Vehicle-to-X communication for 5G - a killer application of millimeter wave

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Also with MIMO Wireless Inc (see http://www.mimowireless.com).
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See vehicular initiative http://www.utsaves.org

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Fifth generation (5G) cellular communication

**Multidimensional objectives***
- Peak data rate
- User exp. data rate
- Spectrum efficiency
- Mobility
- Connection density
- Latency
- Area traffic capacity
- Energy efficiency

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

Automotive industry is providing key requirements for the development of 5G

V2X for advanced driver assistance systems

Sensors require line-of-sight
Communication can expand sensing range
Both communication and automotive sensors are useful for collision avoidance

“See through”

Low latency but modest data rate requirements for alerting driver
High data rate if “see through” capability is included
V2X for fully automated driving

Exchanging raw sensor data provides information for fully automated safety-critical functions.

Sharing local sensors information ~ 100x Mbps for safety app.

Enables cloud control of vehicles through intersections or congested areas.

Downloading high-definition 3D map data (~Gbyte) for precise navigation.

Full automation requires Gbps data rates and ms latencies.
Higher levels of traffic coordination like platooning reduces braking shockwaves due to congestion. More efficient use of intersections. Low latency but low rate connectivity may be sufficient.
Infotainment applications increase with higher levels of automation.

Mobile base station for passengers

Multimedia and gaming 100x Mbps - Gbps

High rate and low latency Internet access required to keep passengers happy.
## Summary of current technologies for V2X

<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>Comm. fee</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>

Low latency and Gbps data rates are not supported

mmWave 5G will enable Gbps V2X data rates

- High data rates due to high bandwidth channels
- Many simultaneous connections allowed thanks to spatial reuse with narrow beams
- Both direct vehicle (V2V) and vehicle-to-base station (V2I) supported
- Ultra low latency easier to support due to smaller packet sizes

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

Can mmWave really work with high mobility?

Many misconceptions surround mmWave communications in mobile channels

Doppler is too high

Beams are too hard to configure

Nothing is known about the channel
Channel and beam coherence times

Narrow beams increase the channel coherence time, if beams can be pointed

Optimum beamwidth is a tradeoff between pointing error and Doppler

Beams should be narrow but not too “pointy”

Long term beamforming can be used

Doppler does not have to be significant in a mmWave system

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Position aided beam training in mmWave V2X

Machine learning used to help deal with blockage events

Restricted candidate beams

Position information with estimation noise

GPS derived location information can reduce beam training overhead

Radar can be used to track vehicles.

Radar can be used to predict blockages.

The dominant DoAs for the communication signal also appear at the radar echo in a different band.

Beam-selection in mmWave V2I aided by sub-6GHz info

Multi-Antenna Multi-band BS

Millimeter Wave Antenna Array

Sub-6 GHz Antenna Array

Multi-Antenna Multi-band UE

Out-of-band-info about likely AoA directions

Fully digital sub-6 GHz system provides prior info about main channel directions used to reduce training length at mmWave

Creating a new cellular infrastructure in 5G for V2X

Combination of sensing, learning and communication

Sensing co-located with communication at the infrastructure

V2X is not just a 5G vertical: It is a new paradigm for sensing and cellular communication
WNCG @ UT maintains a top position on research on mmWave communications and V2X

Efficient array configuration using out-of-band info

Joint vehicular comm. and radar

Low power V2X

Coverage and rate analysis

Collaborations with DOT, TxDOT, automotive and wireless companies

UT SAVES http://www.utsaves.org

Prototyping mmWave for V2X
In summary

Millimeter wave is a key technology for connected vehicles in 5G

Thank you!

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