Vehicular Urban Sensing: Dissemination and Retrieval

UC Irvine, May 21, 2009

Mario Gerla
Computer Science Dept, UCLA
www.cs.ucla.edu/NRL
Outline

- **Vehicular Ad Hoc Networks (VANETs)**
  - Opportunistic ad hoc networking
- **V2V applications**
  - Content distribution
  - Urban sensing
    - Mobeyes (UCLA)
  - Bio inspired “harvesting”
  - Security implications
- **The UCLA CAMPUS Testbed**
Traditional Mobile Ad Hoc Network

- Instantly deployable, re-configurable (no fixed infrastructure)
- Satisfy a “temporary” need
- Mobile (e.g., PDAs)
  - Low energy
- Multi-hopping (to overcome obstacles, etc.)
- Challenges: Ad hoc routing, multicast, TCP, etc.

Examples: military, civilian disaster recovery
Vehicular Ad Hoc Network (VANET)

• **No fixed infrastructure?**
  – Several “infrastructures”: WiFi, Cellular, WiMAX, Satellite..

• **“Temporary” need?**
  – For vehicles, well defined, permanent applications

• **Mobile?**
  – YES!!! But not “energy starved”

• **Multi-hop routing?**
  – Most of the applications require broadcast or “proximity” routing
  – Infrastructure offers short cuts to distant destinations
  – Multihop routing required only in limited situations (eg, Katrina scenario)

• **VANET => Opportunistic Ad Hoc Network**
  – Access to Internet readily available, but..
  – opportunistically “bypass it” with “ad hoc” if too costly or inadequate
VANET New Research Opportunities

• **Physical and MAC layers:**
  - Radios (MIMO, multi-channel, cognitive)
  - Positioning in GPS deprived areas

• **Network Layer & Routing:**
  - Mobility models
  - Network Coding
  - Geo routing
  - Content based routing
  - Delay tolerant routing

• **Security and privacy**

• **New Applications:**
  - Content distribution, mobile sensing, safety, etc
The Enabling Standard: DSRC / IEEE 802.11p

- Car-Car communications at 5.9Ghz
- Derived from 802.11a
- Three types of channels: Vehicle-Vehicle service, a Vehicle-Roadside service and a control broadcast channel.
- Ad hoc mode; and infrastructure mode
- 802.11p: IEEE Task Group for Car-Car communications
V2V Applications

- Safe Navigation
- Efficient Navigation/Commuting (ITS)
- Location Relevant Content Distr.
- Urban Sensing
- Advertising, Commerce, Games
- Etc
V2V Applications

• Safe navigation:
  – Forward Collision Warning,
  – Intersection Collision Warning……..
  – Advisories to other vehicles about road perils
    • “Ice on bridge”, “Congestion ahead”…..
Car to Car communications for Safe Driving

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

Alert Status: None

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

Alert Status: Inattentive Driver on Right
Alert Status: Slowing vehicle ahead
Alert Status: Passing vehicle on left

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

Alert Status: None

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

Alert Status: Passing Vehicle on left
V2V Applications (cont)

• **Efficient Navigation**
  - GPS Based Navigators
  - Dash Express (just came to market in 2008):
Intelligent Transport Systems

intelligent lane reservations

QuickTime™ and a TIFF (Uncompressed) decompressor are needed to see this picture.
V2V Applications (cont)

• Environment sensing/monitoring:
  – Traffic monitoring
  – Pollution probing
  – Pavement conditions (eg, potholes)
  – Urban surveillance (eg, disturbance)
  – Witnessing of accidents/crimes
V2V Applications (cont)

• Location related content delivery/sharing:
  – Traffic information
  – Local attractions
  – Tourist information, etc
V2V Applications (cont)

Advertising (Ad Torrent):
- Access Points push Ads to passing cars
- Advertisement: multimedia file (data, image, video)
- Movie trailer; restaurant ad; club; local merchant

Commerce (Flea Net):
- virtual market (bazaar) concept in VANET
- A mix of mobile and stationary users buy/sell goods using the vehicular network
CarTorrent: cooperative download of location multimedia files
You are driving to Vegas
You hear of this new show on the radio
Video preview on the web (10MB)
One option: Highway Infostation download

Internet

file

WiFi

McDonald's
Incentive for opportunistic “ad hoc networking”

Problems:

Stopping at gas station for full download is a nuisance
Downloading from GPRS/3G too slow and quite expensive
3G broadcast services (MBMS, MediaFLO) only for TV

Observation: many other drivers are interested in download sharing (like in the Internet)

Solution: Co–operative P2P Downloading via Car–Torrent
CarTorrent: Basic Idea

Internet

Download a piece

Outside Range of Gateway

Transferring Piece of File from Gateway
Co-operative Download: Car Torrent

Internet

Vehicle-Vehicle Communication

Exchanging Pieces of File Later
Car Torrent inspired by BitTorrent: Internet P2P file downloading
Selection Strategy Critical
CarTorrent with Network Coding

- **Limitations of Car Torrent**
  - Piece selection critical
  - Frequent failures due to loss, path breaks

- **New Approach – network coding**
  - “Mix and encode” the packet contents at intermediate nodes
  - Random mixing (with arbitrary weights) will do the job!
Network Coding

\[ e_1 e_2 e_3 e_4 \] encoding vector tells how packet was mixed (e.g. coded packet \( p = \sum e_ix_i \) where \( x_i \) is original packet)

Receiver recovers original by matrix inversion

Intermediate nodes

buffer

random mixing
**CodeTorrent**

- Single-hop pulling (instead of *CarTorrent* multihop)

---

**Internet**

**File: k blocks**

**Random Linear Combination**

- **B1**
- **B2**
- **B3**

"coded" block

**Re-Encoding: Random Linear Comb. of Encoded Blocks in the Buffer**

**Exchange Re-Encoded Blocks**

**Downloading Coded Blocks from AP**

**Meeting Other Vehicles with Coded Blocks**
Simulation Results

- Completion time density

200 nodes
40% popularity
Simulation Results

- **Impact of mobility**
  - Speed helps disseminate from AP and among vehicles
  - Speed hurts multihop routing (*CarTorrent*)
  - Car density+multihop promotes congestion (*CarTorrent*)
Vehicular Sensor Applications

• Environment
  – Traffic density/congestion monitoring
  – Urban pollution monitoring
  – Pavement, visibility conditions

• Civic and Homeland security
  – Forensic accident or crime site investigations
  – Terrorist alerts
Accident Scenario: storage and retrieval

- Public/Private Cars (e.g., busses, taxicabs, police, commuters, etc):
  - Continuously collect images on the street (store data locally)
  - Process the data and detect an event
  - Classify the event as Meta-data (Type, Option, Loc, time, Vehicle ID)
  - Distribute Metadata to neighbors probabilistically (i.e., “gossip”)
- Police retrieve data from public/private cars
Mobility-assist Meta-data Diffusion/Harvesting

- Agent harvests a set of missing meta-data from neighbors
- Periodical meta-data broadcasting
- Broadcasting meta-data to neighbors
- Listen/store received meta-data
How to store/retrieve the Metadata?

To store data (and maintain an index to it) several options:

- Upload to nearest Access Point (Dash Express; Cartel project, MIT)
- “Flood” data to all vehicles (eg, bomb threat)
- Publish/subscribe model: publish to a mobile server (eg, an “elected” vehicle)
- Distributed Hash Tables (eg, Virtual Ring Routing - Sigcomm 06)
- “Epidemic diffusion” -> our proposed approach
CarTel: A Distributed Mobile Sensor Computing System*

Hari Barakrishnan
Comp Science Dept, MIT

Dash Express Navigation System

- **Network connectivity in Dash Express**
  - Cellular (GSM) and open WiFi to provide Internet connectivity
- **Dash Express node as a sensor reports the traffic information to Internet portal**
  - Real-time traffic information gathering
  - Gathered traffic information is used for traffic flow analysis
  - Routing recommendations based on traffic flow statistics + real-time traffic information
- **Dash Express users pull real-time traffic information via GSM or WiFi**
- **Product released in Q1 2008**
MobEyes (UCLA)

• “Epidemic diffusion”:
  – *Mobile nodes* periodically broadcast *meta-data* of events to their neighbors
  – A *mobile agent* (the police) queries nodes and harvests events
  – Data dropped when stale and/or geographically irrelevant
MobEyes: Mobility-assisted Diffusion/Harvesting

• **Mobeyes** exploit “mobility” to disseminate meta-data!

• *Mobile nodes* periodically broadcast meta-data to their neighbors
  – Only “originator” advertises meta-data to neighbors
  – Neighbors store advertisements in their local memory
  – Drop stale data

• A *mobile agent* (the police) harvests meta-data from mobile nodes by actively querying them (with Bloom filter)
Simulation Experiment

- **Simulation Setup**
  - NS-2 simulator
  - 802.11: 11Mbps, 250m tx range
  - Average speed: 5 to 25 m/s
  - Mobility Models
    - Random waypoint (RWP)
    - Real-track model (RT):
      - Group mobility model
      - merge and split at intersections
    - *Westwood* map
Meta-data harvesting delay with RWP

- Higher mobility decreases harvesting delay
Harvesting Results with “Real Track”

- Restricted mobility results in larger delay
Multi-agent Harvesting

• Challenges
  – Scale of operation: harvested region may include several city blocks
  – Location and nature of the critical information not known a priori
  – *Multi-agent harvesting*

• Bio Inspired Approach
  – “Social” animals solve a similar problem – *foraging* to find reliable food sources
Bio Inspired Algorithm Design

- **Data-taxis**
  - Similar to the chemotactic behavior of E-coli bacteria
    - Modes of locomotion: tumble, swim, search
    - Strategy: greedy approach with random search
  - Three modes of agent operation

- **Collision avoidance**
  - Avoids collecting the same data by different agents
  - Pheromone trail
  - Move in a direction to minimize collision (Levy jump)
Evaluation Framework

- **Simulation setup**
  - Manhattan mobility model
  - Streets 2 and 6 with valuable information
  - Up to 4 agents

- **Candidate algorithms**
  - RWF (Random Walk Foraging)
  - BRWF (Biased RWF)
  - PPF (Preset Pattern Foraging)
  - DTF (Data-taxis Foraging)

7x7 Manhattan grid
Performance Results

Aggregate number of harvested data

QuickTime™ and a decompressor are needed to see this picture.
Vehicular Security requirements

Sender authentication
Verification of data consistency
Protection from Denial of Service
Non-repudiation
Privacy

Challenge: Real-time constraint
Privacy Attack: Tracking
New security requirements for dissemination

Selective, private dissemination:

• **Example #1:** A driver wants to alert all taxicabs of company A on Washington Street between 10-11 pm that convention attendees need rides

• **Example #2:** A Police Agent has detected a dangerous radiation leak:
  – He wants to warn the private cars in the radiation area ONLY
  – He wants to notify all the paramedics and firemen in a larger surrounding area.
Situation Aware Trust (SAT)
critical for “selective” dissemination

Situation?

Attribute based Trust
- Situation elements are encoded into some attributes
- Static attributes (affiliation)
- Dynamic attributes (time and place)

Social Trust
- Bootstrap initial trust
- Transitive trust relations

Dynamic attributes can be predicted

Attributes bootstrapped by social networks

Proactive Trust
- predict dyn attributes based on mobility and location service
- establish trust in advance

An attribute based situation example:
Yellow Cab AND Taxi AND Washington Street AND 10-11pm 8/22/08
Security: attributes and policy group

A driver wants to alert all taxicabs of company A on Washington Street between 10-11pm that convention attendees need rides.

Central Key Master

Extension of Attribute based Encryption (ABE) scheme [IEEE S&P 07] to incorporate dynamic access tree

Attribute (companyA AND taxi AND Washington St. AND 10-11am)

Receivers who satisfy those encoded attributes (have the corresponding private key) can decrypt the message.
C-VeT
Campus - Vehicular Testbed

E. Giordano, A. Ghosh,
G. Marfia, S. Ho, J.S. Park, PhD
System Design: Giovanni Pau, PhD
Advisor: Mario Gerla, PhD
The Plan

• **We plan to install our node equipment in:**
  – 30 Campus operated vehicles (including shuttles and facility management trucks).
    • Exploit “on a schedule” and “random” campus fleet mobility patterns
  – 30 Commuting Vans: Measure urban pollution, traffic congestion etc
  – 12 Private Vehicles: controlled motion experiments
  – Cross campus connectivity using 10 node Mesh  (Poli Milano).
C-VeT Goals

Provide:

• A shared virtualized environment to test new protocols and applications
• Full Virtualization
  – MadWiFi Virtualization (with on demand exclusive use)
  – Multiple OS support (Linux, Windows).

Allow:

• Collection of mobility traces and network statistics
• Provide a platform for Urban Sensing, Geo routing etc
• Deployment of innovative V2V/V2I applications
Preliminary Experiments

• Equipment:
  – 6 Cars roaming the UCLA Campus
  – 802.11g radios
  – Routing protocol: OLSR
  – 1 EVDO interface in the Lead Car
  – 1 Remote Monitor connected to the Lead Car through EVDO and Internet

• Experiments:
  – Connectivity map computed by OLSR
  – Azureus P2P application
Campus Initial Coverage Using MobiMesh
“Instrumenting” the vehicle
Campus Demo: connectivity via OLSR
Conclusions

New VANET research opportunities:

• Mobility models:
  – Collection, measurements
  – Interaction between motion and network models

• Routing:
  – Geo routing, Delay tolerant routing, Network Coding,

• New Applications:
  – Content, mobile sensing, harvesting
  – Urban surveillance; pollution monitoring
  – Intelligent highways

• Security:
  – Private dissemination
  – Situation Aware Trust
The Future

• Still, lots of exciting research ahead

• And, need a testbed to validate it!
  – Realistic assessment of radio, mobility characteristics
  – Account for user behavior
  – Interaction with (and support of) the Infrastructure
  – Scalability to thousands of vehicles using hybrid simulation

• We are building one at UCLA - come and share!
Thank You!