Location-Aware Protocols in Vehicular Networks

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Intelligent Transportation System Applications

- Vehicular networks likely driver for deployment of wireless ad hoc and sensor systems
  - Compelling application scenarios: Vehicular accidents account for ~40,000 fatalities/yr (in US)
  - FCC approved spectrum for Dedicated Short Range Communications
  - IEEE 802.11p will standardize MAC for vehicular environment
  - Challenging requirements: high velocity, low-latency environment, privacy, security, reliability

- Automotive safety
  - Obstacle/slow-traffic-ahead warning
  - Red-light warning
  - Active Collision Avoidance

- Congestion Management
  - Real-time traffic information
  - Navigation traffic-aware travel time optimization
  - Improved information for traffic engineering

- Entertainment
  - Video, Web, Gaming

- Efficient Pricing and Payment
  - “Pay-as-you-drive” insurance
  - Highway tolls
  - Gas station payments

- Point-of-Interest Queries
  - Finding nearby hotels, gas stations; travel guides, local entertainment

- Fleet management
  - Tracking fleet of company vehicles

Key Applications
Add-on Applications
Vehicle-to-Vehicle Communications (V2V)

- Current Automotive Technology
  - Passive safety
    - Seatbelts
    - Airbags
  - Active safety through in-vehicle sensors
    - ESP
    - Brake Assist
    - Adaptive Cruise Control

- V2V Opportunities
  - Extended sensing range
  - Inter-vehicle coordination

Extended Sensing Examples

- GPS/V2V Stalled vehicle warning
- GPS/V2V Blind spot warning

Source: GM Press Release 2005
Longer-term vision: Smart Bridge with Closed-Loop Interaction
Research Challenges

- **MAC/Routing**
  - Reliable messaging with high frame error rates (fast-changing obstructions)
  - Low-latency requirements
  - Frequent topology change
  - Highly-variable node density

- **Group/Swarm formation**
  - Quick connection establishment
  - Closed-loop interaction
  - Addressing/identifying relevant vehicles

- **Security & Privacy**
  - Unique addresses enables monitoring of nearby vehicles
  - Criteria for pseudonymity and anonymity of location traces
  - Denial-of-service resistant MAC and routing protocols

- **Performance Evaluation**
  - Improved simulation models: mobility patterns, channel errors
  - Testbeds to reduce effort of experimental performance validations

Not 802.11 + AODV/DSR. Need bottom-up Cross-layer design For vehicular networks
## Challenge: Connection Setup Delay

<table>
<thead>
<tr>
<th>Layer</th>
<th>Item</th>
<th>Time</th>
</tr>
</thead>
<tbody>
<tr>
<td>L2</td>
<td>802.11 scan (passive)</td>
<td>0 ms (cached), 1 second (wait for Beacon)</td>
</tr>
<tr>
<td>L2</td>
<td>802.11 scan (active)</td>
<td>40 to 300 ms</td>
</tr>
<tr>
<td>L2</td>
<td>802.11 assoc/reassoc (no IAPP)</td>
<td>2</td>
</tr>
<tr>
<td>L2</td>
<td>802.11 assoc/reassoc (w/ IAPP)</td>
<td>40</td>
</tr>
<tr>
<td>L2</td>
<td>802.1X authentication (full)</td>
<td>1000</td>
</tr>
<tr>
<td>L2</td>
<td>802.1X authentication (fast resume)</td>
<td>250</td>
</tr>
<tr>
<td>L2</td>
<td>Fast handoff (4-way handshake only)</td>
<td>60</td>
</tr>
<tr>
<td>L3</td>
<td>DHCPv4</td>
<td>1000</td>
</tr>
<tr>
<td>L3</td>
<td>Initial RS/RA</td>
<td>5</td>
</tr>
<tr>
<td>L3</td>
<td>Wait for subsequent RA</td>
<td>1500</td>
</tr>
<tr>
<td>L3</td>
<td>DAD (full)</td>
<td>1000</td>
</tr>
<tr>
<td>L3</td>
<td>Optimistic DAD</td>
<td>0</td>
</tr>
<tr>
<td>L3</td>
<td>MN-HA BU</td>
<td>1 RTT (IKE w/HA SA), 4 RTT (IKE w/CoA SA)</td>
</tr>
<tr>
<td>L3</td>
<td>MN-CN BU</td>
<td>1-1.5 RTT (CAM) to 2.5 RTT (RR)</td>
</tr>
<tr>
<td>L4</td>
<td>TCP parameter adjustment (status quo)</td>
<td>5000 (802.11/CDMA) - 20000 (802.11/GPRS)</td>
</tr>
</tbody>
</table>

**Best case**
- All fixes

**Average case**
- 6to4, RR, Active scan

**Worst case**
- No TCP changes, full EAP auth, IAPP, DHCPv4

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Challenge: High node densities

- Warning messages must be reliably delivered in both low and high density scenarios
- 802.11 broadcast suffers too many collisions in high density case
Experimental 802.11 MAC Scalability Analysis

- ORBIT: 400 nodes in 20m x 20m– two 802.11 radios each (atheros and intel-based)
- Experiment: Measure cumulative goodput in saturation for different numbers of senders
Scalability Results

Without rate adaptation (rate fixed to 54Mbps)

Standard MAC
Implementation 1: SampleRate

Standard MAC
Implementation 2: Onoe

Throughput (packets per second)
Location in Vehicular Networks

- Vehicular networks have many properties of conventional ad hoc networks
  - Do not scale well to large networks with high node mobility
- Key difference: Positioning through GPS already available in many vehicles
  - Positioning coverage can be increased through integration with vehicle velocity, inertial sensors, compass, etc.
  - Vehicles also travel on (short-term) predictable paths and contain map information
- Enables a set of new protocols
Example: Opportunistic Geocast for Warning Messages

- Location is a more natural addressing mechanism
  - Location becomes more important than a network address
- Opportunistic message forwarding within geographic perimeter
- Retransmissions from different vehicles
- (Delay-tolerant networking)

Desired message delivery zone

(Idealized) Broadcast range

Image © 2005 Sunborn
Location-Based Flooding

- Packets carry perimeter and directional information
- Location-based assignment of delay:

\[ T_{\text{delay}} = \text{Max}_{\text{delay}} \times \text{GaussianRV}(1 - \text{progress}, 0.3) \]
- Timer-based suppression of multiple rebroadcasts

Receive a packet \( PID = k \)
measure \( \text{Pkt}_\text{interval} \)
if (first reception for \( PID = k \))
    Set the timer as \( T_{\text{delay}} \)
else
    increase \( \text{Counter} \) for \( PID = k \)
Timer expire
if (\( \text{Counter for PID} = k < \text{Max}_{\text{count}} \) & \( \text{RV}(0, 1) < \text{Pkt}_\text{interval} \times \alpha \))
    Forward \( PID = k \)
else
    Drop \( PID = k \)
Packet Delivery Rate Improvements

- 200 vehicles distributed over road segment
- DSRC MAC parameters
- Location-based forwarding shows improved packet delivery rate and efficiency
Location-based Channel Assignment

- Motivation
  - Vehicles sporadically disconnected from infrastructure, requires self-organization
  - Storage (e.g., flash) becoming increasingly affordable

- Location-based clustering and channel assignment
  - Vehicles select channel and node cluster based on a predefined geographic channel map
  - Allows remote monitoring and management
  - Map can be updated periodically (e.g., daily, weekly)
Privacy for Location Information

Identification based on public records, subpoenas not necessary

Geocoded Address Database (TIGER/LINE):

John Doe
1234 Main St
Anywhere, US
(515110X 4300483Y, 13Z)
Privacy Architecture Components

- Applications
- Location Service
- Network
- MAC

Access Control
On-Device Localization
Silent Periods Disp. Addresses
Location Cloaking

Accuracy reduction

Coarse resolution throughout Internet
Medium resolution shared throughout local network
Maximum resolution shared with 1-hop neighbors

IAB Spring 2006
Anonymizing Traces: Path Segmentation Algorithms

- : perturbation area
- : path confusion
- : perturbed location samples
- : original location samples

IAB Spring 2006
Summary

- Vehicular applications is an area where wireless networking can make a real difference and it expose challenging requirements
  - High velocities
  - High reliability constraints
  - Privacy, Security

- Location information is an integral part of or can help to solve many of these problems

- Need for a location architecture
  - No clear unifying candidate among routing/transport protocols: sensing systems will choose from a larger set of possible protocols based on application requirements

- User privacy and accountability are key requirements for location architecture
  - Consider access control and accuracy reduction techniques

- Evaluation strategy leveraging the WINLAB Orbit testbed facilities