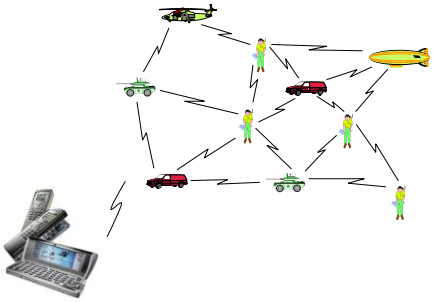
# Topic 9:

# Ad hoc Network (Mesh Network)

*Professor Eric Hsiaokuang Wu*

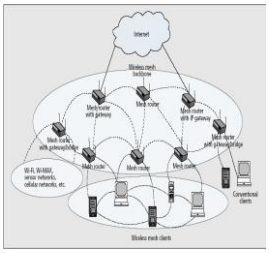
*2010*





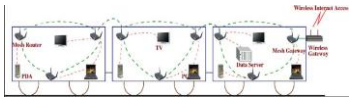


## Wireless Mesh Network.



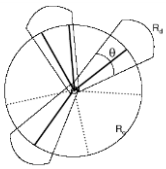


## Mesh Network Scenario





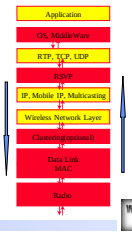
## Multi-channel, Multi-Radio, Directional Antenna






## Two Issues for Collaborative Computing

- Network Layer Collaborative:
  - Ad hoc~ Infrastructure-less ~ support “anytime, anywhere”
  - To support communications between ad hoc nodes
    - To guide the packets effectively to satisfy different requirements
    - To adjust to dynamical topology change (due to Mobility)
- Application Collaborative:
  - Video Conferencing, News Broadcasting
  - Group of users to share the same information
  - Mobility Support

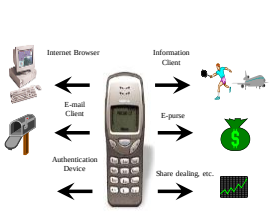


## Trend Evolution

- IP success
  - The involvement and level of responsibility of end users have dramatically increased
  - The freedom has fueled creativity
- Infrastructure-less, self-organized networks
  - The network runs solely by operation of end users
  - Progress of electronic integration and wireless communication
  - Complement these infrastructures in cases where cost, constraints, or environment require self-organized solutions
  - Will be interconnected with the Internet and cellular networks



## Mobile Computing to Pervasive Computing



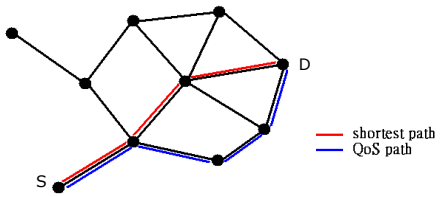



## Mesh Network Scenario



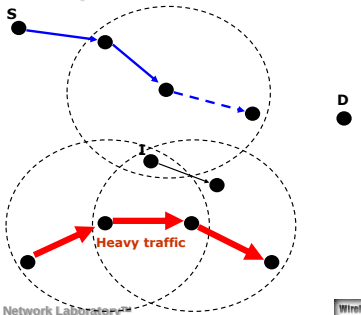
## Why not existing routing protocol

- Existing routing protocol search for shortest path not guarantee any QoS.



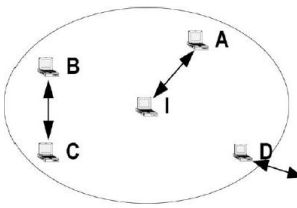



## Bandwidth influence ~ hidden route problem






## Traffic aggregation of existing flow




**$B_{self}$: Tx or Rx by I.**

**$B_{neighborhood}$: traffic between I's neighbors.**

**$B_{boundary}$: connection cross I's access range.**

$$B_{\text{available}}(I) = B - \sum_{J \in N(I)} B_{\text{self}}(J).$$

## 802.11 Bandwidth Estimation

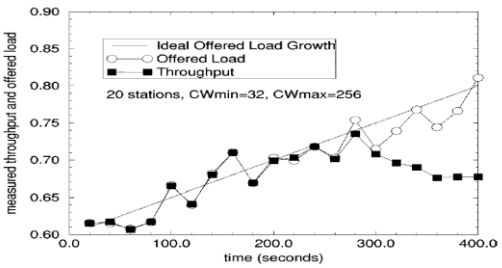



Fig. 3. Measured Throughput with slowly increasing offered load.



## Markov chain model

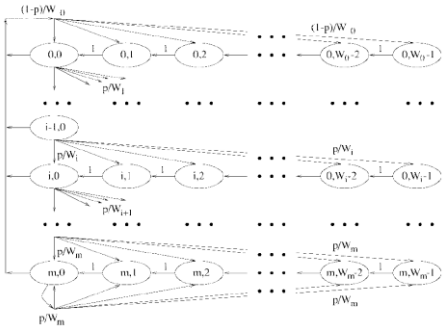
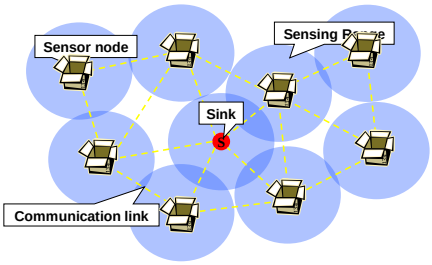


Fig. 3. Markov chain model for the backoff window size.



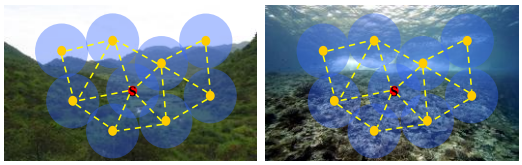
## Wireless sensor network: data gathering





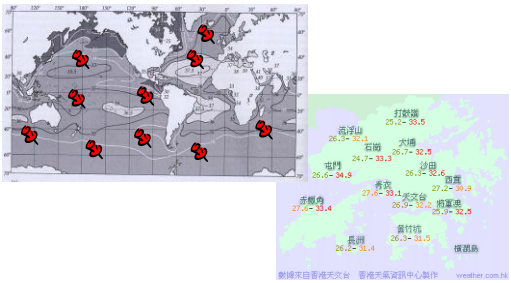

## Energy constraint of sensor network

- Battery-equipped, limited energy
- Remote environment, re-charge is hard





## Spatial correlation among measured data

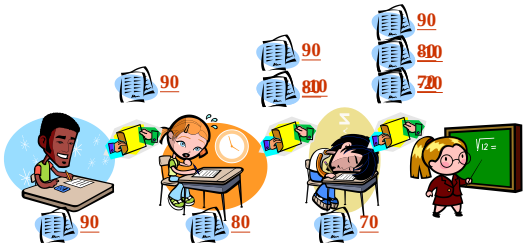




## Correlated data encoding for energy efficiency

- Exploit spatial correlation to encode measured data to reduce amount of information.
- Explicit communication approach proposed by Razvan Cristescu et al. IEEE/ACM Trans. On Networking 2006.

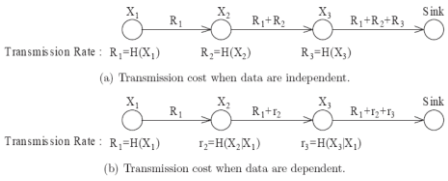
## Explicit communication approach





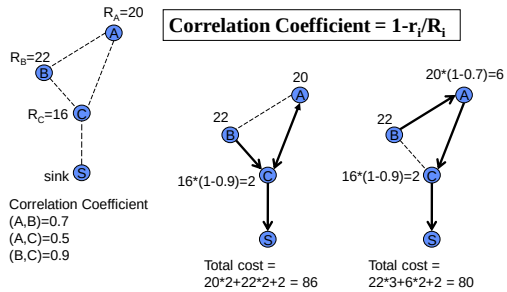

## Explicit communication approach

- $H(X_i)$ is entropy of random variable $X_i$, and represents the amount of information.






## Joint optimization of rate allocation and routing path





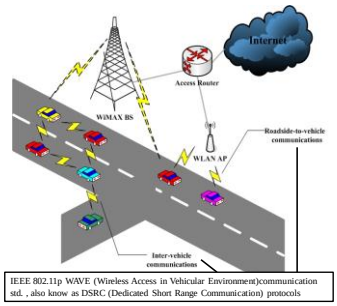

## Video Transmission in VANET

GPS gets instant video streams from the surveillance cameras at an intersection.

The driver can get a better view of the traffic.



## What is a VANET (Vehicular Ad hoc Network) ?




IEEE 802.11p WAVE (Wireless Access in Vehicular Environment)communication std. , also know as DSRC (Dedicated Short Range Communication) protocols



## VANET vs. MANET

- VANET can be considered as one of concrete applications of MANETs in the future
- The difference between VANET and MANET
  - (i) VANET have vehicles as network nodes and their main characteristics are highly mobility and speed
  - (ii) VANET nodes move non-randomly along specific paths (roads)
  - (iii) VANET nodes are vehicles, so there are less power and storage constraints
- Due to the characteristic of (i) (ii), VANET will suffer *rapid changes in network topology*, and will be subject to *frequent fragmentation*

## Vehicular communications: why?

- Traffic jams generate a tremendous waste of time

- Try to *improve driving safety* and *traffic management* while providing drivers and passengers with *Internet access*



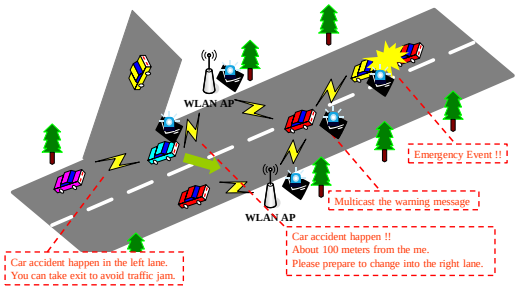
## Applications of vehicular communications

- There are many applications envisioned for VANETs, we can divide the applications into two major categories:
  - ***Safety-related applications***
    - Collision avoidance
    - Cooperative driving
  - ***Non-safety (private) applications***
    - Traffic optimization
    - Payment services (toll collections)
    - Location-based services (find the closest fuel station)
    - Infotainment (Internet access)



## Scenario of VANET safety applications

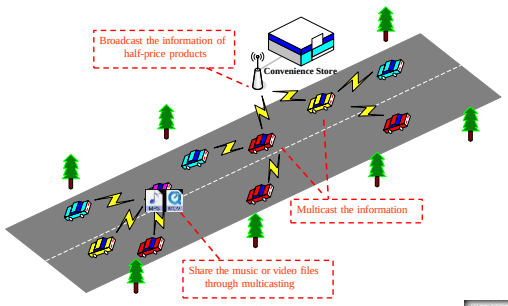
**Multicasting warning messages**





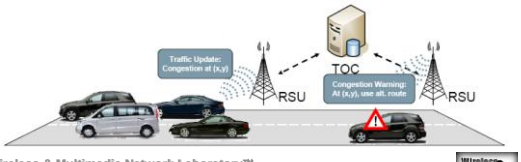

## Scenario of VANET private applications

**Multicasting infotainment messages**






## Vehicular Ad Hoc Network Scenario

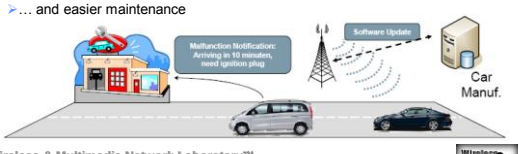





## Vehicular Ad Hoc Network Scenario

- more fun,

- … and easier maintenance

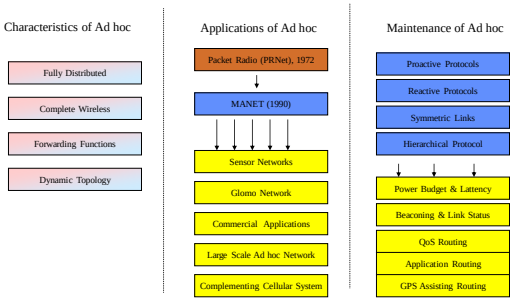


## Observations

Personal Communications have been the dominant paradigm so far, but mobile ad hoc networks open new possibilities, such as the communication between objects



## Survey of Ad hoc Researches






## Reading

- [Jean2001] Jean-Pieere Hubaux, Thumas Gross, Jean-Yues Le Boudec, and Martin Vetterli, “Toward Self-Organized Mobile Ad Hoc Networks: The Terminodes Project”
- [Ian 2005] Ian F. Akyildiz, A Survey on Wireless Mesh Networks, IEEE Radio Communications September 2005

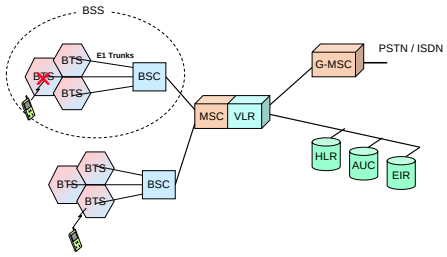


## Agenda

- Overview of Mobile Ad Hoc Networks
- Major Technical challenges:
  - Networking
  - Real time services
  - Software
- Long-term Research Project:
  - Terminodes Projects



## Cellular based

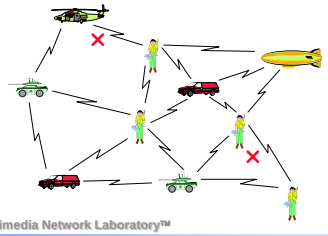


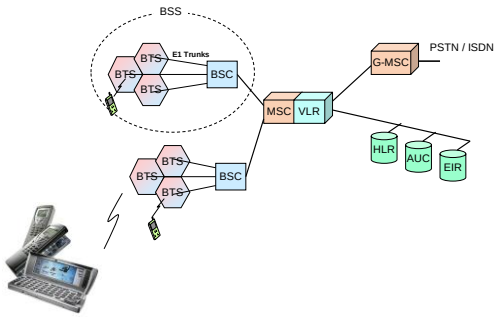

GSM Network Infrastructure



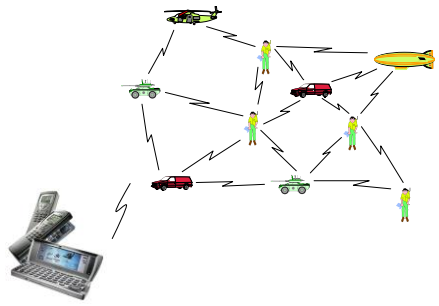
## Ad-hoc network

- No centralized controller ( base stations )
- No wired inter-connection backbone
- Forwarding function should be provided by mobile nodes



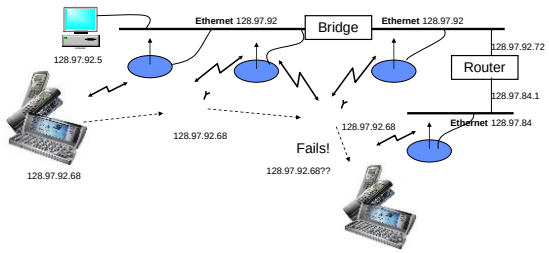




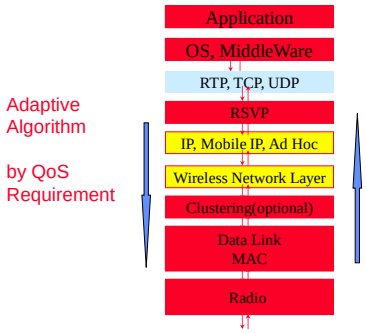


## Mobility in Wireless LANs: Mobile IP






## QoS and Multimedia Traffic Support




Adaptive Algorithm

by QoS Requirement

Mobility Unpredictable channel

by QoS Information



## Introduction

Self-Organized Mobile Ad Hoc Networks



## Overview (MANET)

- Packet Radio Networks ('70)
  - Research Results
    - Radio Resource Allocation
    - Network Organization
  - An Individual, handheld device
  - Military application (provide person-to-person communications on the battlefield)

## MANET

- Potential Applications:
  - Manmade disasters
  - Relief operation
  - Military applications
  - Car-based networks
  - Sensor networks
  - The Provision of wireless connectivity in remote areas
  - Collaborative Computing, Video Conferences



## MANET, Peculiarities

- They can act independent of any provider
- They have to be highly cooperative: The tasks are distributed over the nodes
- Any operation is the result of the collaboration of a group of them
- The nodes rely on batteries for their energy, energy saving
- Power aware: the set of functions offered by a node depends on its available power
- Highly dynamic topology
- Security is difficult to implement



## Technical Issues

- Routing
- Mobility Management
- IP Address
- Transport Layer
- Air Interface
- Security
- Power Management
- Standards and Products



## Routing

- Ad hoc routing
  - Different from traditional solutions in the Internet or cellular phone networks (relative stable, distributed routing databases)
  - IETF (The Internet Engineering Task Force) MANET address the challenge
  - Distant vector, links state, source routing (table driven, on-demand)
  - Geographic methods: nodes are informed of their own geographic position



## Routing Protocol

- Traditional Routing
  - Distance Vector ( Bellman Ford )
  - Link State
- Ad Hoc Routing Protocols
  - DSDV
  - DSR
  - AODV
  - TORA



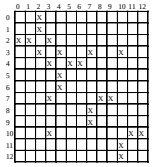
## Traditional Routing

- Distance Vector ( Table Driven )
  - Each node maintains its own routing table
  - Routing table contains
    - destination node index
    - next hop
    - metric
  - Periodic routing table exchange
- Disadvantage
  - Count-Infinity Problem
  - Convergence Problem

| A | B | C |
|---|---|---|
| B-A-1 | A-B-1<br>C-B-1 | B-C-1 |
| B-B-1<br>C-B-2 | A-B-1<br>C-B-1 | B-B-1<br>A-B-2 |
| 0 | 1 | 2 |
| x | 1 | 2 |
| x | 3 | 2 |
| x | 3 | 4 |
| x | 5 | 4 |
| x | ∞ | ∞ |

## Traditional Routing ( Cont. )

- Link State Routing
- Procedures
  - Neighbor Discovery
  - Routing Information Broadcast
  - Shortest Path Finding ( e.g. Dijkstra's algorithm )
- Disadvantage
  - short-live looping problem



adjacency matrix



## Ad Hoc Routing - DSDV

- DSDV
  - Destination Sequence Distance Vector Routing
  - Each route information is labeled with a increasing sequence number
    - Route info. with greatest number will be update
  - Route info. of broken link is broadcast with odd sequence one greater than the original sequence number
- Contribution
  - Main contribution of DSDV is freedom-loop guarantee
- Disadvantage
  - The periodic broadcast adds the overhead into the network

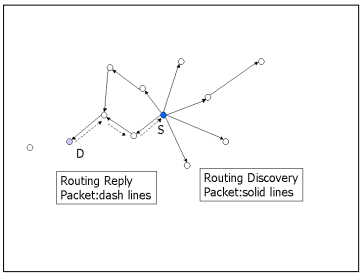


## Ad Hoc Routing - DSR

- DSR
  - Dynamic Source Routing
  - Route Discovery
    - Source node flooding routing request (RREQ) packet
    - Destination ( inter-node ) node reply RREP packet that piggybacks the route info.
    - Source node caches the route info
  - Route Maintenance
    - The route info. will be remove after receiving RERR packet
- Advantage
  - Requires no periodical routing exchange
- Disadvantage
  - packet is larger because of carrying route info.

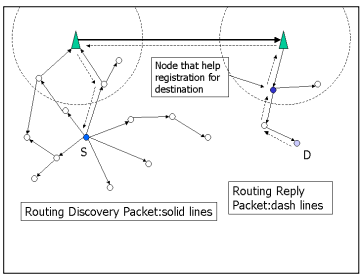



## Routing in ad hoc network environment only





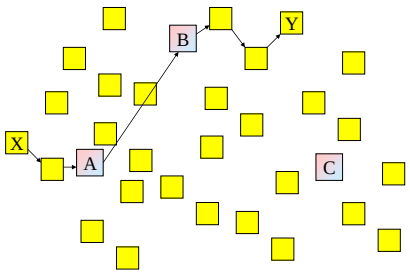

## Routing in heterogeneous environment





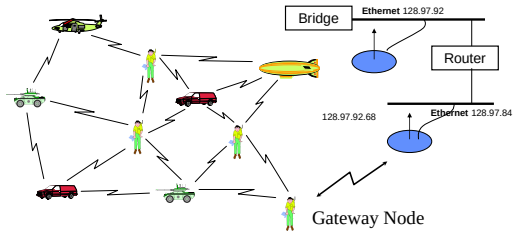

## Heterogeneous Network Support

- Use of Interface Indices in DSR



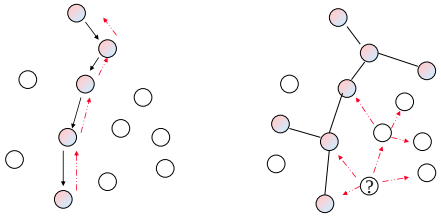
## Internet Interconnection and Mobile IP

- DSR support the seamless interoperation between an ad hoc network and the Internet






## On Demand Support Multicast & QoS




Bandwidth (QoS) Parameters

Multicast Join



## Ad Hoc Routing - AODV

- AODV
  - Ad-hoc On-demand Distance Vector
  - Shares the advantages of DSR and distance vector
  - Route Discovery
    - Similar to DSR
  - Route Maintenance - Table Entry
    - Destination IP, Destination Sequence, Hop Count, Next Hop, Life Time
  - The route info. Is invalid if
    - Life Time is expired
    - Receive RERR packet

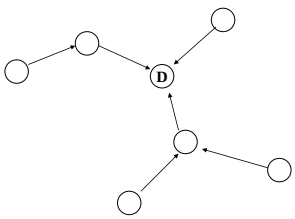


## Ad Hoc Routing - TORA

- TORA
  - Temporally-Ordered Routing Algorithm
  - Routing procedures
    - Flood QUERY packet
    - UPDATE packet will be broadcast from destination or inter-node
    - HEIGHT info. is appended to UPDATE packet
    - the node receives UPDATE packet set its height and the forwarding UPDATE packet's height to a value one greater than original one
  - Source node send data to the destination via neighbor that have lower height with respect to the destination
- Advantage
  - Minimizes the reaction due to changes of network topology
- Disadvantage
  - Depend on Internet MANET encapsulation Protocol, the overhead is large



## Ad Hoc Routing - TORA ( Cont. )




Directed acyclic graph rooted at destination

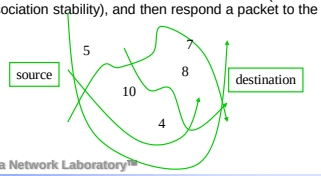


## ABR (Associativity-Based Routing)

- ABR considers the stability of a link.
  - The metric is called degree of association stability.
- Basic Idea:
  - Each node periodically generates a beacon to signify its existence.
  - On receipt of the beacon, a neighboring node will increase the "tick" of the sender by 1.
    - A higher degree of association stability (i.e., ticks) may indicate a low mobility of that node.
    - A low degree of association stability may indicate a high mobility of that node.
  - When a link becomes broken, the node will set the tick of the other node to 0.

## ABR Outline

- Route Discovery:
  - (similar to DSR)
    - On needing a route, a host will broadcast a ROUTE_REQUEST packet.
    - Each receiving host will append its address to the packet.
  - The association stability (represented by "ticks") is also appended in the ROUTE_REQUEST packet.
  - The destination node will select the best route (in terms of association stability), and then respond a packet to the source.



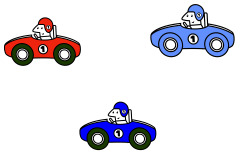



- Route Reconstruction:
  - On route error, a node will perform a local search in hope of rebuild the path.
  - If the local search fails, a ROUTE_ERROR will be reported to the source.




## Mobility Management

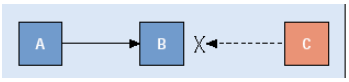
- Broadcasting a paging message the whole network: won't scale well
- Different from centralized servers (either HLR in GSM), location must be distributed among the nodes
- Prediction of the future locations





## Radio Interface

- CSMA/CA: hidden terminal




- Defining master and slaves roles: Bluetooth



## MACA/PR

- The key component
  - the MAC protocol for data transmission
  - Reservation scheme for real-time connection setup
  - QoS Routing algorithm

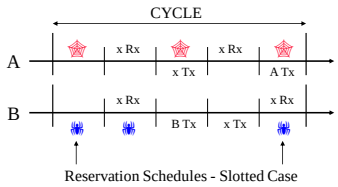


## MACA/PR - MAC

- Data-gram Traffic
  - RTS - CTS - PKT - ACK
  - <RTS,CTS> for hidden terminal avoidance, ACK for retransmission
- Real-Time Traffic
  - < RTS - CTS > - PKT - ACK
  - <RTS,CTS> used for first time transmission to set up the reservation
  - ACK for renewing the reservation, not recovery

## MACA/PR - Reservation/QoS Routing

- CYCLE is the max. interval allowed between two real-time packets
- Each node maintains its own reservation table
- DSDV routing is employed
- Bandwidth info. can be easily obtained via reservation table



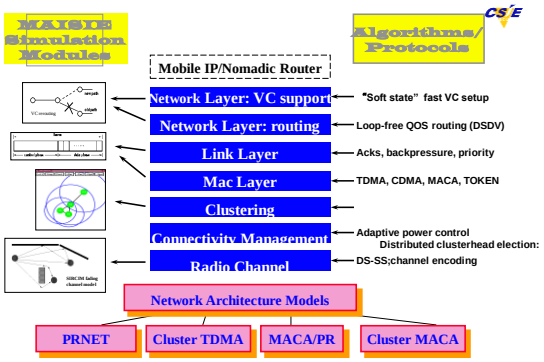
Reservation Schedules - Slotted Case



## MACA/PR - Properties

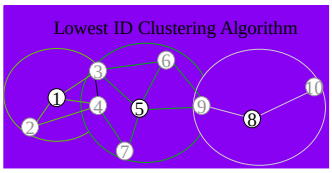
- Asynchronous approach
- Low latency, low packet loss rate
  - Hidden Terminal Problem is solve automatically
- Fair bandwidth sharing
- Good mobility handling
  - Maintain secondary routing path
- Low implementation costs



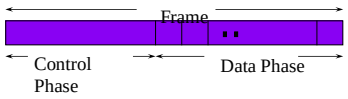





## Cluster TDMA

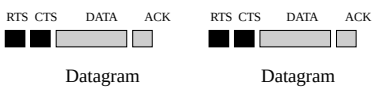


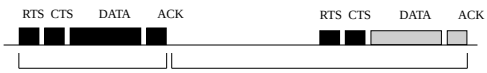

Within each cluster: time-slotted frame






## Cluster MACA




VC Reservation Setup VC Cycle time



## The Paradigm Shift and Some Open Research Questions

MANET

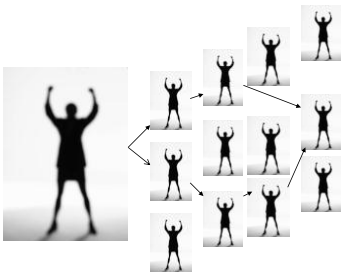
## Terminodes Projects

- Large scale self-organized mobile ad hoc networks
- All layers and interlay interactions
  - From physical layer up to software architecture and applications
- Try to capture the business and societal potential
- Three levels:
  - Technical challenges
  - Intellectual fantasy
  - Societal/political vision



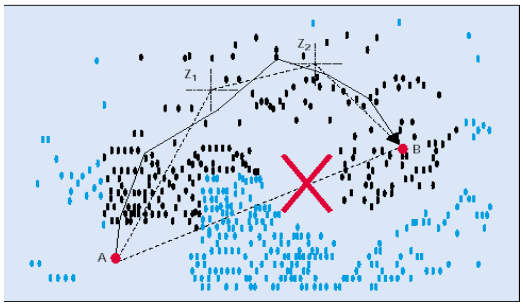
## Terminodes

- Networking Issues
  - Scalability
- Virtual Currency
  - Obligation
- Real Time Services
  - QoS



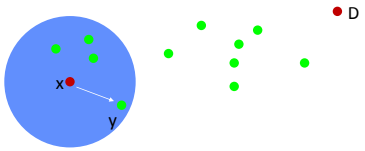


## Networking Issues



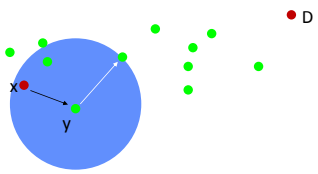



## Greedy Forwarding



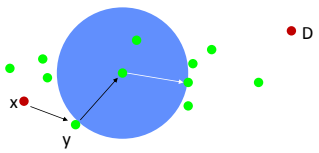



## Greedy Forwarding

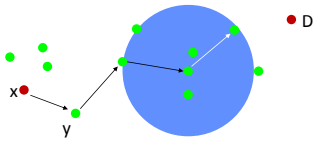





## Greedy Forwarding

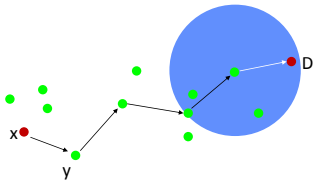


## Greedy Forwarding



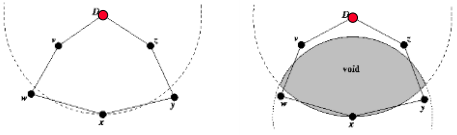



## Greedy Forwarding



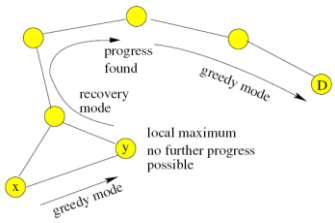



## Greedy Forwarding Failure



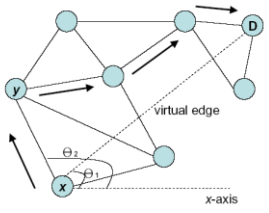



## Recover Mode (GPSR two modes)



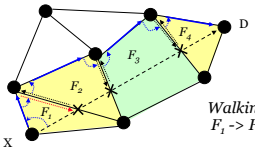



## Right hand rule






## Face (Perimeter) traversal on a planar graph

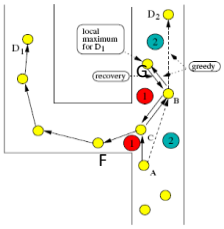



*Two primitives:*
*(1) the right-hand rule*
*(2) face-changes*

*Walking sequence:*
$F_1$ -> $F_2$ -> $F_3$ -> $F_4$

## Scenarios Where GPCR does not work Well

For Destination D2, the source A has to send to C even if it can send directly to more closer node B.




For Destination D1 The source A has to send to C (Junction node) then to B (because it is closer to D1 than F), then G. Then it goes for recovery mode because G is the local maxima and return back to C. C sends to F and finally Data is sent to D1.

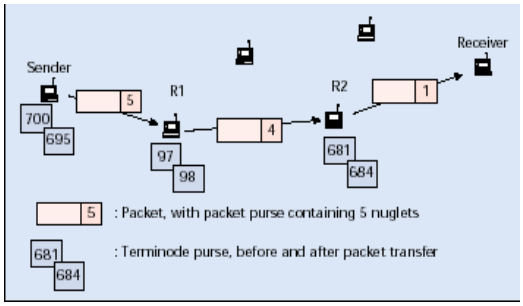


## Routing for Terminode

- Each Terminode has
  - A permanent unique node identier, EUI (End System Unique Identifier)
  - Location-Dependent Address (LDA)
- Geodesic Packet Forwarding:
  - The packet is forwarded to the neighbor closest to the direction in which the destination is located
- Terminode local routing
  - MANET routing (link State, Distance Vector, Source Routing)



## Networking Issues



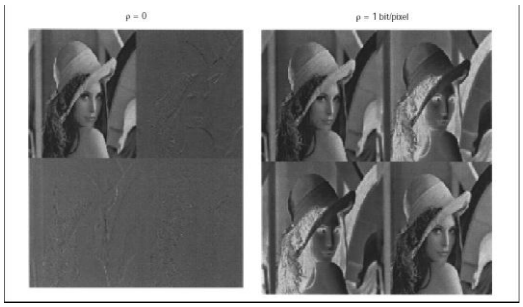



## Virtual Currency (Nuglet)

- Service Availability is a major requirement for self-organization
- The End users must be given incentive to cooperate
- They must be encouraged to not overload the network



## Multiple description coding






## Real-Time Services over Ad hoc Networks

- Real-Time Services
  - Voice or video over ad hoc networks
  - Unreliable <-> stringent delay
  - Large error , node failure
- Redundancy, error correction codes over parallel connections

## Software Aspects

- Software implementations:
  - Base software: Routing algorithms, accounting system and security system
  - Application software: Software that makes a collection of terminodes useful for a client
  - Flexible software architectures
- Resource Allocations
  - Contract
  - Loader
  - Dynamic checks



## Discussions

- Three Networks:
  - Telecom networks
  - The Internet
  - Self-Organized Mobile Ad Hoc Networks

| Network | Infrastructure | Security | Applications |
|---|---|---|---|
| Telecom networks | Telcos | Telcos | Telcos (IN) |
| Internet | ISPs + telcos | ISPs + users (PGP) | Users |
| Self-org. ad hoc NW | Users + vendors | Users + vendors | Users |

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