The Role and Design of V2X Communications for Automated Driving

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V2X Communications can be very important sensor for automated driving. It can provide collaborated driving, long range sensing and non line-of-sight capability for automated car.
Background: The Connected Vehicle

- E-payment
- Signal Phase and Timing
- Safety Messages
- Probe Data
- Instrumented Roadside
- “The Network”

Opportunity for Innovation

- Real Time Network Data
- Situation Relevant Information

Instrumented Roadside
Collision Avoidance: What if …?

Legend:

- Message Transmission (range 100s meters)
- Vehicle heading

In-Vehicle Warning

Intersection Warning

Forward Collision Warning

Blind Spot Caution
DSRC Technology

• DSRC: Dedicated Short-Range Communication
  – Ad hoc networking technology that allows vehicles to communicate with each other and with roadside devices
  – IEEE portions also called: WAVE (Wireless Access in Vehicular Environments)

• An active research for many years
• Moving toward deployment
• Many stakeholders in US and elsewhere
Radar versus V2X

- Contrast radar and V2X

Autonomous Radar

Packet header  intersection state

Frequent broadcasts
360 Degree dissemination
Communication Advantages

- Much more precise data exchanged
- Range = 100s meters
- Communicate with non-nearest neighbors
- Non-line-of-sight capability
- 360 degrees with one device

→ Communication and Sensors are complementary
How does it work?

Example of DSRC Prototype System
Many suppliers are in this space
How does it prevent collisions?

- Each vehicle sends “safety messages”
  - Includes core state info
  - All neighbors receive it
  - Updated frequently (e.g. 100 msec)
  - Sent on dedicated safety channel

- Receiving vehicle models location of all neighbors
  - If potential collision detected, system can warn driver

- This V2X safety application is driving deployment, but there are many other possible future applications
Would Communication play a role in design of Automated Car?

Wireless communication can be quite important technology for getting a non line-of-sight view for the automated driving vehicles.
Problem Statement

• Car is equipped with a set of local sensing modalities (Radar, LiDar, Camera etc.)
• Create a real-time, 3D map of the surroundings up to the sensing distance of local sensors
  – Some applications might require a extended map
  – **Solution:** Extend the map of regions not directly sensed by local sensors through communicating map info
Communication System for Automated Driving

• **Main Idea:**
  – Automated car should not only transmit its GPS information (as in V2X safety communications),
  
  • Also transmit other object information
    – Cars, pedestrians, potholes, signs etc..
    – Notices on the map using its local sensors (camera, radar, lidar etc.)
Proposed System Model

- Communication should collaborate with other sensors (cameras, radars etc.) in building the real-time map of the road.
Proposed System Model

CSAM: Cooperative Situational Awareness Message
Latest map information collected by Radar, Camera etc., and communication messages received over-the-air
Present day Communication Technology

• We set-up NS-3 simulations
  – Total length of the highway = 4Km
  – Number of Cars on the road = 100 per Km
  – Power =~ 500 m transmission range (in ns3 simulator)
  – Message rate = 10 Hz
  – Packet size:
    • V2X safety message = 350 Bytes
    • Automated driving message = 350 + x*50 bytes
      – x represents how many other objects vehicle is observing from local sensors
      – 50 Bytes represent an estimate of object information
Numerical Results

- CBP = Channel Busy Percentage (a measure of wireless channel load)

Packet Size = 350 Bytes; x = 0

Packet Size = 2350 Bytes; x = 40

Channel is saturated
Communication Module

Innovative solutions for setting power, message rate, message content are required.
MRDP Control Strategies

• Control strategies of MRDP module
  – Rate-control schemes
  – Range-control schemes
  – Content-control schemes
    • Less congestion broadcast a higher-resolution map
      – Enhance both temporal and spatial accuracy of the map

• Ideally a combination of joint message content, rate, and power (or range) control such that all three parameters are dynamically adapted to control the channel load.
  – Our Current Focus: Fix Message rate and transmit power. Adapt the content of automated driving message.
Map Representation

- Known Objects: use libraries to reduce data size

\( \text{Type}_k, \Delta x_k, \Delta y_k, x_\text{ }(C,k), y_\text{ }(C,k), v_k, H_k, [\Omega_k] \)

Optional history: \( \Omega_k = (x_\text{ }(C,k,m), y_\text{ }(C,k,m), v(k,m), H(k,m), \theta(k,m)) \)

- \( \text{Type}_k \): type of the known object from a finite set (e.g., car, truck, motorcycle, bicycle, and pedestrian)
- \( \Delta x_k \) and \( \Delta y_k \): object’s \( x \) and \( y \) dimensions
- \( (x_\text{ }(C,k), y_\text{ }(C,k)) \): location of the center of the \( k \)th object
- \( v_k \): object’s velocity
- \( H_k \): movement heading
- \( \Omega_k \): optional set with a fixed length \( M \), containing the path history and/or path prediction information about the \( k \)th known object
Map Representation

• Unknown Objects: use multi-resolution map
  – The volume occupied by the $u$th unknown object is divided into $N_u$ cubic sub-regions:
    $$(x_&(u,n), y_&(u,n), z_&(u,n), D_&(u,n))$$
  – $(x_&(u,n), y_&(u,n), z_&(u,n))$: center of the $n$th cube
  – $D_&(u,n)$: dimension of the cube
  – Higher $N_u$ or lower $D_&(u,n)$ -> higher resolution
Adaptive Content Control

- Message size is derived so that the measured load of the network remains within a desirable range.
  - Determine the number of known and unknown objects

- Intelligently determine the content of the automated driving message
  - Distance-sensitive forwarding: Information of objects closer to the sender are included in the message with a higher probability.
  - Don't re-transmit the data for objects that has been recently broadcasted on the channel
Results

Car Density = 125 vehicles/Km

Average CBR Over All Vehicles versus Time

Message size adaptation reduces channel CBR.

- No Length Control, No Content Control
- Adaptive Length Control, No Content Control
- Adaptive Length Control, Adaptive Content Control
Results

Car Density = 125 vehicles/Km

Information age is measure of how quickly automated car knows about the changes on the map

Should be further optimized with joint rate, power and content control
Conclusions

• V2X is revolutionary – the next frontier for wireless.
  – We’ve come a long way in technical areas for V2X Safety Communications
    • feasibility and basic technology now pretty mature

• V2X can play an important role in automated driving
  – Innovative algorithms for automated driving communications will be required
Questions?

Thank You