Vehicular Millimeter Wave Communications: Opportunities and Challenges

Professor Robert W. Heath Jr.

Wireless Networking and Communications Group
Department of Electrical and Computer Engineering
The University of Texas at Austin

www.profheath.org
**Introduction**

- Dedicated Short Range Communication is a mature technology
  - Based on 15 year old WiFi technology
  - Products already available on market
    - Arada LocoMate, Redpine Signals, etc.
  - Supports very low data rates (27 Mbps max)
- **Connected vehicles** will need gigabit per second (Gbps) data rates
  - Expanding number of sensors: radar, LIDAR, camera, etc.
  - Can not achieve Gbps in the small 10 MHz channels in 5.9GHz band
- How can higher data rates be achieved?

Using the millimeter wave (mmWave) band!!

* http://www.aradasystems.com/
Why millimeter wave?

- Huge amount of spectrum (possibly repurposed) at mmWave bands
- Technology advances make mmWave possible in low cost consumer devices

* United States radio spectrum frequency allocation chart as of 2011
MmWave for WLAN/WPAN

<table>
<thead>
<tr>
<th>Standard</th>
<th>Bandwidth</th>
<th>Rates</th>
<th>Approval Date</th>
</tr>
</thead>
<tbody>
<tr>
<td>IEEE 802.11ad</td>
<td>2.16 GHz</td>
<td>6.76 Gbps</td>
<td>Dec. 2012</td>
</tr>
</tbody>
</table>

- Standards developed @ unlicensed 60 GHz band
  - WirelessHD: Targeting HD video streaming
  - IEEE 802.11ad: Targeting Gbps WLAN

- Compliant products already available
  - Dell Alienware laptops, Epson projectors, etc.
  - 11ad Chipset available from Wilocity, Tensorcom, Nitero

- Extension of 802.11ad is underway (>20 Gbps)*

* http://www.ieee802.org/11/Reports/ng60_update.htm
** http://www.wirelesshd.org/consumers/product-listing/
*** http://www.dailytech.com/
MmWave is coming for 5G cellular

- Repurpose existing mmWave spectrum for mobile cellular applications
  - MmWave used to provide high throughput in small geographic areas
- MmWave cellular networks differ from < 3GHz networks
  - Directional beamforming for signal power and reduced interference
  - Sensitivity to blockages, indoor coverage more challenging

MmWave for automotive radar

- Long range radar (LRR) is used for automatic cruise control (ACC)
- Medium range radar (MRR) supports CTA, LCA, stop&go and BSD
- Short range radar (SRR) is used for parking aid and precrash applications

<table>
<thead>
<tr>
<th>Type</th>
<th>LRR</th>
<th>MRR</th>
<th>SRR</th>
</tr>
</thead>
<tbody>
<tr>
<td>Frequency band (GHz)</td>
<td>76-77</td>
<td>77-81</td>
<td>77-81</td>
</tr>
<tr>
<td>Bandwidth (GHz)</td>
<td>0.6</td>
<td>0.6</td>
<td>4</td>
</tr>
<tr>
<td>Range (m)</td>
<td>10-25</td>
<td>1-100</td>
<td>0.15-3</td>
</tr>
<tr>
<td>Distance accuracy</td>
<td>0.1</td>
<td>0.1</td>
<td>0.02</td>
</tr>
</tbody>
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Potential of mmWave V2V

- Enhanced local sensing capability in connected cars
  - Share high rate sensor data: radar, LIDAR, video, IR video, other sensors
  - Data fusion from other cars can enlarge the sensing range
- Enable the transition from driver assisted to autonomous vehicles
  - Develop a better understanding of the local environment
  - Seamlessly scales with more vehicles

Potential of mmWave V2I

- Cloud processing of sensor data from vehicles
  - Centralized driver assistance and traffic management
  - Precise traffic monitoring and congestion control
  - Improved safety through more accurate window into the roadway
- Infotainment services
  - Video, multimedia, and data for passengers
Vehicular mmWave challenges: Channel modeling

- **V2V channels**
  - Low antenna height
  - Both TX and RX are moving

- **MmWave channel characteristics**
  - High path loss
  - High penetration loss and poor diffraction capability

- **Channel classifications considered at 5.9GHz is unlikely to scale**
  - More sensitive to antenna orientation
  - More sensitive to traffic density (higher blockage probability)
  - Effect of directive transmission is unknown

- **Few measurements available**

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** S. Takahashi, et al., “Distance dependence of path loss for millimeter wave inter-vehicle communications,” in VTC 2003-Fall, Oct. 2003,

Vehicular mmWave challenges: Antenna placement

- A classic problem even at low frequencies*
  - Shadowing becomes blockage for mmWave
  - Directional transmission adds another challenge
- V2V require 360 degree coverage but antennas can not penetrate car
  - Front bumper location causes blockage at the back side
  - Rooftop location causes blockage at the front side due to roof curvature
  - Sensitive to antenna orientation

Vehicular mmWave challenges: Beam alignment

- Beamforming with narrow beams required to compensate high path loss
  - Narrow beam needed for reasonable coverage range
  - Narrow beam needed to suppress Doppler spread
- Existing methods are designed for low mobility environment
  - Beam sweeping based on hierarchical beam codebook
- Alignment overhead within coherence time: gain vs. overhead tradeoff

Preliminary result: Coherence time and beamwidth

- Mathematical expression relating coherence time and beamwidth
  - Accounts for beam pointing angular difference as oppose to classical models
  - Dependent on angle between beam direction and direction of travel
  - There exists optimal beamwidth maximizing the coherence time

Combining communication and radar at mmWave

- MmWave is already used for radar, why not share with communication?
  - Combines the objectives of radar and communication
  - Shared hardware reduces cost, size, and spectrum usage
A communication-radar framework

Common optimized waveform for radar and communication

Develop software-defined radio prototype w/ National Instruments

MmWave communication-radar challenges

- Optimization of sensing and data communication
  - LFM waveform provides low data rate
  - DSSS exhibits poor radar performance
  - No single waveform yet available
  - Interference issue

- Assumption of full-duplex
  - Separate transmit and receive antenna
  - Use of directional antennas

Preliminary result: Range and velocity estimation

IEEE 802.11ad waveform works well for radar

- Leverages existing WLAN receiver algorithms for parameter estimation
- Special structure of preamble enables improved radar performance

Conclusions

- MmWave brings new benefits to V2V and V2I
  - Higher data rates using existing mmWave radar waveforms
  - Exchange of sensor/camera/radar data among connected vehicles
  - Sensor fusion between communication and radar for collision avoidance

- Many challenges remain to make mmWave a reality

D-STOP at UT is making fundamental progress in mmWave for V2X