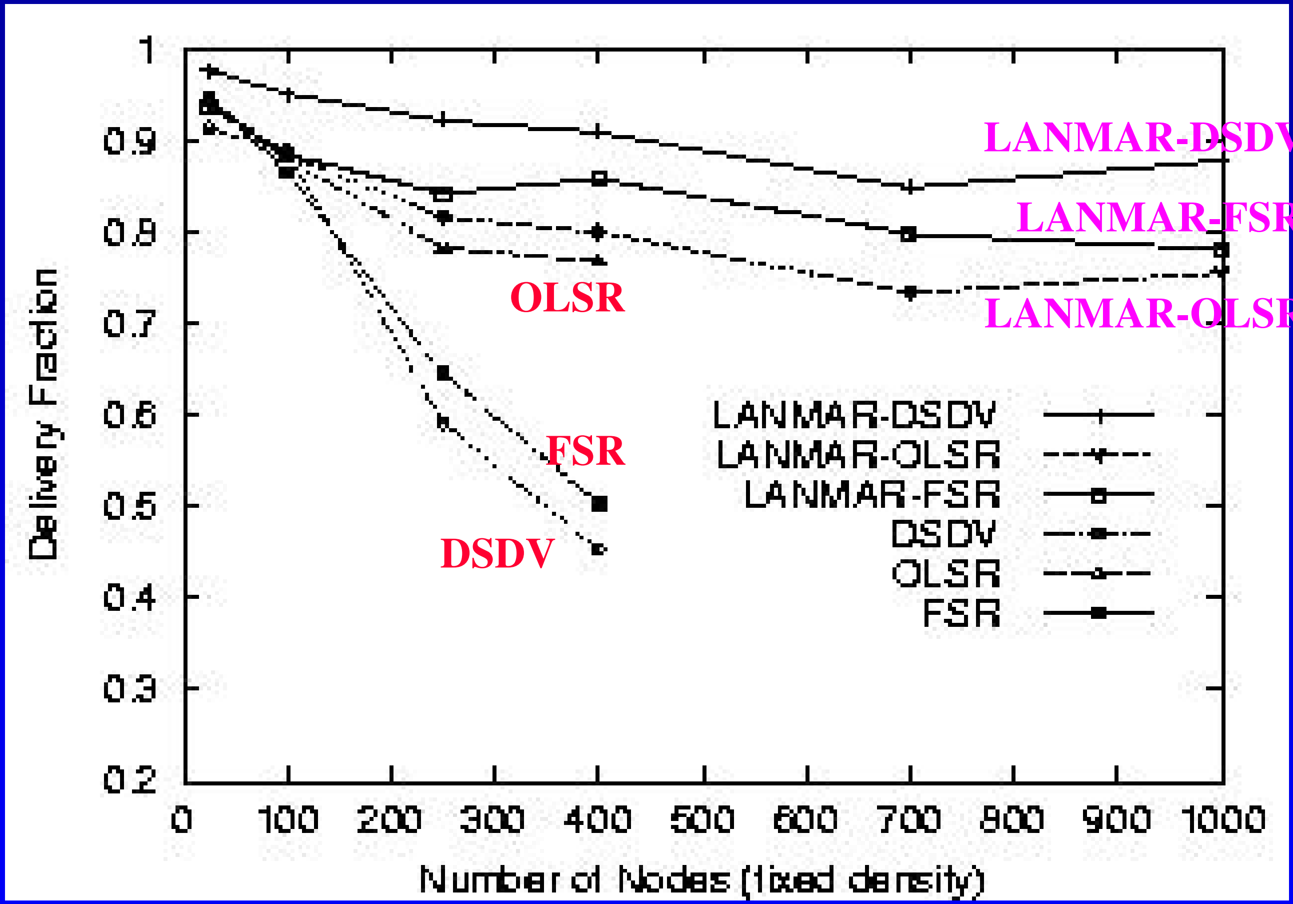
LANMAR "Overlay" enhances MANET routing schemes

We compare:

(a) MANET routing schemes: DSDV, OLSR and FSR; and

(b) same MANET schemes, BUT with LANMAR overlay on top

Delivery Ratio



- •DSDV and FSR decrease quickly when number of nodes increases
- •OLSR generates excessive control packets, cannot exceed 400 nodes

QoS support in LANMAR

- **Inter swarm: Each Landmark advertises Av Bdw "within its swarm" into the net**
- **Within a swarm:**
  - A time cycle is defined: real time sources transmit first, then best effort sources
  - Landmark maintain cycle and schedules real time sources
  - Real time sources follow each other and broadcast to all nodes in the swarm (for robust communications)
  - Data sources go next and transmit until the end of cycle
  - Data: Low latency sources have priority over best effort

Physical, Mobile Backbone Overlay

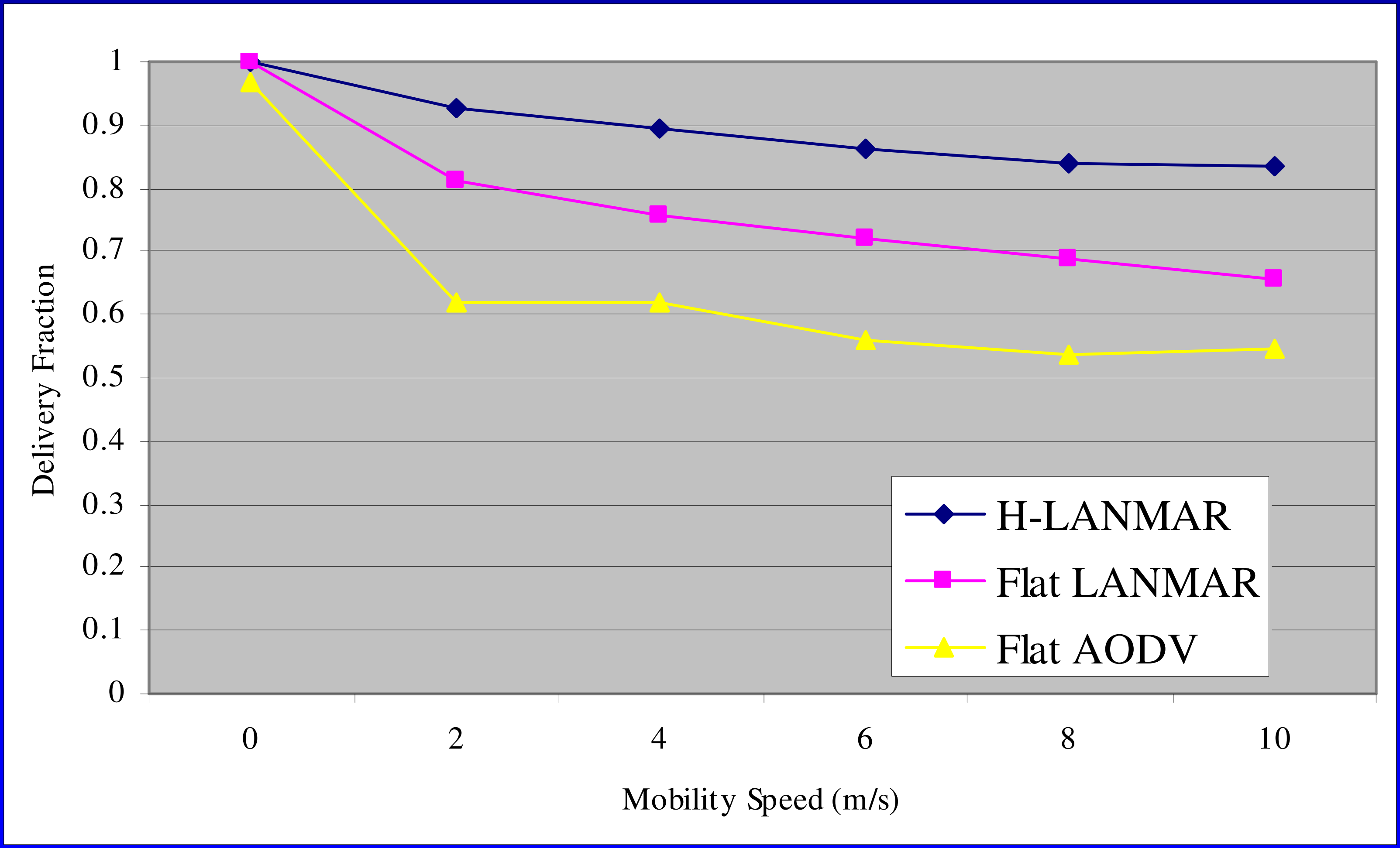
- Landmark Overlay provides routing scalability
- However the network is still flat - paths have many hops → poor TCP and QoS performance!!
- Solution: Mobile Backbone Overlay
- MBO is a physical overlay – ie long links
- MBO provides performance scalability
- LANMAR extends "transparently" to the MBO

Backbone Node Automatic Deployment

- **Objectives**
  - Robust and autonomous backbone network maintenance
  - Uniform distribution to cover the field
- **Approach**
  - Dynamic backbone node election: Deploy redundant backbone capable nodes and select a few
  - Backbone node automatic placement: Relocate backbone nodes from dense to sparse regions

Variable Speed with 1000 nodes

Delivery fraction while increasing mobility speed



The next challenge : “commodity” ad hoc networks

- **Military and civilian (disaster recovery) and hoc networks are motivated by:**
  - Instant deployment
  - Lack of infrastructure
  - Large scale
  - Very specialized mission/function
  - Cost not most critical issue
- **Commercial, “commodity” ad hoc networks have different requirements**
  - Cost is an issue (eg, ad hoc vs W-LAN vs 2.5 G)
  - Connection to Internet is desirable (sometimes, a “must”)
  - Often, small scale
  - Multipurpose networking

- **Enter “opportunistic ad hoc networking**

Vision: Opportunistic Ad Hoc Networking

“Commodity” ad hoc networks will not “happen” as isolated, self configured nets

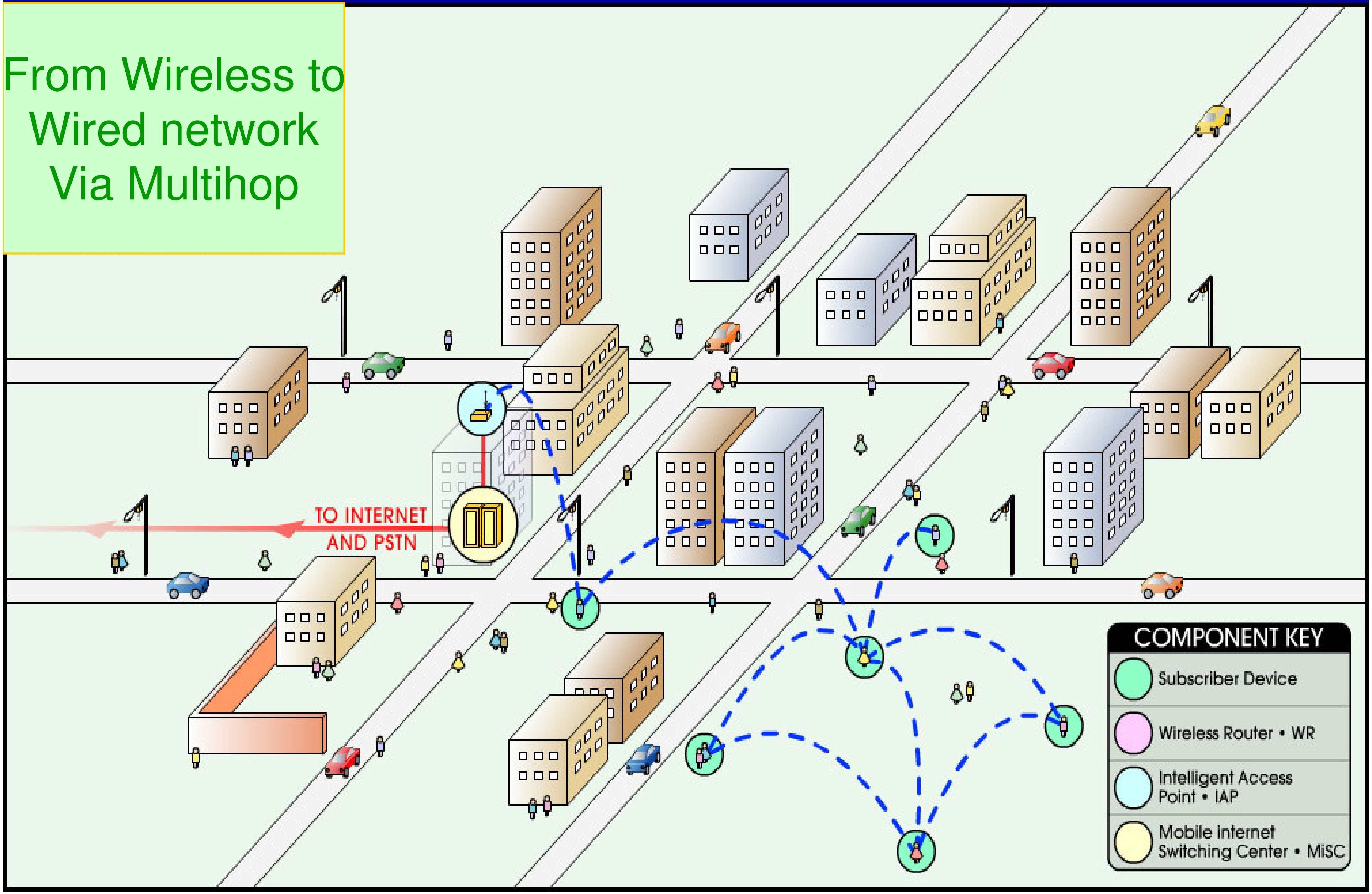
Rather, they will coexist with the “infrastructure”

Ad hoc extensions (of Wireless Internet)

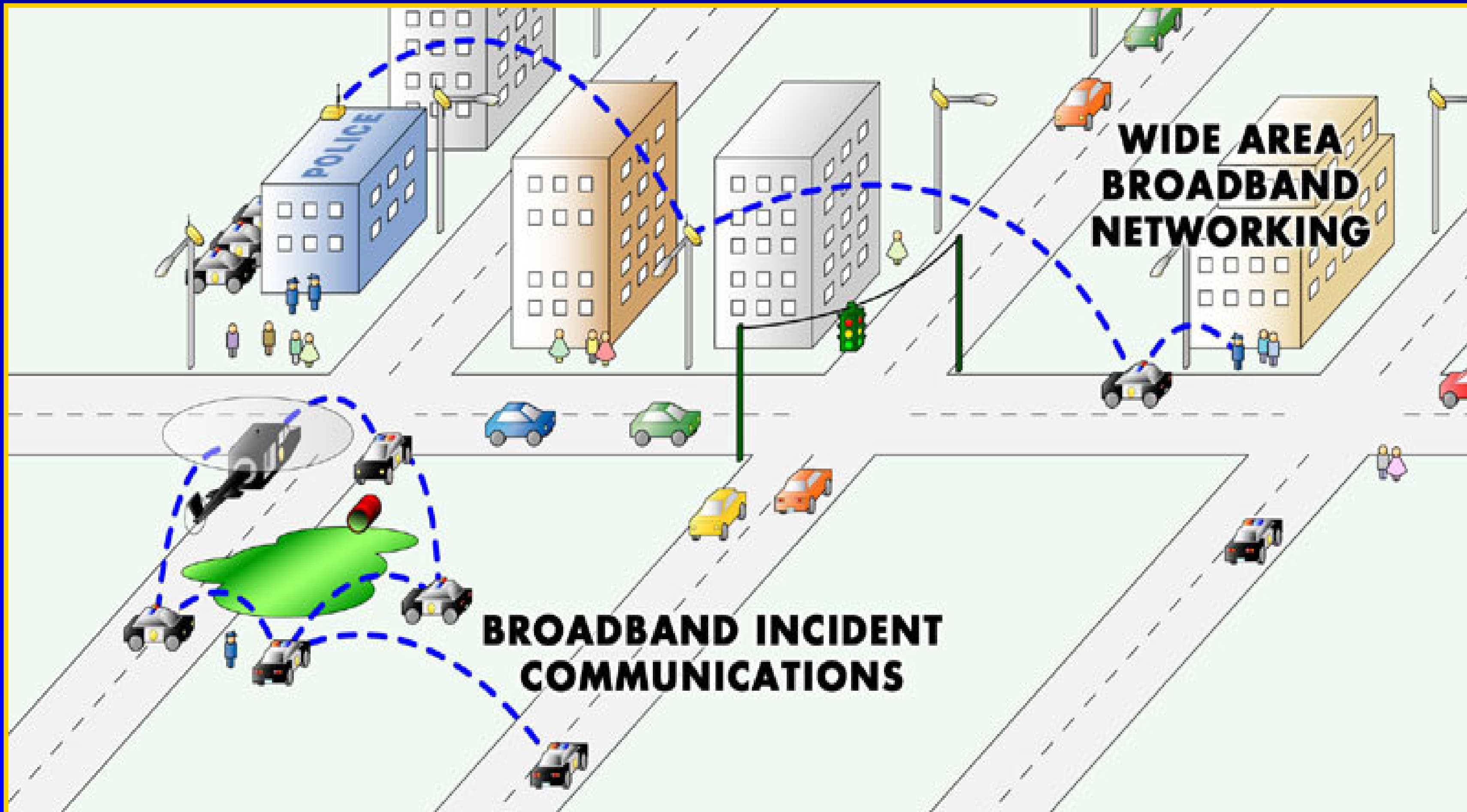
- Indoor W-LAN extended coverage
- Indoor network appliances (Bluetooth, Home RF)
- Hot spots (Mesh Networks)
- Campus, shopping mall, etc
- Aircraft cabins
- **Urban vehicle grid**

Urban "opportunistic" ad hoc networking

From Wireless to
Wired network
Via Multihop



Ad Hoc networking for Accident Recovery



Urban Ad Hoc net in action: Safe Driving

Vehicle type: Cadillac XLR
Curb weight: 3,547 lbs
Speed: 65 mph
Acceleration: **- 5m/sec^2**
Coefficient of friction: .65
Driver Attention: Yes
Etc.

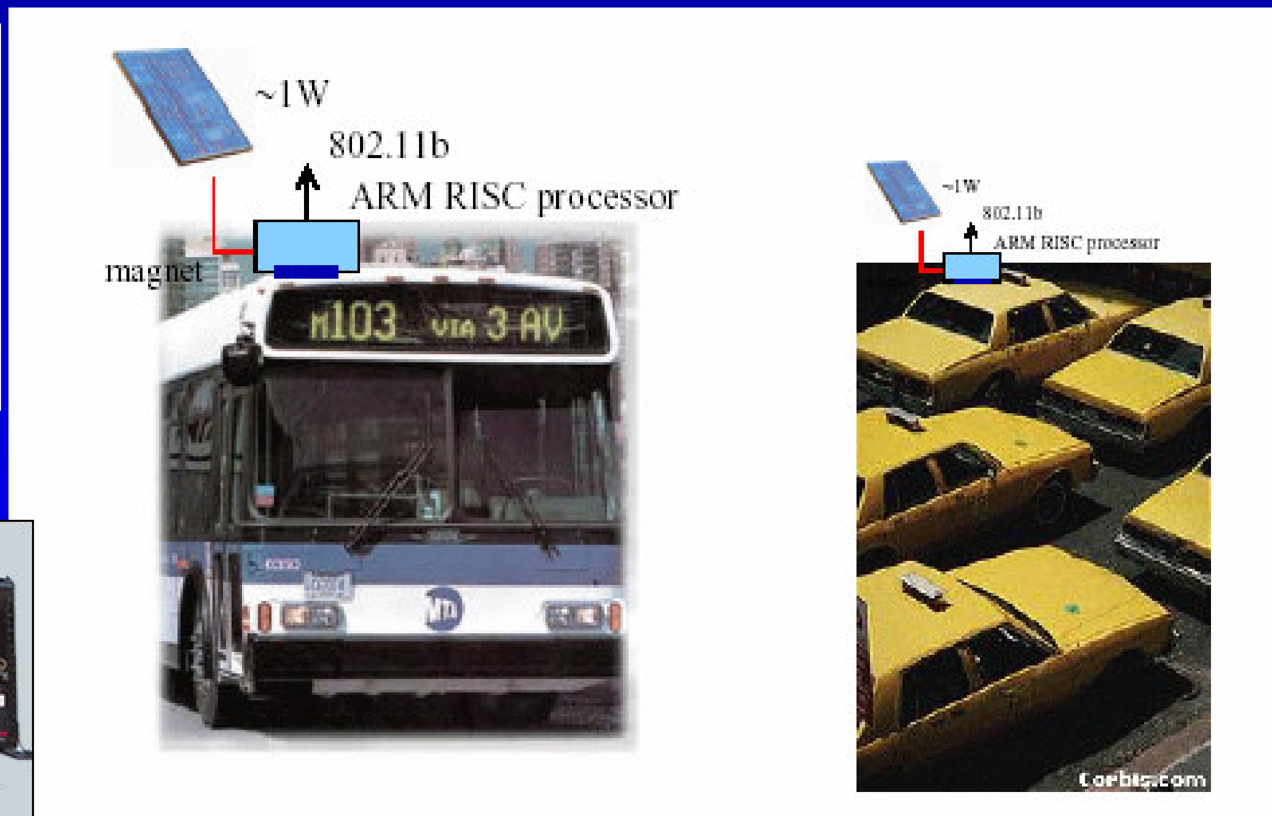
Vehicle type: Cadillac XLR
Curb weight: 3,547 lbs
Speed: 75 mph
Acceleration: **+ 20m/sec^2**
Coefficient of friction: .65
Driver Attention: Yes
Etc.

Vehicle type: Cadillac XLR
Curb weight: 3,547 lbs
Speed: 45 mph
Acceleration: **- 20m/sec^2**
Coefficient of friction: .65
Driver Attention: **No**
Etc.

Vehicle type: Cadillac XLR
Curb weight: 3,547 lbs
Speed: 75 mph
Acceleration: **+ 10m/sec^2**
Coefficient of friction: .65
Driver Attention: **Yes**
Etc.

Opportunistic piggy rides in the urban mesh

Pedestrian transmits a large file in blocks to the passing cars, busses
The carriers deliver the blocks to the hot spot



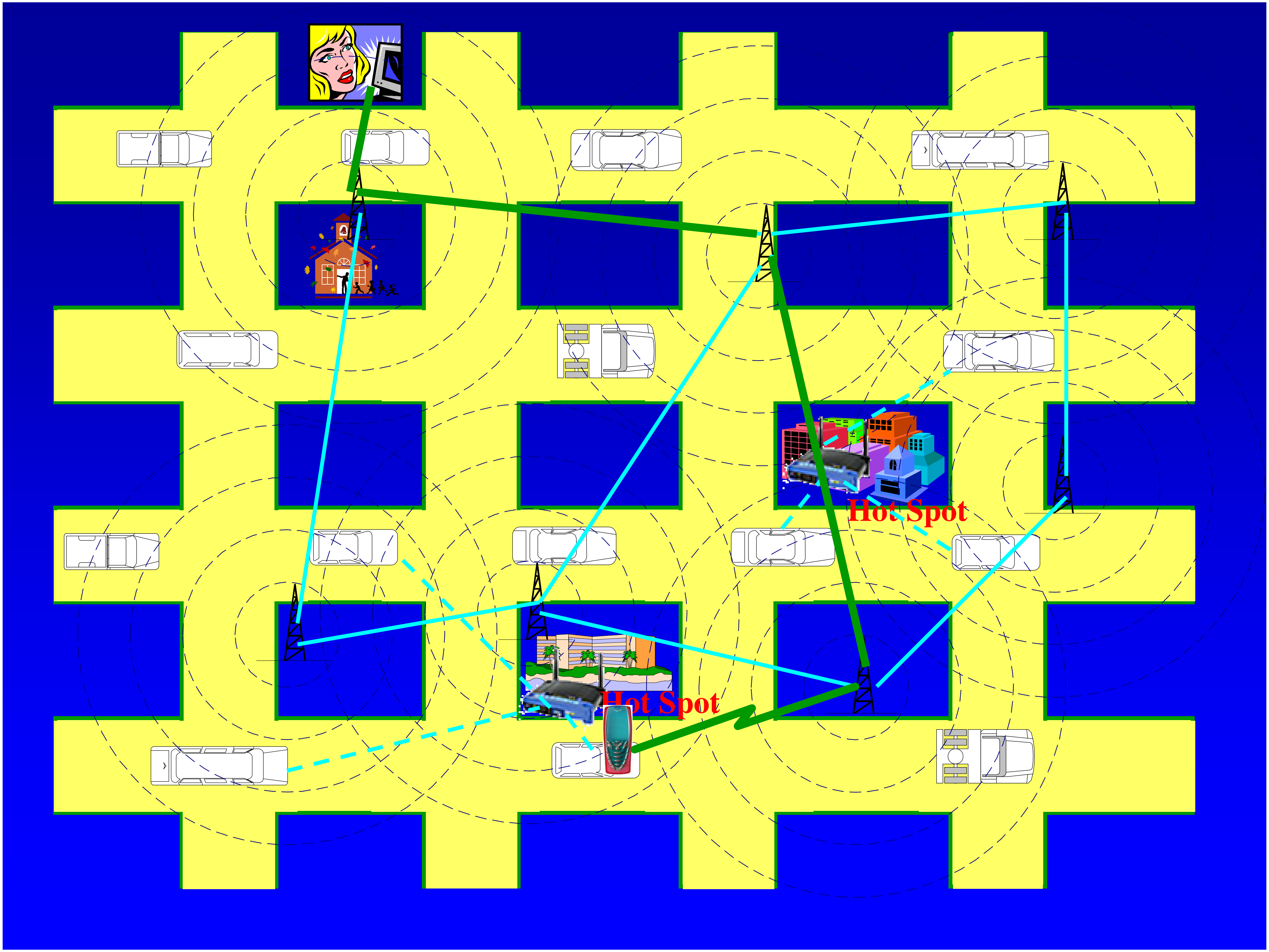
"Data Mule" concept

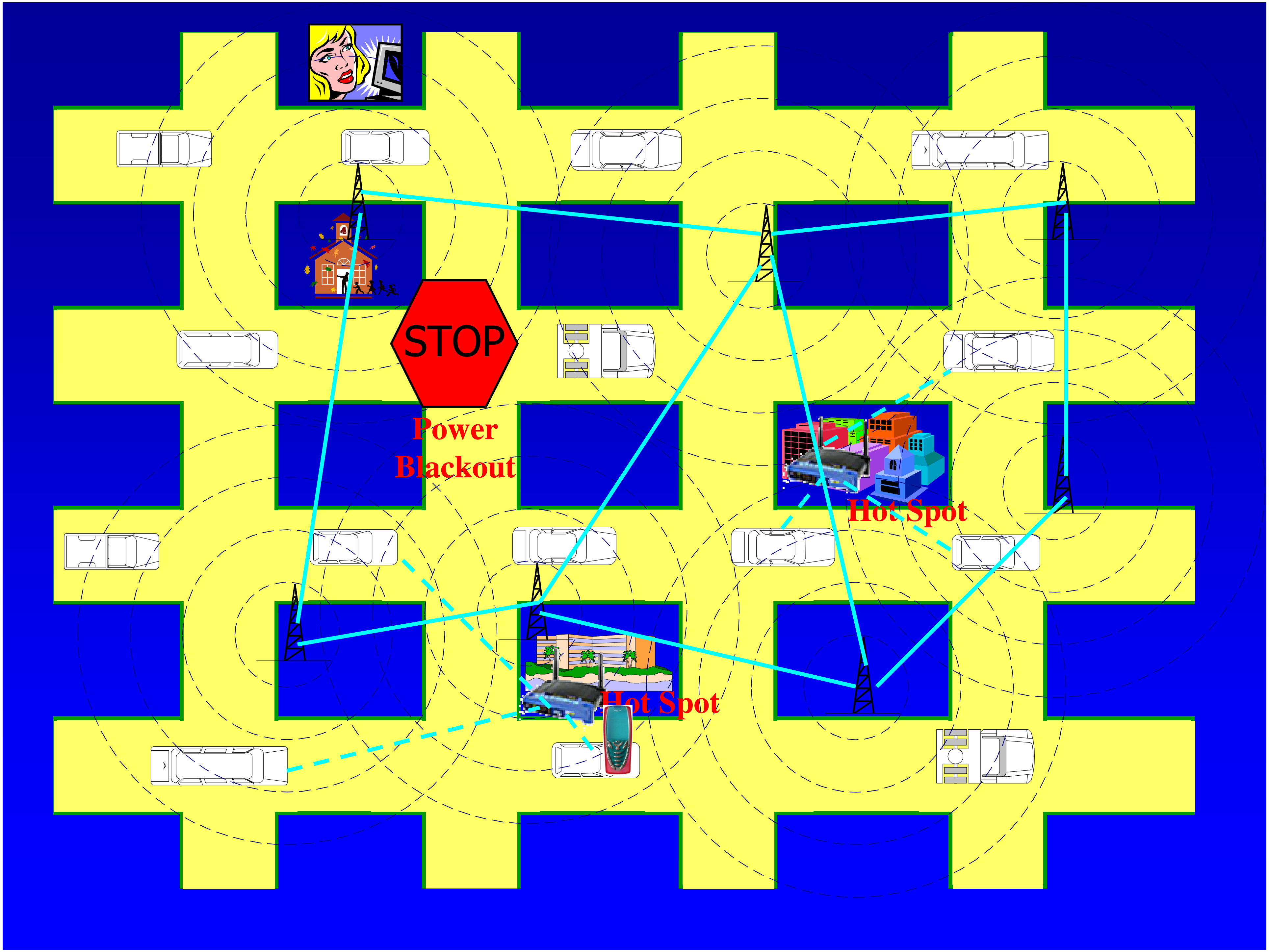
Other opportunistic examples

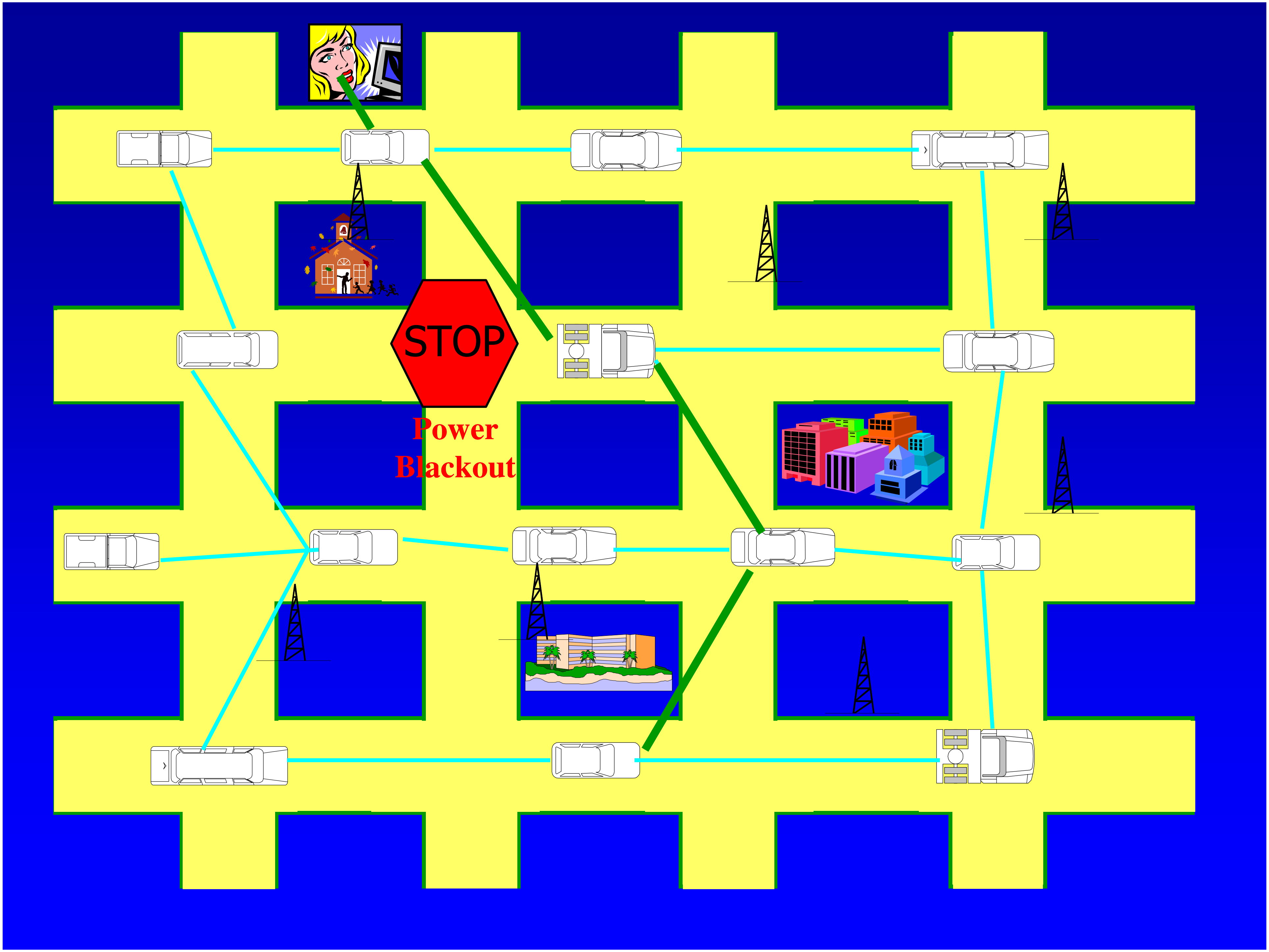
- Extend the home Wireless LAN with an ad hoc net to reach the backyard
- Daisy-chain friends to a 2.5G connection
- Interconnect patients in a hospital with low power ad hoc LAN to avoid interference
- Connect cars in the city with an urban ad hoc grid (for driving safety, environment awareness, kid games, etc)
- Note: while primary goal may have been inexpensive access to Internet, eventually these ad hoc nets will take on a life of their own!

The Urban Grid Vision

- **Many wireless options available in the urban grid**
  - Cellular (3G)
  - Mesh and Hot Spots
  - Car to car ad hoc networking
- **These options interwork to provide the best service for each (different) requirement**
- **Suppose the "fixed" infrastructure fails (black out, chemical disaster, terrorist attack)**
- **The car-to-car network will survive (as long as the batteries will..)**
- **Could be the first line of protection in case of major failure**


Hot Spot
Hot Spot


STOP
Power Blackout
Hot Spot
Hot Spot


STOP
Power Blackout

CarTorrent : A Swarming Protocol for Vehicular Networks

You are driving to Vegas
You hear of this new show on the radio
Video preview on the web (10MB)

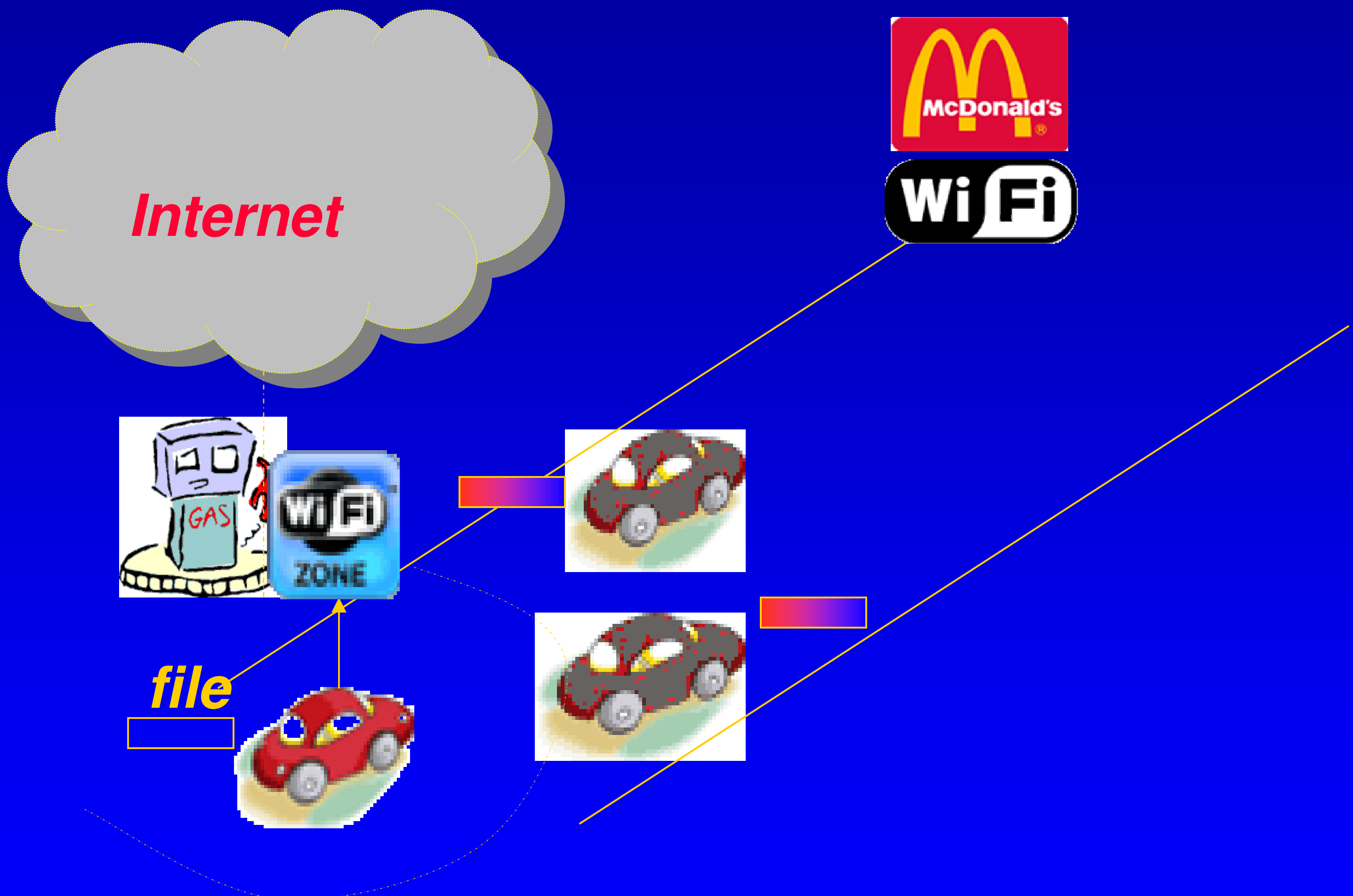
But …

Problem: Everyone crossing the billboard thinks the same!!

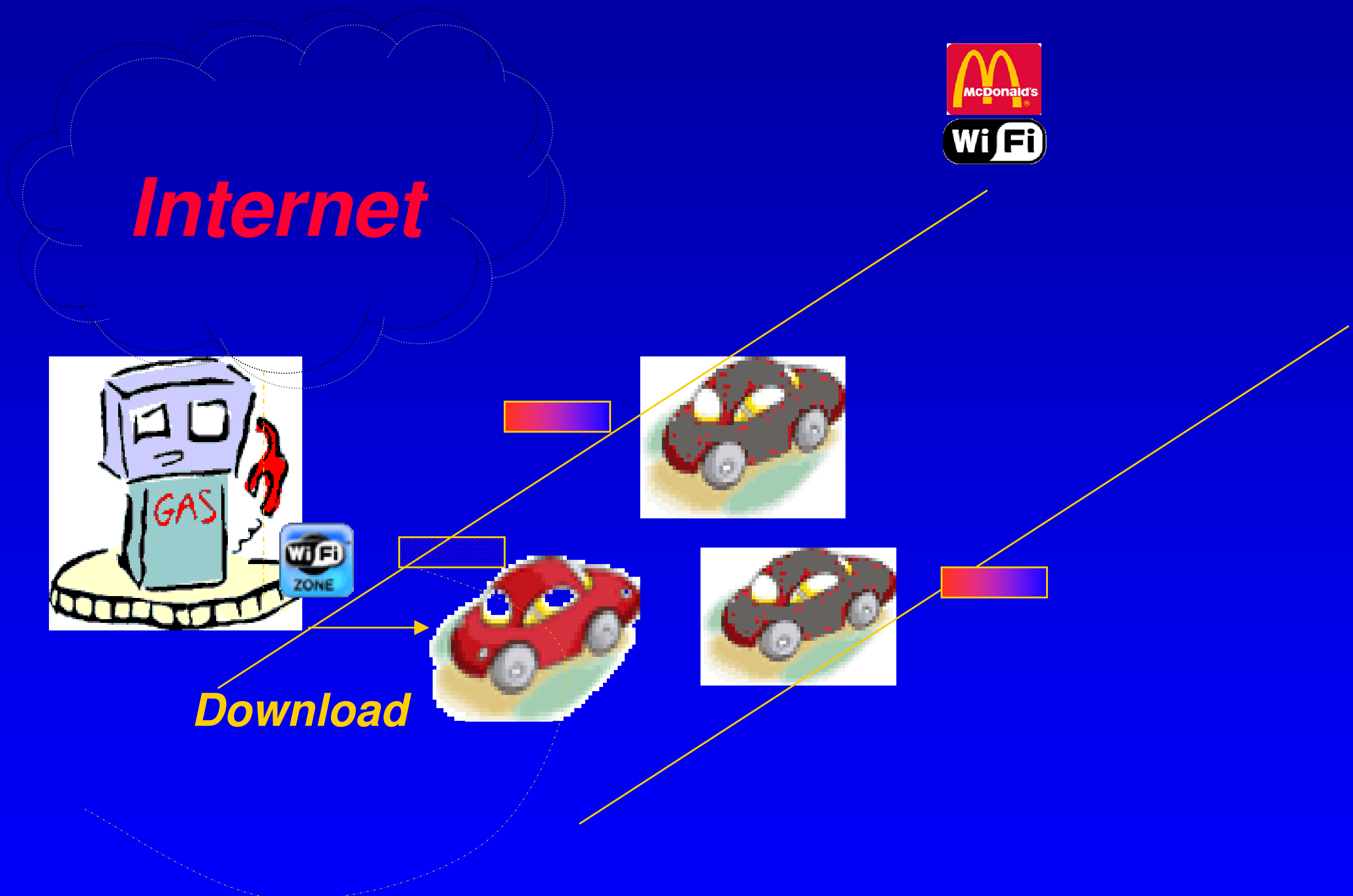
Consequence: Congestion !!

Solution: Co-operative Downloading, swarming protocol for Vehicular Network

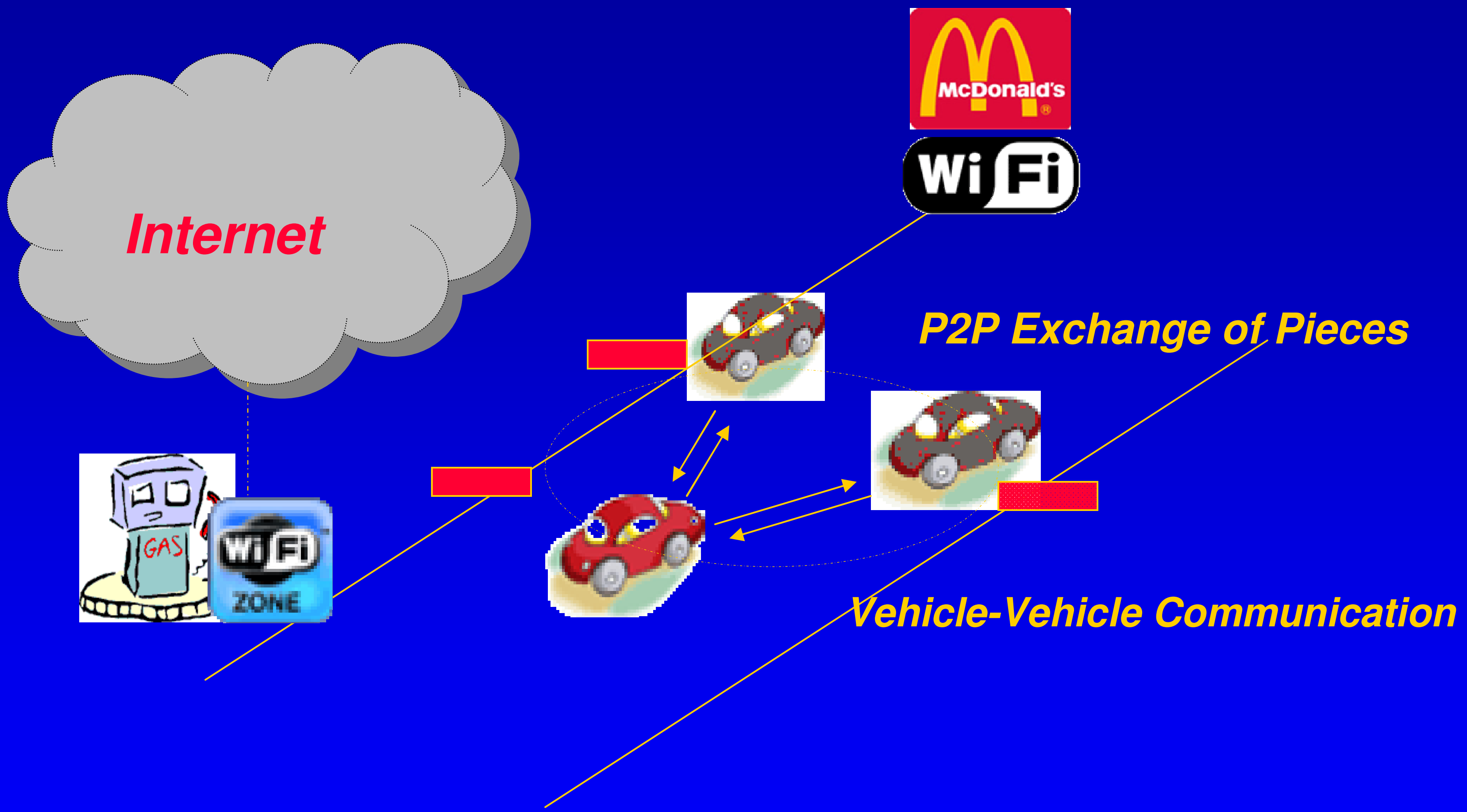
Highway Infostation download



Partial download from Infostation



Co-operative P2P Download



Ad Hoc Nets: the Future

- **Commercial ad hoc networks will happen first as "opportunistic extensions" of the wireless infrastructure (3G, WLANs, Satellites, sensor fields, etc)**
- **Ad hoc nets will play an important role in the 4G wireless generation**
- **Aggressive research is critical for the smooth integration into 4G:**
  - P2P protocols
  - Soft handoff
  - Security
  - Incentives for 3rd party store-and- forwarding
  - etc

The End

Thank You!