Vehicular cloud computing: from intelligent transport to urban surveillance

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Outline

• The emergence of vehicular communications: VII and “Connected Vehicle”
  – Initial applications: safety and content distribution

• Vehicular Cloud computing
  – Principles and Challenges
  – Vehicle Cloud vs Internet Cloud

• Two Vehicle Cloud Applications:
  – Urban surveillance
  – Vehicular Traffic Management

• Future Directions
The Vehicle Transport Challenge

Safety
• 33,963 deaths/year (2009)
• 5,800,000 crashes/year
• Leading cause of death for ages 4 to 34

Mobility
• 4.2 billion hours of travel delay
• $78 billion cost of urban congestion

Environment
• 2.9 billion gallons of wasted fuel
• 22% CO₂ from vehicles
In 2003 DOT launches: Vehicle Infrastr. Integration (VII)

- VII Consortium: USDOT, automakers, suppliers, ..
- Goal: V2V and V2I comms protocols to prevent accidents
  - Technology validation;
  - Business Model Evaluation
  - Legal structure, policies
- Testbeds: Michigan, Oakland (California)
- However: 10 year to deploy 300,000 RSUs and install DSRC on 100% cars
- Meanwhile: can do lots with 3G and smart phones
- Can we speed up “proof of concept”?

Enter Connected Vehicle (2009-2014)
The Connected Vehicle Program

• Previous Veh Infrastr Integr (VII) Model (2003-9)
  – DSRC based for all applications
  – Start with V2I (for all application types) and evolve into V2V (safety)

• Current DOT’s Connected Vehicle Plan
  – Non-safety (mobility, environment)
    • Leverage existing data sources & communications; include DSRC as it becomes available
  – Safety $\rightarrow$ DSRC
    • Aggressively pursue V2V;
    • Can leveraging of nomadic devices & retrofitting accelerate benefits?
Emerging Application Areas

- Safe Navigation
- Location Relevant Content Distr.
- Entertainment, Games
- Urban Sensing
- Efficient, Intelligent, Clean Transport
V2V for 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/sec^2
Coefficient of friction: .65
Driver Attention: Yes
Etc.

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

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

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

Alert Status: None

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

Alert Status: None

Alert Status: Passing Vehicle on left
Location relevant content delivery

- Traffic information
- Local attractions, advertisements
- Tourist information, etc

*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
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

Solution: Co-operative P2P Downloading via Car-Torrent (like BitTorrent in the Internet)
CarTorrent: Basic Idea

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
Vehicular Cloud computing

Observed trends:

1. Vehicles perform increasingly more complex (sensor) data collection/processing
   - road alarms (pedestrian crossing, electr. brake lights, etc)
   - cooperative content downloading via P2P car-torrent
   - surveillance (video, mechanical, chemical sensors)
   - road mapping via “crowd sourcing”
   - accident, crime witnessing (for forensic investigations, etc)

2. Spectrum is scarce => Internet upload expensive

Enter Vehicular Cloud Computing:

Keep and process data on vehicle cloud instead of uploading to Internet cloud
Vehicle Cloud vs Internet Cloud

• **Both offer a significant pool of resources:**
  – computing, storage, communications

**However:**

• **Vehicular applications are mainly location relevant**
  – Data Sources: Drivers or environment
  – Customers: generally the drivers

• **Vehicle cloud interacts with:**
  – Internet cloud
  – Personal (smart phone) cloud

• **Exception: emergency VANET**
  – During an emergency the infrastructure is destroyed
  – Emergency cloud is isolated, works on its own power
  – Vehicle (especially E-vehicles) become the ONLY available computing/comms resource
We review two emerging Vehicle Cloud applications

• **Surveillance**
  – Monitoring the environment events (natural or manmade)

• **Urban Traffic management:**
  – From totally centralized to locally distributed to evacuation
Surveillance Scenario: storage and retrieval

- Participating Cars (busess, taxicabs, commuters):
  - Continuously collect images from the street (store data locally)
  - Process the data and detect an event
  - Classify the event as Meta-data (Type, Option, Loc, time, Vehicle ID)

- Question: how to access this info?

![Diagram of crash scenario with sensing, processing, and reporting components.]
Mobility-assisted Meta-data Diffusion/Harvesting (*Mobeyes 2007*)

- + Broadcasting meta-data to neighbors
- + Listen/store received meta-data
- Periodical meta-data broadcasting
- Agent harvests a set of missing meta-data from neighbors

Diagram:
- HREQ
- HREP
MobEyes: Mobility-assisted Epidemic Dissemination

• Mobeyes exploit “mobility” to disseminate meta-data!
• Source periodically broadcasts meta-data to neighbors
  – Only source can advertise meta-data
  – Neighbors store advertisements in their local memory
  – Drop stale data
• A mobile agent (the police) harvests meta-data from vehicles by querying them (with Bloom filter)
Urban Surveillance as a Service

• Suppose a green truck was involved in a suicidal terrorist attack
  – The truck blows up
  – The Agency wants to find out the approach path of the vehicle
  – Wants to learn if any accomplices drove along with the truck up to the target

• Conventional solution: “road side” video cameras
  – Sophisticated attacker can avoid video cameras, or disable them

• Mobeyes based solution:
  – Reconstruct the path by using the other vehicles video cameras

• We have run a simulation experiment in a 2kmx2km area, with 100 vehicles roaming
  – Vehicles watch each other and agent reconstructs all paths
Trace Reconstruction

![Graph showing Max and Average Uncovered Intervals](image)
Trace Reconstruction
Vehicle Cloud for intelligent navigation

- GPS Based Navigators
- Dash Express (came to market in 2008):
  - Synergy between Navigator Server and City Transport Authority
NAVOPT – Navigator Assisted Route Optimization

• **On Board Navigator**
  - Interacts with the Server
  - Periodically transmits GPS and route
  - Receives route instructions

• **Manhattan grid (10x10)**
  - 5 routes (F1~ F5) from source to destination
  - Link capacity: 14,925 [vehicles/h]
Analytic Results

Total average delay (h/veh)
Sumo simulation results

- **Sumo-0.12**
  - 10 X10 grid
  - Road segment: 400m
  - Length of vehicle: 4m
  - Max speed limit: 60Km/h

- **Average delay**
  - Delay increases drastically around 15000 rate [veh/h] in case of shortest path
  - In NAVOPT, delay slightly increases around 20000
Distributed traffic management

- Centralized traffic management cannot react promptly to local traffic perturbations
  - A doubled parked truck in the next block; A traffic accident; A sudden surge of traffic
  - Internet based Navigator Server cannot micro-manage traffic for scalability reasons
- Enter distributed, v-cloud based traffic mgmt
  - Distributed approach a good complement of centralized supervision
CATE: Comp Assisted Travl Environment

• Vehicles crowd source traffic information and traffic load data base:
  – 1) sensing traffic information;
  – 2) sharing it with neighboring vehicles (in an ad hoc manner); and
  – 3) dynamically recomputing the best route to destination from the current position based on the collected information.

• The study was done by simulation:
  – QUALNET a popular event driven MANET simulator, and
  – MobiDense, a mobility simulator that combines topology and traffic flow information to generate a mobility trace.
  – Case Study: Traffic pattern for Portland obtained from Los Alamos Lab

• Potential limitations of CATE:
  – Delay in traffic loads propagation; lack of trip destination info
Traffic loading w/o CATE

Green no congest   Yellow moderate   Red heavy congest
Traffic loading with CATE

Green no congest  Yellow moderate  Red heavy congest
Information Propagation Speed

Two-dimensional Heatmap of age of received information (in seconds) about the link highlighted by the arrow (bridge).
CATE tested on C-VET

- Up to 8 vehicles roaming the Campus with GPS, WiFi radios and 250m range
- Static throughput between two nodes = 30Mps
- At 30km/h throughput = 7Mbps
- Propagation of a 2MB block (traffic sample) from one node to the other 7 nodes:
  - First vehicle received full block in 20s
  - Next four in < 72s
  - Last two in < 125s
Work ahead in Vehicle Cloud research

- Vehicle cloud formation and maintenance
  - Subclouds with common “social” interests
- In-Cloud networking
  - Cloud Content dissemination, storage, indexing, search (Content Centric Networking)
- Efficient spectrum usage (via cog radios)
  - Exploit WiFi spectrum – short range
  - Exploit TV spectrum – long range connections (to other vehicle clouds)
- User-centric security and privacy protection
- Interaction with Internet Cloud
- Interaction with pedestrian (people) clouds
The End

Thank You