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 paymetns
- 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

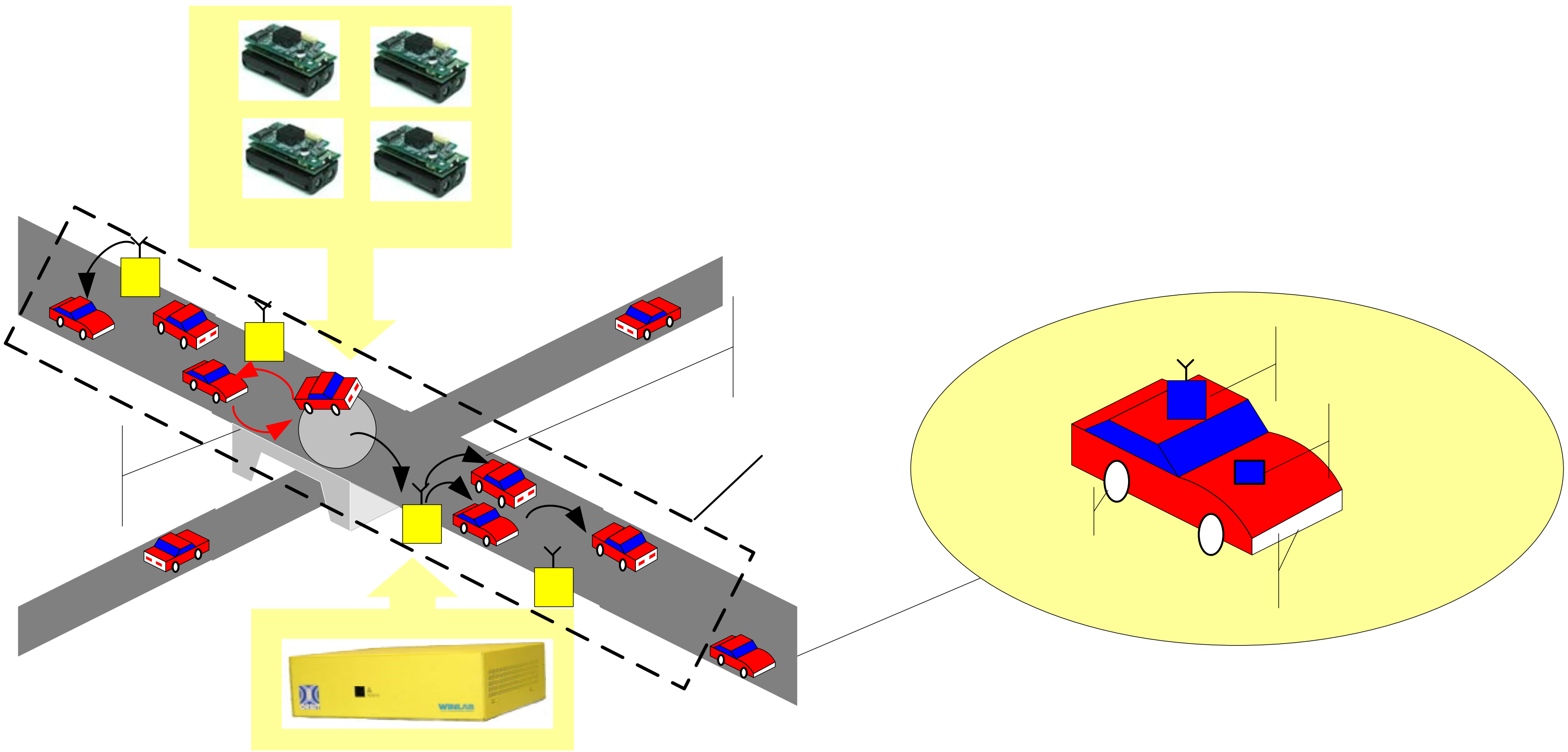
Extended Sensing Examples

GPS/V2V Stalled vehicle warning

GPS/V2V Blind spot warning

Source: GM Press Release 2005

Longer-term vision: Smart Bridge with Closed-Loop Interaction



Sensor Fie

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 pseudonimity 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

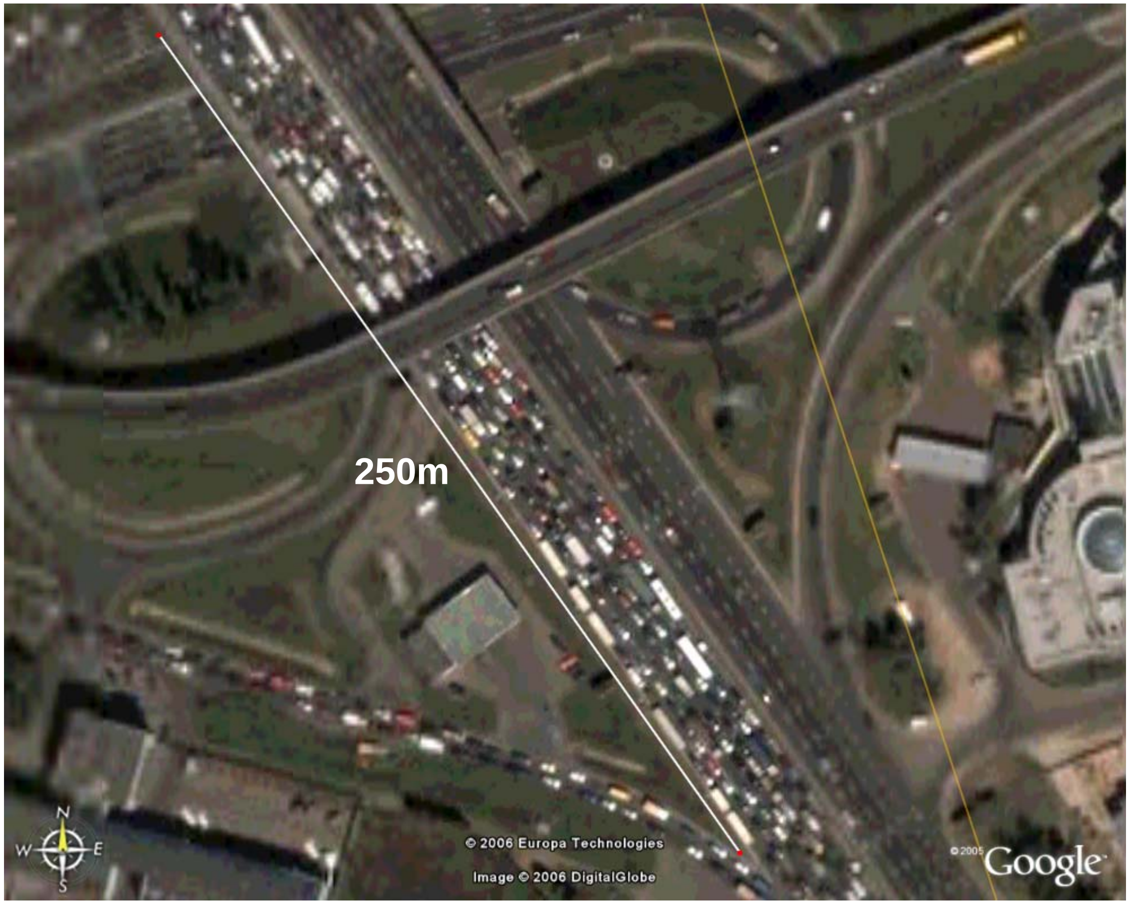
Challenge: Connection Setup Delay

Layer	Item	Time (ms)
L2	802.11 scan (passive)	0 ms (cached), 1 second (wait for Beacon)
L2	802.11 scan (active)	40 to 300 ms
L2	802.11 assoc/reassoc (no IAPP)	2
L2	802.11 assoc/reassoc (w/ IAPP)	40
L2	802.1X authentication (full)	1000
L2	802.1X authentication (fast resume)	250
L2	Fast handoff (4-way handshake only)	60
L3	DHCPv4	1000
L3	Initial RS/RA	5
L3	Wait for subsequent RA	1500
L3	DAD (full)	1000
L3	Optimistic DAD	0
L3	MN-HA BU	1 RTT (IKE w/HA SA), 4 RTT (IKE w/CoA SA)
L3	MN-CN BU	1-1.5 RTT (CAM) to 2.5 RTT (RR)
L4	TCP parameter adjustment (status quo)	5000 (802.11/CDMA) - 20000 (802.11/GPRS)
Best case	All fixes	150 ms
Average case	6to4, RR, Active scan	1300 ms
Worst case	No TCP changes, full EAP auth, IAPP, DHCPv4	25000 ms

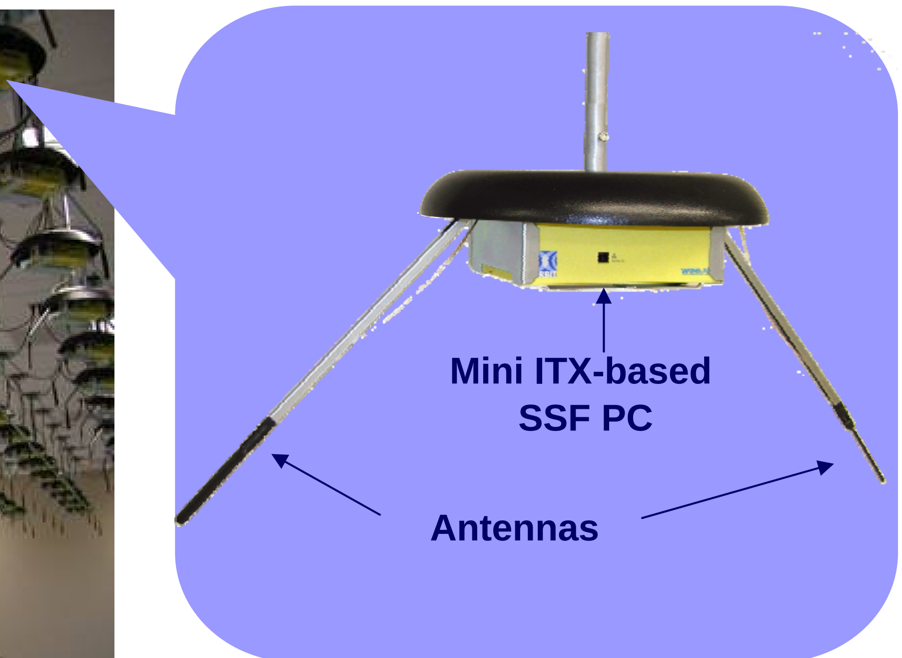
Source: Bernard Aboba, http://www.drizzle.com/~aboba/IEEE/

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

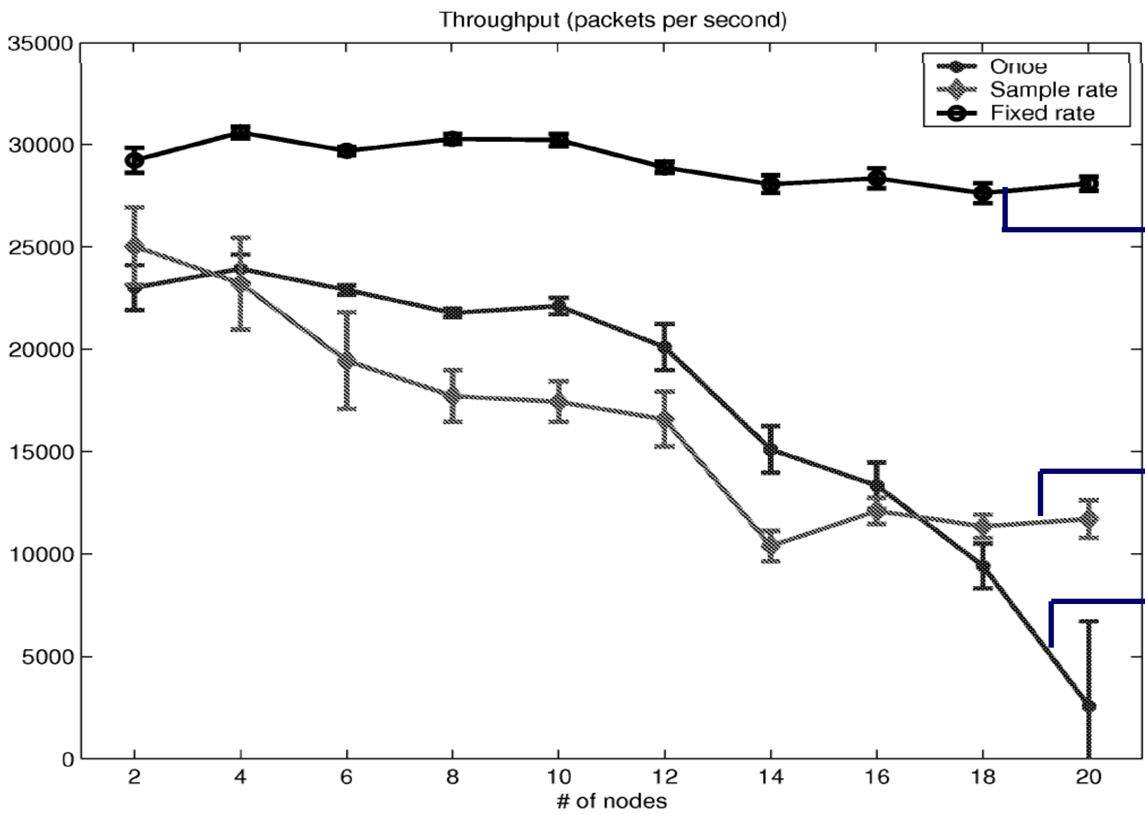


Experimental 802.11 MAC Scalability Analysis



- 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)

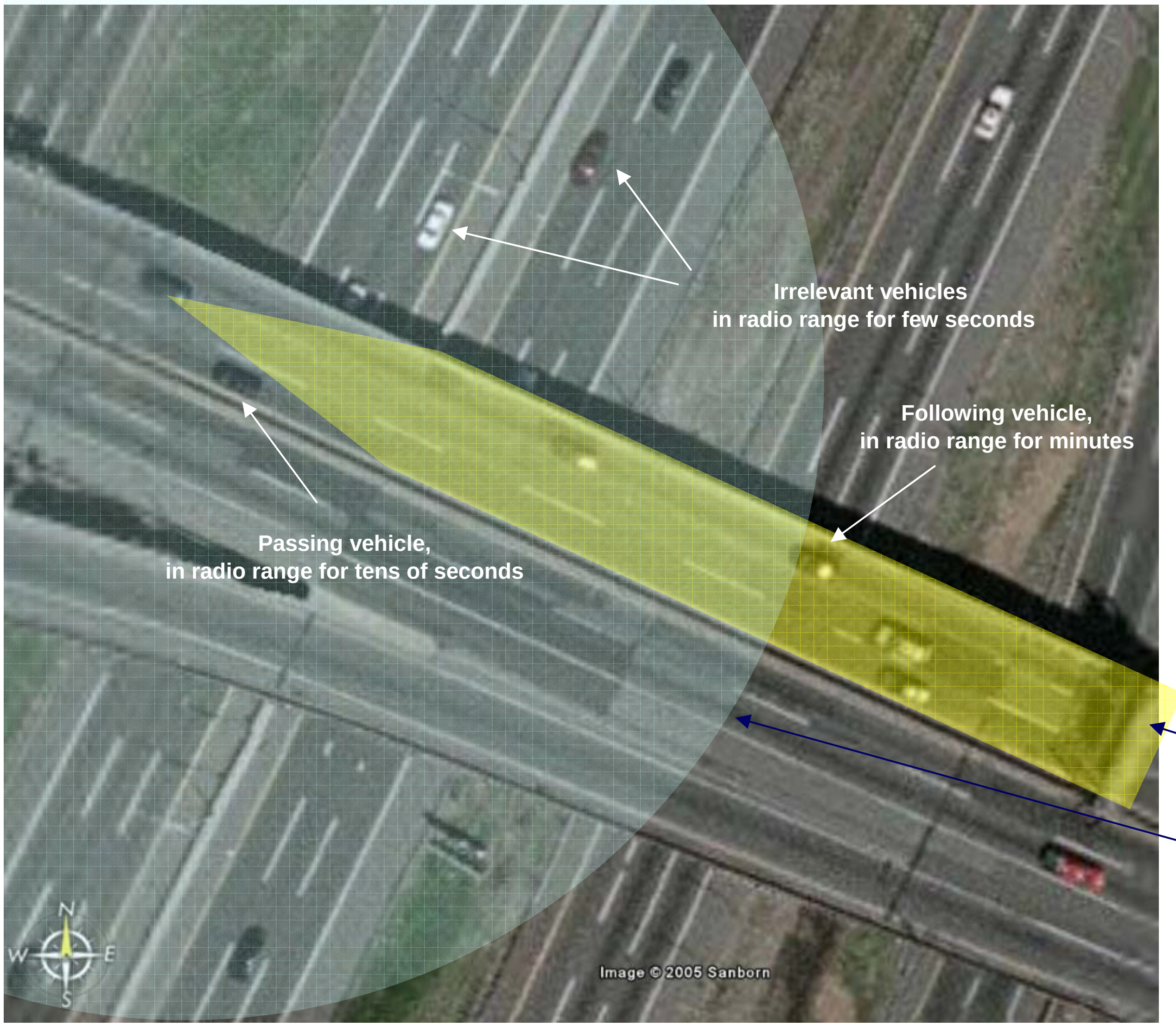
Standard MAC Implementation 1: SampleRate

Standard MAC implementation 2: Onoe

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)

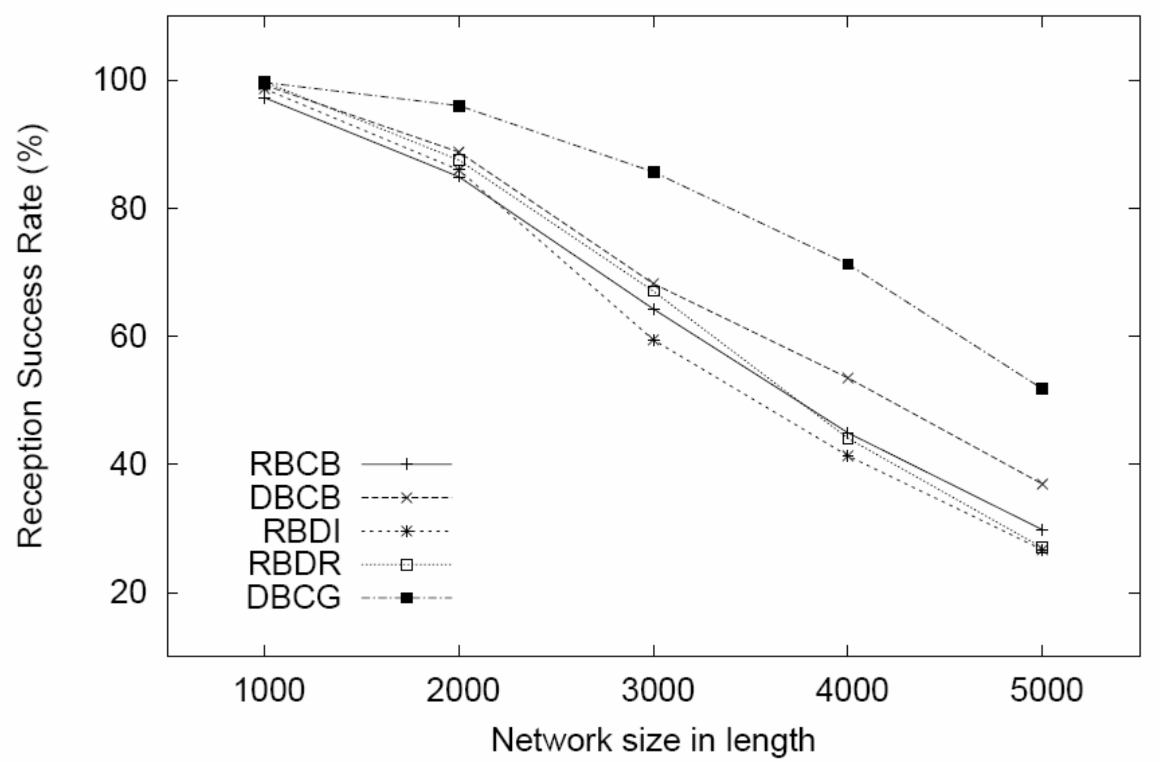
Location-Based Flooding

Receive a packet $PID = k$
    measure $Pkt\_interval$
    if (first reception for $PID = k$)
        Set the timer as T_delay
    else
        increase $Counter$ for $PID = k$
Timer exprire
    if ($Counter\ for\ PID = k < Max\_count\ \&$
      $RV(0,1) < Pkt\_interval * \alpha$)
        Forward $PID = k$
    else
        Drop $PID = k$

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

  T_delay = Max_delay * GaussianRV((1- progress), 0.3)
- Timer-based suppression of multiple rebroadcasts

Packet Delivery Rate Improvements

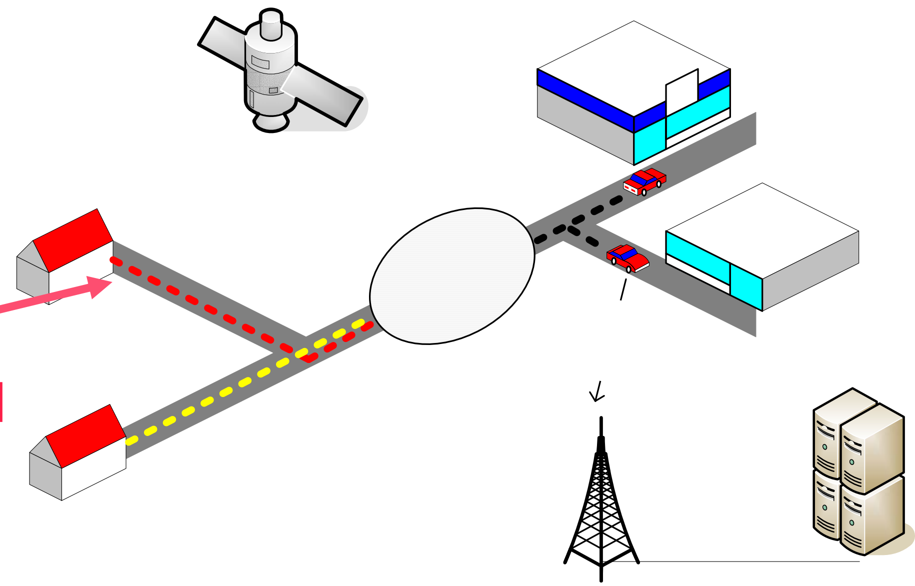


- 200 vehicles distributed over road segment
- DSRC MAC parameters
- Location-based forwarding shows improved packet delivery rate and efficiency

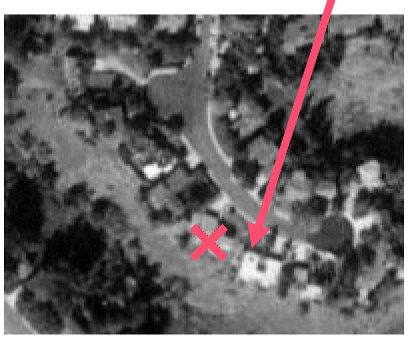
Location-based Channel Assignment

- 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



[515110X 4300483Y 13Z]

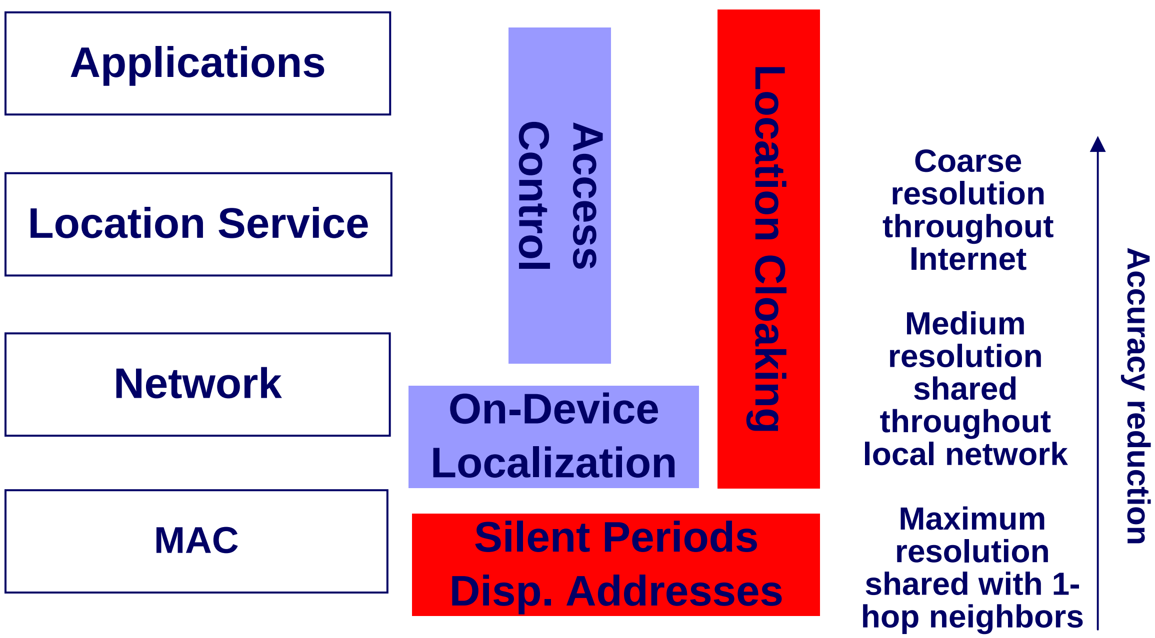


Geocoded Address Database (TIGER/LINE):

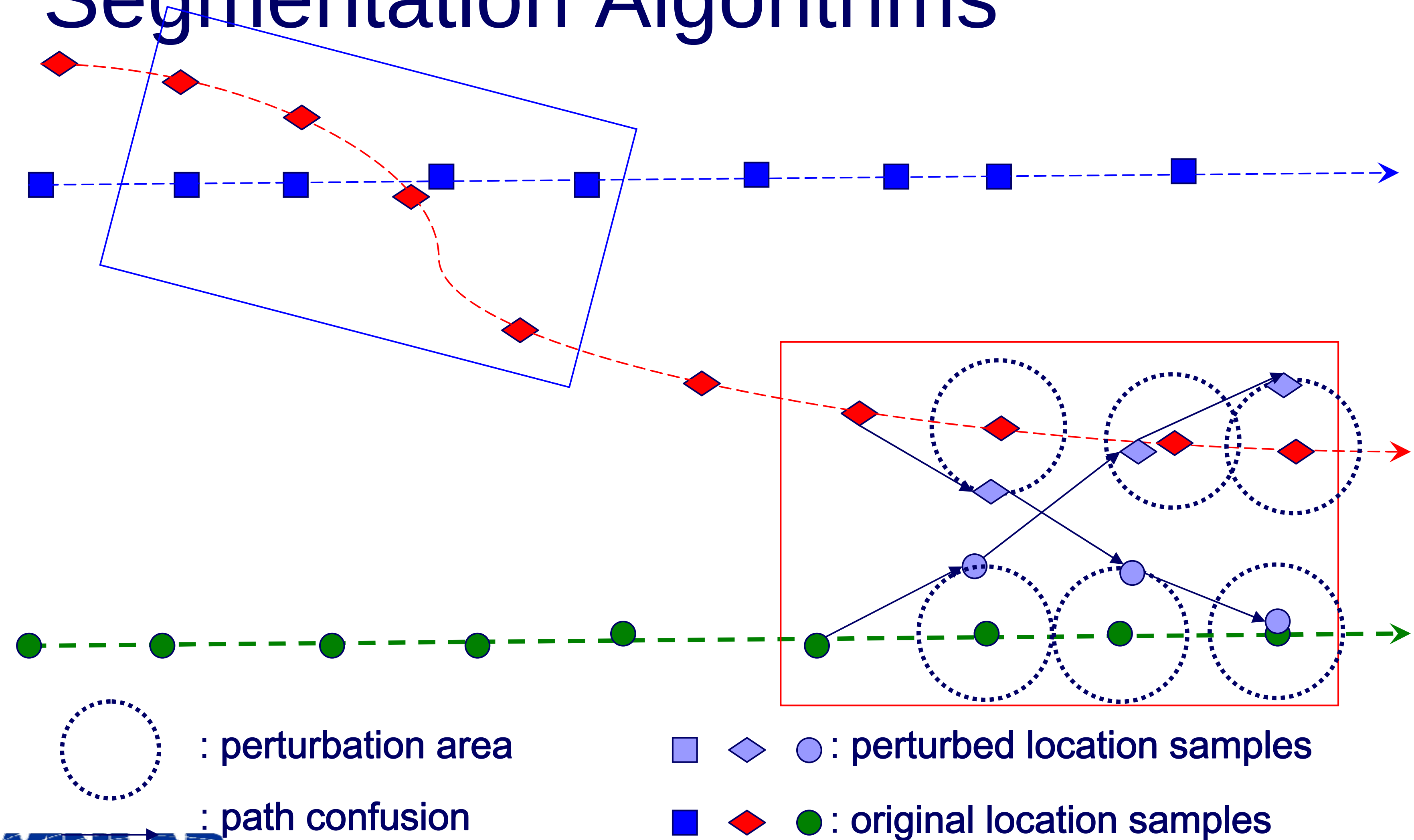
John Doe
1234 Main St
Anywhere, US
(515110X 4300483Y, 13Z)

Identification based on public records, subpoenas not necessary

Privacy Architecture Components



Anonymizing Traces: Path Segmentation Algorithms



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