EEC173B/ECS152C

Research activities in wireless & mobile networks

- Delay Tolerant Networking (DTN)
- Example Applications in Industry
- Vehicular Ad Hoc Networks
- Activities at UC Davis

Delay Tolerant Networking

- DTNRG (http://www.dtnrg.org/)
  - Architectural and protocol design to address the need for interoperable communications in performance-challenged environment with only intermittent connectivity
    - E.g., spacecraft, military/tactical, disaster response, underwater
- Challenges
  - Large delay due to physical link properties or extended periods of network partitioning
  - Routing
  - End-to-end reliability
  - Heterogeneous underlying network technologies
  - Security
  - Application structure

Other DTN-like Projects

- DataMules
  - http://www.cs.washington.edu/homes/sushjain/pubs2/snpa03-mules.abs.html
- DakNet, First Mile Solutions
  - http://www.firstmilesolutions.com/
  - Rethinking Connectivity in Developing Nations
- Interplanetary Internet
  - http://www.ipnsig.org
  - Define the architecture and protocols necessary to permit interoperation of the Internet resident on Earth with other remotely located internets resident on other planets or spacecraft in transit.
- ZebraNet
  - http://www.princeton.edu/~mrm/zebranet.html
- MindStream Project
  - http://mindstream.watsmore.net

Example Applications in Industry: Smart Patient ID Card

Key Benefits
- Data Portability & Security
- Physician & Patient Mobility
- Error Detection & Prevention
- Replacement of Paper & Phone
- Streamlined Service

Key Features
- Identification Card
  - Design Choices
  - Effective Branding
- Secure Data Storage
  - Programmable Chip
  - Read & Write Memory
  - PIN Based Protection
- System Interfaces
  - Physician Office
  - ADT / Scheduling
  - Hospital Departments
    - Surgery
    - Lab / diagnostics
    - Pharmacy
  - Eligibility & 3rd party services

Sample Usage Steps 1-3: Remote Clinic

1. The patient presents her Smart Health Card at the physicians' office.
2. The physician and/or nurse inserts the card into a Reader connected to his PC to view and update the patient record using Aquave software. The latest data from the card is used to support better clinician decisions.
3. After seeing the patient, the physician enters the information about the procedures to be performed at the hospital, including:
   - Lab Testing
   - Surgical Procedures
   - Prescriptions

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Sample Usage Steps 4-6: Hospital Admissions

4. The patient presents her Smart Health Card at the hospital's admissions.
5. The admissions staff verifies the patient record using Aquave software to check eligibility, register the patient and route her to the appropriate department. Check-in can also be carried out using a patient self-service kiosk.
6. Data from the card is transferred to HIS systems to update the medical record and store the procedure instruction. The patient is put into the queue for the appropriate department.

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Sample Usage Steps 7-9: Ancillary Department

7. (OPTIONAL) The patient presents her Smart Health Card at an ancillary department
8. (OPTIONAL) The department staff reads the card to confirm the registration information and read detailed directions on the procedure to be performed. Alternatively, the data may be retrieved directly from HIS systems.
9. (OPTIONAL) After procedure is completed, the results and the charge are stored into the card and copied into HIS systems. Physician's office can see them when the patient returns with the card, or alternatively, when they are be printed out and mailed, or made available online.

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Vehicular Ad Hoc Networks

How's it different from other mobile ad hoc networks (MANET)?

- Ample power/energy supply!
  - Can be equipped with storage, processing, sensing capability
- Travel at high speed => dynamic channels
  - Challenging to sustain communications between stationary sites and moving vehicles
  - Hand-off issues
- More predictable path
  - Random mobility patterns do not hold!
  - Defined structure depending on transportation grid

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Motivation

- Challenges and demands in surface transportation
- Distances between home and workplaces leads to daily commute by millions of people
  - Persistent heavy traffic flow in and out of cities from 5am through 10pm
- Low cost wireless communication devices can be embedded in vehicles
- New applications of wireless ad hoc networks with vehicular traffic

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DSRC: Dedicated Short Range Communications

- US FCC allocated a block of spectrum (5.850 to 5.925 GHz) to enhance the safety and the productivity of the transportation system
  - Over roadside-to-vehicle and vehicle-to-vehicle communication channels.
  - Support both public safety and licensed private operations
  - Medium range communication service
    - Very high data transfer rates, minimal latency in relatively small isolated communication zones
  - Complements cellular communications

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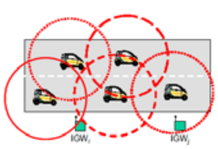
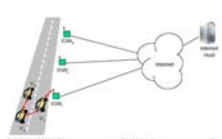
Applications

- Existing work on vehicular communications focused on two broad categories of applications:
  1. Automotive telematics
  2. Extending Internet access to mobile users





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1. Automotive Telematics

- Vehicle Driver-Safety Applications
  - Collision and congestion avoidance
  - Propagating “brake” alert messages to vehicles behind you
- Vehicular traffic monitoring
- Infotainment
- Remote diagnosis using data from onboard sensors

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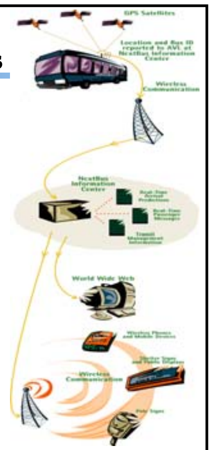
2. Mobile Network Access

- Internet access in cars
  - Broadband services
  - Entertainment (distributed games)
- Information services
  - Trip planning
    - *Where are the restaurants within 20 minute driving time from X?*
  - NextBus
    - http://www.nextbus.com/
    - Real-time arrival prediction
- Temporarily relieve load from cellular infrastructure



Related Work

- Intelligent Transportation Systems (ITS)
- PATH Project (UC Berkeley)
  - Traffic modeling and data analysis
  - Communication and road sensor network
- Autonet (UC Irvine)
- Fleetnet, Germany
- VMesh, UCDavis
  - More later …

Related Activities at UC Davis (1)

- UC Davis Networks Lab http://networks.cs.ucdavis.edu/people.html
  - B. Mukherjee (CS)
  - C-N. Chuah (ECE)
  - D. Ghosal (CS)
  - D. Aksoy (CS)
  - P. Mohapatra (CS)
  - X. Liu (CS)
- Topics include:
  - Sensor network tracking/localization (Yick, Ghosal)
  - Opportunistic Networking (J. LeBrun, Chuah)
  - Virtual patrol and target tracking (C. Gui, Mohapatra)
  - Energy-aware node placement (Liu, Chuah)

Related Activities at UC Davis (2)

- Electrical & Computer Engineering
  - L. Szumel & J. Owens: Mobile Agent Framework
  - Q. Zhao: MAC-layer design, fundamental limits of large-scale sensor and ad hoc networks
- Computer Science
  - R. Pandey: Software Environment for Networks of Sensors and Embedded Systems (SENSES)

Example Project#1: PLASMA

- PLAnetary Scale Monitoring Architecture (Prof. Demet Aksoy and her students)
  - http://www.cs.ucdavis.edu/~aksoy/PLASMA/
  - Study novel integrated data management and networking architectures for planetary-scale monitoring
    - Hierarchical distributed network with heterogenous reachability, power and processing capabilities.
    - Cross layer optimization. Traditional layered approach is not suited for sensor communication. We study light-weight protocols for energy efficiency.
    - Scheduled communication: Sensors should not compete with each other for the shared wireless communication channel. We apply an application-aware scheduling to organize data communications.
    - In-network data aggregation: Sensor nodes cooperate with each other to verify/filter their own readings before forwarding the data long distances.

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Example Project#2: Resource Management in Wireless Networks

- Xin Liu (http://www.cs.ucdavis.edu/~liu/), CS
- Multi-hop wireless networks
  - Robust topology control
  - Efficient broadcasting
  - Multi-radio Multi-channel allocation
- Spectrum-agile wireless networks
  - Fundamental properties of spectrum-agile networks
  - Fast dissemination of critical information
  - Sensing-based opportunistic channel access
- Wireless sensor networks
  - Dynamic information query and discovery
  - Energy-based network deployment
  - Information-theoretical connectivity
- Graduate students
  - Wei Wang, Ranjan Pal, Haiping Liu, Seokman Paul Han

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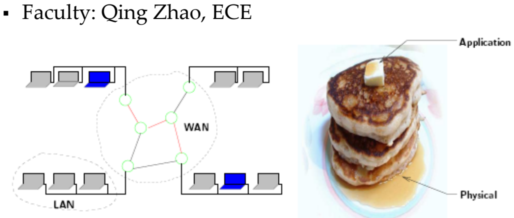
Example project #3: Signal Processing for Wireless Networks

- Faculty: Qing Zhao, ECE



Objective: The General
- Millions of users
- Thousands of applications
- A growing variety of devices.

Solution: A Modular Approach
- Partition network functions into layers
- Design each layer separately
- SP relegated to two ends of protocol stack

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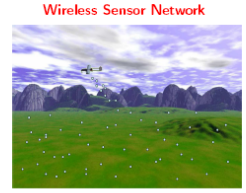
Emerging Applications of Wireless Networking

Network-Centric Combat System

Wireless Sensor Network



Fundamental Shift in Design Paradigm:
- Design Objective: the general ⇒ the application-specific
- Design Focus: performance ⇒ energy & bandwidth constraint
- Design Principle: modular, layered ⇒ integrated, cross-layer

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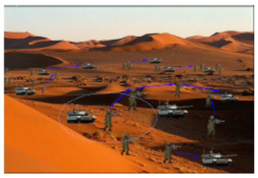
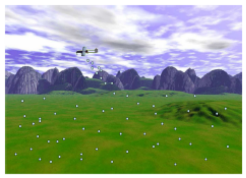
Q. Zhao: Current Research Focus

Mobile Ad Hoc Network



Wireless Sensor Network



- Fundamental limits on energy efficiency
- Energy-efficient MAC and routing
- Adaptive strategy for heterogeneous traffic
- Signal processing for traffic tracking

- Opportunistic strategy for energy efficiency
- Distributed protocol for lifetime maximization
- Energy efficiency under application constraints
- Signal processing for network monitoring

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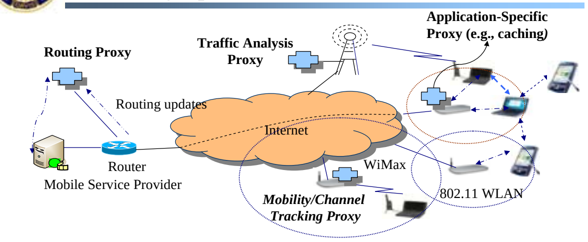
Example Project#4: Mobile Infrastructure Enablers for Streaming Optimization & New Services



- Exploit multi-tier wireless networks, multiple interface, and P2P connectivity
- Proxy-based approach: monitoring, mobility tracking, persistent data caching, traffic analysis, accounting, dynamic service creations
- Target applications: multimedia streaming, gaming, content distribution, security services
- Sponsors: Hewlett Packard, Intel, UC Micro
- http://www.ece.ucdavis.edu/rubinet/minestrone.html

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Example Project#5: VMesh, VGrid, VSense

- Collaborative project
  - Chen-Nee Chuah, Electrical & Computer Engineering
  - Dipak Ghosal, Computer Science
  - Michael Zhang, Civil Engineering
- Vehicular wireless mesh networks can provide powerful networking, computing, and sensing primitives
  - A single store-and-forward mobile router, or collectively as a self-organized, mobile transit networks
  - Distributed grid computing platforms
    - Large density of nodes for grid computing in front of bay bridge every morning! ☺
  - Mobile sensors network
    - Collecting data and tracking mobile targets

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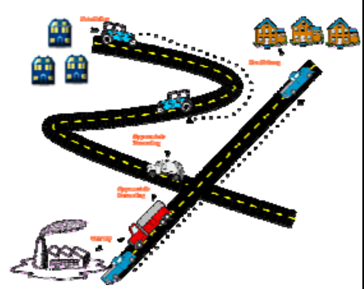
VMESH as Mobile Transit Networks

- Inter-connect static patches of sensors or info. kiosks
  - Dissemination and retrieval of information
- Example Applications
  - Precision Agriculture
  - Cal Energy Demand Response (DR)



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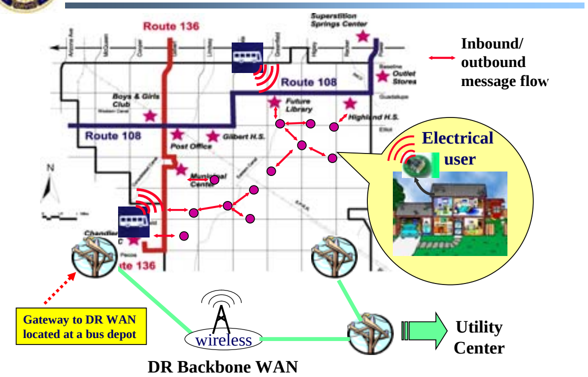
Enabling Utility Demand Response (DR)

- California Energy Commission (CEC) initiative
  - Goal: Monitor “demand/load” on electricity grid in real-time and adapt energy prices as “feedback” to influence consumer behavior
- Utility meters (electricity, water, gas) at user premise
  - Wireless sensors transmit usage information (inbound message) and receive/process pricing information (outbound message)
- DR backbone: wide area network (WAN) connected to the central utility center
- How to connect the end-users to the DR backbone using a **LOW COST, SCALABLE,** and **FAULT-TOLERANT** network?

VMesh – A Potential Solution for DR

- Distributed, low cost, vehicular mesh network to inter-connect end-users to the DR backbone WAN
- Combine *static* concentration points and *mobil*e routers (MRs)
- Leverage various types of vehicles to participate as MRs and form the VMesh
  - buses, light rail, postal vans, utility/garbage trucks
  - FEDEX, UPS, and other vendor trucks
  - police cars and personal automobiles

VMesh Architecture



Architecture and Component (1)

- Sensor-transceiver units at end-users (STUs)
  - Unique ID Number
  - Geographical location of aggregation point (APs)
- User-side aggregation points (APs)
  - Each AP collect data from a set of STUs and relay the data to the vehicular based mobile routers (MRs)
  - E.g., bus stops, light poles (more about placement problem later)

Architecture and Component (2)

- Mobile Routers (MRs)
  - Vehicles equipped with storage, processing power (intelligence) and wireless communication capabilities
  - Can form ad hoc networks with other mobile routers or static roadside gateways
  - E.g., buses
- Utility-side gateways (UGs)
  - These are gateways to the DR backbone network
  - E.g., main bus station

Design Rationale (1)

- Leverage diversity in spatial and temporal coverage to perform *multi-resolution* adjustment
- Example: Bus as primary MR
  - Schedule offers multiple *temporal granularity*
    - Fixed schedule: Predictable message delivery time/delay
    - More frequent during peak hours: coincide with peak usage period
    - More frequent and dense in urban areas (where energy consumption is high) than rural area.
  - Natural clustering
    - Bus routes are designed to provide efficient coverage of residential, especially areas with heavy concentration of buildings, where DR matters

Design Rationale (2)

- Scalable to large deployment
  - Minimize the number of concentration points
  - Minimize maintenance cost – MRs (e.g., buses) can drive to a station for repairs and software upgrades
  - Leverage the vehicular mesh network for other applications -> amortize cost
    - Vehicular traffic flow control and management
    - Enhanced amber alert

Design Rationale (3)

- Vehicles equipped with GPS and intelligence to support dynamic tariffs and other DR strategies
  - Computing/storage resources
  - MRs can enable local marginal pricing (LMP)
    - Make local decisions in a distributed manner at a faster time-scale, and rely on the utility center to do global adjustment at a slower time-scale

Design Rationale (4)

- Survivability and Redundancy
  - Leverage overlapping bus routes to provide multiple paths for routing DR messages
  - Primary/secondary MRs
    - When the primary MRs fail (e.g., buses running late, accidents), leverage other vehicles, e.g., FEDEX/UPS trucks or vendor vehicles, as backup “information collector/disseminator” to form a secondary VMesh
  - Deflection routing algorithms to forward messages around trouble spots towards the destinations

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Routing in DTN

- Flooding
  - Gets the message out to everyone
  - Lots of control overhead
- Probabilistic Routing
  - Needs non-random mobility
  - Decision based on likelihood of encounter
- Attentive Routing
  - Pay attention to physical attributes
  - Needs information location

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VGrid: What causes congestion?

- On/off-ramps, lane changing, accidents, random slowdowns
- How can we mitigate congestion?
  - Let drivers see further ahead
    - More time to react
    - Gradually decrease speed rather than slamming on brakes
    - Change lanes early to avoid accident
    - Give room to merging traffic
  - Set variable speed limit
    - Prevent oscillations
    - Decrease average speed but increase flow

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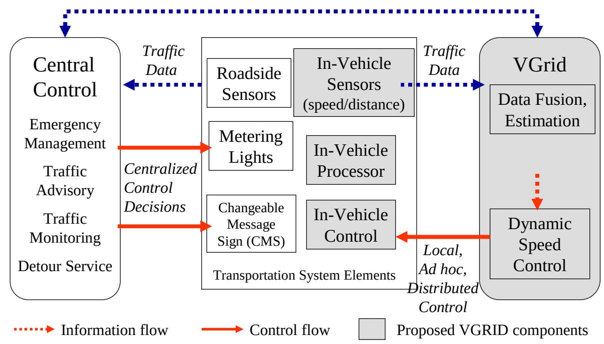
Changing the landscape of Intelligent Transportation System



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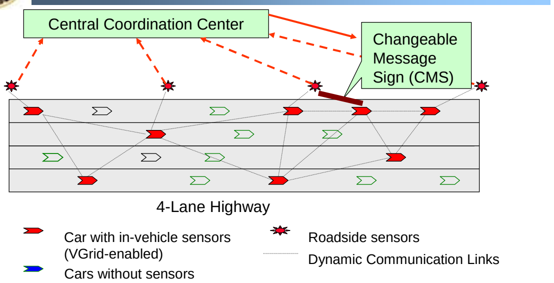
Hybrid Approach: VGrid + Fixed Infrastructure



- Cars exchange speed/location info; propagate upstream accident info.
- Sensors gather flow info over time, relay data to/from vehicles, set variable speed limit

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Distributed Sensing and Grid Computing for Homogenizing Vehicular Traffic Flows

- Idea: rapid, automatic creation of ad hoc grid computers consisting of wireless enabled vehicles
- Design challenges compared to traditional grid computer
  - Variable topology of grid computers
    - Nodes are dynamic (high mobility)
    - Node density can vary widely and unpredictably
  - Time-varying link quality
  - Security and privacy issues
    - Built upon wireless & pervasive network

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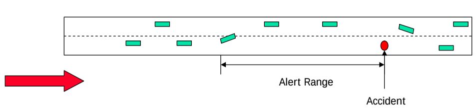
Case Study #1: Post Accident Flow Homogenization

- Accident alert: broadcast location of stalled car
  - Vehicles receiving alert from downstream will try to change lane in advance
  - Probability of lane change increases as the vehicle gets nearer to accident location.
- Performance
  - Average travel time (seconds)
  - # of packet collisions/failed transmission
  - Variability in speed



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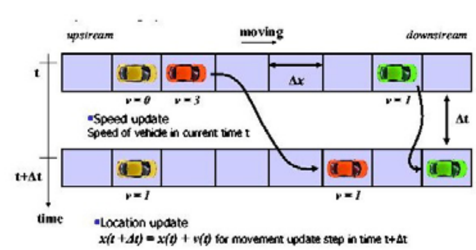
Simulation using Cellular Automata Model

- Discrete system (in terms of space, time, states of the system)
- Current cell state solely depends on the cell's previous state and its neighbors' previous state, all cells updated synchronously
- Basic model: Nagel-Schreckenberg



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Simulation Scenarios

- Compare
  - Alert vs. No alert
  - Vary non-participant density
  - Vary traffic density
  - Vary transmission range
- 1000 cells (750m)
- 4 lanes, one-way
- Accident position: random
- Free flow speed: 4 cells/time step
- Simulation time: 1000 s

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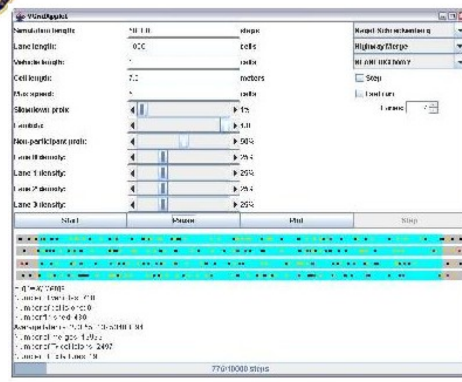
Simulation ScreenShot



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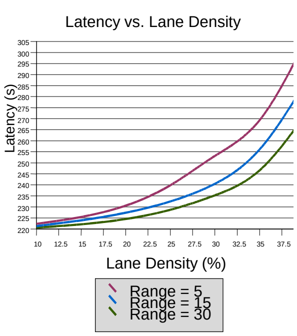
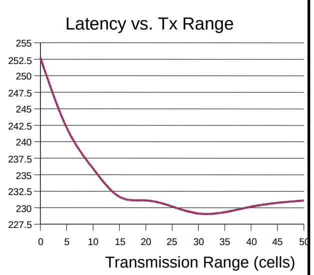
Results (1)





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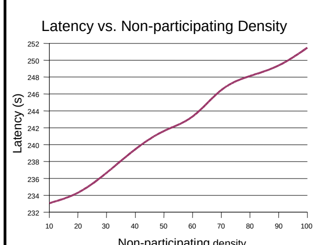
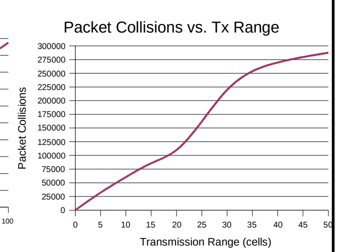
Results (2)





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Summary

- This is just the beginning, we have a lot more to do …
- Adaptive resource control: distributed MAC
- Mobile agents: keeping data/computation localized
- Security
  - Access control
    - Only authorized users can participate in the system
  - Authenticity and integrity of information
  - Denial-of-Service
- Economic Models
  - Incentive mechanism for user to participate

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Opportunistic Networking

- Emerging wireless personal area networks (WPANs) & heterogeneous wireless connectivity (WiFi/WiMax)
- Capitalize on open wireless connectivity from both infrastructure & peers to support new delay-tolerant applications
  - E.g., RSS publishing, web blogging, etc.
- Sponsors: Intel Research, Sprint
- Recent UniTran Bus experiments to track user 'mobility/connectivity'
  - Installed i-MOTES on 37 campus buses to track ad hoc wireless connectivity of bluetooth-enabled devices

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Opportunistic Forwarding

- When a contact occurs, a decision must be made.
- How do we evaluate our neighbor?
- Does mobility information help more than location information alone?
- MoVe Algorithm
  - When two nodes meet, make a decision
  - Decision based on speed and direction
  - Use mobility to our advantage

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MoVe – Motion Vector Routing

- Periodic HELLO beacons for detection
- RESPONSE message establishes contact
- Decision made on *per-contact* basis
- At contact, exchange mobility information
  - Location
  - Heading
  - Speed
- Will neighboring node get closer?

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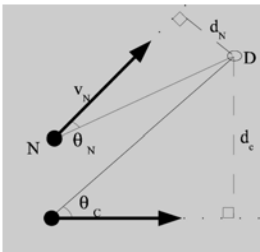
MoVe – Motion Vector Routing



Current	Neighbor	Forward
Still	Still	No
Still	Away	No
Still	Towards	Yes
Away	Still	Yes
Away	Away	if $\vec{ND} < \vec{CD}$
Away	Towards	Yes
Towards	Still	No
Towards	Away	No
Towards	Towards	if $d_N < d_C$

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