Realizing the Potential of 5G NR C-V2X

Shailesh Patil
Head of 5G for Automotive Research @ Qualcomm
5G NR C-V2X: Main Questions

• 5G NR C-V2X: Where are we?

• What are the enhancements enabled by 5G NR C-V2X?
  ◦ Focus on sidelink or PC5

• What can 5G NR C-V2X do?
  ◦ How can 5G NR C-V2X solve generic V2X challenges? => Network effect
5G NR C-V2X
Status
Evolving C-V2X Direct Communications towards 5G NR
While maintaining backward capabilities

Evolution to 5G NR, while being backward compatible
C-V2X Rel-14 is necessary and operates with Rel-16

Autonomous driving use cases
5G NR C-V2X Rel-16

Support Autonomous Driving

Advanced applications for manual driving

Basic and enhanced safety
C-V2X Rel-14/Rel-15 with enhanced range and reliability

Basic Safety

R-16 is ongoing in 3GPP and will be the first iteration

<table>
<thead>
<tr>
<th>Year</th>
<th>Q1</th>
<th>Q2</th>
<th>Q3</th>
<th>Q4</th>
</tr>
</thead>
<tbody>
<tr>
<td>2017</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2018</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2019</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

RAN
- R-16 SI
- R-16 WI

SA2
- R-16 SI
- R-16 WI
5G NR C-V2X Enhancements
5G NR C-V2X will build on LTE & NR features

Build on features from NR R-15 & lessons learnt from LTE V2X trials

NR R-15
- Wideband support
- Flexible numerology
- Advanced coding
- Frame structure
- Reference signals

LTE V2X R-14
- Frequency division multiplexing
- Guaranteed latency performance
- Prioritization support
- Backward/forward compatibility

NR V2X R-16
- High speed performance
- Higher reliability using multicast
- Flexible & distance aware resource allocation
- Distance based HARQ
- Connectionless ‘on the fly’ distance based groups
- Low latency
- Spatial multiplexing support

*R-16 standards is still a work in progress
Evolving C-V2X Direct Communications towards 5G NR

5G NR C-V2X will be forward/backwards compatible with C-V2X R14/R15

C-V2X R14 only car

Advanced use cases

Autonomous driving

C-V2X R14 / R16
V2X Transport profiles decided by upper layers
Enabling coexistence of multiple RATs and features in R14/15, extend to R16
High Speed Performance

NR can support ~5x higher spectral efficiency as compared to LTE at high speeds

- Higher carrier spacing allows better handling of Doppler and frequency offset
  - We will target typically 30 KHz
- Variable reference signal design density
- Strategic placement of reference symbols
- Up to ~5x higher spectral efficiency at 250+250
High Reliability
Enable multicast in addition to broadcast

- Broadcast without feedback cannot ensure reliability

- Multicast with feedback introduced to get higher reliability

- HARQ feedback can be ‘SFN’ to achieve reliability with limited feedback
Distance Aware Resource Allocation

Avoid resources being used by another vehicle within a certain distance

- Important to make sure that there is large distance between vehicles tx on same resource

- Why use distance and not received power?

- Received power suffers from fading

- Distance can be particularly useful for cases where signal is weak but still quite useful
  - Example is across intersection
Distance Based HARQ

Minimum coverage range in most geographic scenarios:

- Range is very much dependent on the physical terrain between tx and rx
  - LOS range can be 5x NLOS range

- However requirements are based on ‘minimum coverage’

- Distance based HARQ ensures coverage in most geographic scenarios

- Receivers within certain distance provide HARQ feedback to achieve minimum coverage
Distance Based HARQ

Ability to control coverage for different applications

- Different applications will target different ranges & reliability

- Distance based HARQ can be application aware and can add correspondingly
  - E.g. Number of HARQ retx can be a function of target reliability

- Can lead to better reuse of resources and more efficiency
Connectionless ‘On the Fly’ Distance based Groups
Vehicles within a certain distance & interested in same services form a group

Vehicles approaching intersection

Group formed among vehicles for coordinated intersection management

Group disbanded after intersection is navigated
Spatial multiplexing
Can we reap benefits of spatial at high speeds and without periodic ref. signals?

- Some of the spatial multiplexing gains can be achieved with conservative link adaptation
- Mainly relevant to unicast

<table>
<thead>
<tr>
<th>Simulation parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Antenna config.</td>
<td>2 (Tx) x 4 (Rx)</td>
</tr>
<tr>
<td>Data tx and CSF</td>
<td>10 Hz (every 100ms)</td>
</tr>
<tr>
<td>feedback periodicity</td>
<td></td>
</tr>
<tr>
<td>CQI Table</td>
<td>peak 256QAM</td>
</tr>
<tr>
<td>PMI codebook</td>
<td>DFT type-1 (O=4)</td>
</tr>
<tr>
<td>OLSM codebook</td>
<td>Householder</td>
</tr>
</tbody>
</table>

15+15kmphr, 2x4 system

~1.8x

~12% CLSM vs OLSM
5G NR C-V2X Benefits
Sensor Object Sharing
Sharing perceived object information

• Vehicles have cameras and others sensor.

• Value in sharing sensor object information
  ◦ Safety: e.g. pedestrian that are around the corner
  ◦ Autonomous driving: path and maneuver planning

• Raw vs object information sharing:
  ◦ Why not share raw object information?
    • Not enough bandwidth available
    • Value of such an exchange is limited
      ◦ Issues like calibration etc.

• Sensor object sharing enables benefit of V2X with limited penetration rate
Coordinated Driving for Autonomous Vehicles

Autonomous vehicles can coordinate to get efficient maneuvers

• Coordinated driving algorithms can allow vehicles to navigate intersections without stopping

• Can be done even in presence of vehicle’s without C-V2X
Mixed deployment of different types of vehicles
How much will V2X vehicles benefit in such mixed deployments?

- V2X can help enable faster maneuvers using trajectory coordination
- How much can sensor sharing & coordinated driving help in mixed scenario?

<table>
<thead>
<tr>
<th>V2X</th>
<th>Sensors</th>
<th>Driving</th>
</tr>
</thead>
<tbody>
<tr>
<td>No</td>
<td>No</td>
<td>Manual</td>
</tr>
<tr>
<td>Yes</td>
<td>Yes</td>
<td>Manual</td>
</tr>
<tr>
<td>No</td>
<td>Yes</td>
<td>Manual</td>
</tr>
<tr>
<td>Yes</td>
<td>Yes</td>
<td>Autonomous</td>
</tr>
<tr>
<td>No</td>
<td>Yes</td>
<td>Autonomous</td>
</tr>
</tbody>
</table>
Example: Urban Simulation Setup

How much can 5G NR C-V2X help in travel time & fuel efficiency?

- Large part of urban travel are maneuvers
  - Lane change
  - Turns
  - Crossing intersection

- How much does the gain cumulatively add up to?
  Single run results - more exploration needed

<table>
<thead>
<tr>
<th>5G NR C-V2X penetration rate</th>
<th>% age gain in fuel efficiency</th>
<th>% gain in time to travel</th>
</tr>
</thead>
<tbody>
<tr>
<td>10%</td>
<td>5%</td>
<td>11%</td>
</tr>
<tr>
<td>25%</td>
<td>14%</td>
<td>19%</td>
</tr>
<tr>
<td>50%</td>
<td>20%</td>
<td>29%</td>
</tr>
<tr>
<td>100%</td>
<td>20%</td>
<td>31%</td>
</tr>
</tbody>
</table>
5G NR C-V2X can provide significant benefits, but...

Benefits can be achieved with limited penetration

- Significant work is needed in upper layer standards body SAE, C-SAE, & ETSI-ITS

- Sensor object sharing between vehicles needs to be standardized
  - Cooperative perception message in ETSI ITS is a good start

- Sensor object sharing messages should allow for ‘proxy’ vehicle reporting

- Coordinated driving messages needs to be defined while take into account presence of non V2X vehicles

- Minimum performance needs to be defined for content of such messages

- Regulatory support & security issues need to be addressed
Conclusions

• 5G NR C-V2X is well on its way to being standardized

• 5G NR C-V2X’s several enhancements that will allow V2X applications to be served in an efficient and flexible manner

• Main applications will be sensor sharing and coordinated driving (for autonomous vehicles)

• Sensor sharing with proxy reporting will allow gains to be achieved even with limited deployment

• This will ultimately enable time and energy savings

• However a lot of work needs to be done at upper layers, on security & regulations to achieve this