Vehicle-to-X communication using millimeter waves

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Thanks to sponsors including the U.S. Department of Transportation through the Data-Supported Transportation Operations and Planning (D-STOP) Tier 1 University Transportation Center, the Texas Department of Transportation under Project 0-6877 entitled “Communications and Radar-Supported Transportation Operations and Planning (CAR-STOP)”, National Instruments, Huawei, and Toyota IDC

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5G is embracing new objectives and applications

Higher rates
- Peak data rate
- User exp. data rate
- Area traffic capacity
- Energy efficiency
- Mobility
- Connection density
- Latency

Lower latency

Multidimensional objectives*

New industry verticals**
- Automotive
- e-Health
- Energy
- Media & Entertainment
- Factory of the Future


5G has many applications in automotive

SAFETY
Exchanging raw sensor data, low latency warnings, leads to better driver assist / automation

TRAFFIC EFFICIENCY
V2X leads to higher levels of traffic coordination & more precise navigation

INFOTAINMENT
Download multimedia data, mobile base station
Infrastructure is also important

- Supports sensing of the environment, does not require all cars to have complete sensing equipment
- Can be used for other functions, for example more precise navigation
- Effective with non-connected cars, bicycles, and pedestrians
- Helps coordinate traffic through intersections, eliminating lights
What are the data rate requirements for sensors?

What are the capabilities of current automotive communication solutions?

Where are the remaining research challenges?
## Sensor applications and data rates

<table>
<thead>
<tr>
<th></th>
<th>Purpose</th>
<th>Drawback</th>
<th>Data rate</th>
<th>Update rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Radar</td>
<td>Target detection, velocity estimation</td>
<td>Hard to distinguish targets</td>
<td>Less than 1 Mbps</td>
<td>50-100 ms</td>
</tr>
<tr>
<td>Camera</td>
<td>Virtual mirrors for drivers</td>
<td>Need computer vision techniques</td>
<td>100-700 Mbps for raw images, 10-90 Mbps for compressed images</td>
<td>60-100 ms</td>
</tr>
<tr>
<td>LIDAR</td>
<td>Target detection and recognition, velocity estimation</td>
<td>High cost</td>
<td>10-100 Mbps</td>
<td>67-200 ms</td>
</tr>
</tbody>
</table>

Is it possible to exchange raw sensor data between cars with current technology?
# Current technologies for V2X: DSRC versus LTE-A

<table>
<thead>
<tr>
<th>Features</th>
<th>DSRC</th>
<th>D2D LTE-V2X</th>
<th>Cellular LTE-V2X</th>
</tr>
</thead>
<tbody>
<tr>
<td>Channel width</td>
<td>10 MHz</td>
<td>Up to 20 MHz</td>
<td>Up to 20 MHz</td>
</tr>
<tr>
<td>Frequency Band</td>
<td>5.9 GHz</td>
<td>5.9 GHz</td>
<td>450 MHz-3.8 GHz</td>
</tr>
<tr>
<td>Bit Rate</td>
<td>3–27 Mb/s</td>
<td>Up to 44 Mb/s</td>
<td>Up to 75 Mb/s</td>
</tr>
<tr>
<td>Range</td>
<td>~ 100s m</td>
<td>~ 100s m</td>
<td>Up to a few km</td>
</tr>
<tr>
<td>Spectral efficiency</td>
<td>0.6 bps/Hz</td>
<td>0.6 bps/Hz (typical)</td>
<td>0.6 bps/Hz (typical)</td>
</tr>
<tr>
<td>Coverage</td>
<td>Ubiquitous</td>
<td>Ubiquitous</td>
<td>Inside cell only</td>
</tr>
<tr>
<td>Mobility support</td>
<td>High speed</td>
<td>High speed</td>
<td>High speed</td>
</tr>
<tr>
<td>Cost</td>
<td>Free</td>
<td>?</td>
<td>?</td>
</tr>
<tr>
<td>Latency</td>
<td>x ms</td>
<td>x10-x100 ms</td>
<td>X10 ms</td>
</tr>
</tbody>
</table>

Gbps data rates are not supported

High data rates with millimeter wave (mmWave)

- Large bandwidth at mmWave
- With channel bonding
  - 20 MHz
  - 160 MHz
  - 2 GHz
- Low freq. antenna
- mmWave antenna
- Shrinking antenna aperture
- Adaptive beam steering
- Arrays needed for gain and aperture

Millimeter wave offers the means to achieve high rates and low latency
mmWave for automated cars

Exchanging raw sensor data is possible

Enables high data rate infotainment applications

MmWave is the only viable approach for high bandwidth connected vehicles*

# Potential bandwidths and data rates at mmWave

<table>
<thead>
<tr>
<th></th>
<th>Total spectrum</th>
<th>Typical bandwidth</th>
<th>Peak rates</th>
</tr>
</thead>
<tbody>
<tr>
<td>IEEE 802.11ad* in 60 GHz</td>
<td>7 GHz</td>
<td>2 GHz</td>
<td>6 Gbps</td>
</tr>
<tr>
<td>IEEE 802.11ay in 60 GHz</td>
<td>7 GHz</td>
<td>4 GHz</td>
<td>100 Gbps</td>
</tr>
<tr>
<td>28 GHz 5G</td>
<td>0.85 GHz</td>
<td>200 MHz</td>
<td>1.5 Gbps</td>
</tr>
<tr>
<td>39 GHz 5G</td>
<td>3 GHz</td>
<td>400 MHz</td>
<td>3 Gbps</td>
</tr>
<tr>
<td>E band 5G</td>
<td>10 GHz</td>
<td>2 GHz</td>
<td>24 Gbps</td>
</tr>
</tbody>
</table>

*IEEE 802.11ad is commercially available*
"mmWave enabled infrastructure for transportation"

Combination of sensing, learning and communication

Sensing at the infrastructure

mmWave sensing-BS

mmWave relay

Multiband-connectivity supporting V2X

Vehicles exchanging sensor data

radar beam

multiband BS
Designing mmWave communication systems @UT

Efficient beam alignment leveraging position info

Computing optimum beamwidth and channel coherence time

Joint mmWave comm. and radar using IEEE 802.11ad

StF: Golay complementary sequences

CEF: Data communication

Radar pulse

Synchronization and channel estimation for communication

Radar and communication beam

mmWave BS supporting V2X+radar

Radar beam in another band

antennas

Radar-aided millimeter wave V2X
Research challenges for PHY design

- Leverage side information for beam training and blockage mitigation
- Fast beam alignment and tracking
- MIMO architectures for mmWave V2X: analog or hybrid?
- Effects of hardware impairments on mmWave V2X

Details on existing solutions and research challenges can be found here.
Looking for new partners!

UT SAVES An initiative in partnership with TOYOTA ITC, Huawei, & National Instruments*

SENSING

COMMUNICATION

ANALYTICS