Multi-RAT, Multi-Link, Multi-operator V2X Communications

Apostolos Kousaridas

Huawei Technologies, Munich Research Center, Germany
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The digitalization of Cars

Future car is
- Robot (“Neural” and “Brain”)
- & Data center
- & High power computing node

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<th>Road safety and Efficiency</th>
<th>Telematics</th>
<th>Infotainment</th>
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<td>Basic Safety Services (examples)</td>
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<td>Collision avoidance</td>
<td>Traffic lights to vehicles, speed guidance</td>
<td>Remote Driving</td>
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<td>Traffic lights to vehicles, speed guidance</td>
<td>Road conditions to vehicles</td>
<td>Remote Vehicle Health Monitoring</td>
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| Autonomous Driving Services | | |
| Platoonning | | |
| Cooperative driving, Sensor sharing | | |
| High-definition map (dynamic creation) | | |

| | Software updates | eCall |
| | Navigation | Parking |
| | | |

... multiple services have to be supported at the same time by the cars for different purposes
C-V2X: unified technology platform for short range and long range communication that is scalable and concurrently supports KPIs of demanding services

- ANY car is able to exchange information with ANY other car/pedestrian/device/…
- Different services have different performance requirements
  - V2X = URLLC & eMBB & mMTC
- EVERYWHERE real-time connection for demanding services
  - Scalable reliability up to 99.999%@1ms@1000byte/packet
  - High Density, high Mobility
Localized V2X Traffic

- Data traffic in many V2X use cases have **localised significance**
  - devices located at **same geographical region**
  - **no** need of a **remote server** (e.g., ITS cloud server)
  - demanding **QoS**
  - **unicast, multicast, broadcast**
eV2X message transmission and reception: Cellular (Uu) and Sidelink (PC5)

- 5G will support both cellular (Uu) and sidelink (PC5) communication interfaces that have different characteristics and features:
  - **Cellular Uu** has larger coverage area, 5QIs, ...
  - **PC5** (e.g., mode 3) increases the system capacity through the spatial frequency reuse

- NR-Uu interface could provide guaranteed QoS (i.e., high reliability, low latency) in the case of:
  - urban road environments or **without Line-of-sight** (LOS) among communicating vehicles (e.g., intersections)
  - poor **radio conditions** in the PC5
  - high vehicles’ **density**, where PC5 may not be efficient or may be overloaded……
Optimize Cellular (Uu) V2X with Local breakout

- Even if communication between UEs under the same BS: **bearers** set up in an **end-to-end way** establishing paths between UE/vehicle and **P-GW (core network)**
  - High Latency
  - Waste of Resources

- **Local breakout mechanisms** introduced to address this inefficiency
  - LIPA (Local IP Access) / SIPTO (Selected IP Traffic Offload)
  - designed for other cases (e.g., traffic offload for private LAN)

  - Not efficient for multicast or broadcast transmissions. Waste of radio resources: multiple unicast streams for a group of vehicles
  - Mobility is not supported when L-GW function collocated with a BS
Enable Multicast Communication for Cellular (Uu) V2X

- V2X messages can be **broadcasted via MBMS**
- **V2X Application Server** transfers V2X messages via MBMS bearer service(s)

- No low latency gain that the SIPTO@LN provides
- V2X application server is needed for data forwarding
- Slow session management
- Although in many V2X services the source and the destination node is not a V2X application server, but the UEs (vehicles).
Optimize Cellular (Uu) V2X with Local e2e Paths

- Idea: establish and manage “local end-to-end (e2e)” paths with guaranteed e2e link performance to address the fast and reliable transmission of localized data traffic among the involved devices.
  - “end-to-end“: the (user plane) radio data paths are established among the involved communicating end devices
  - “local”: the paths are established by (and via) the BSs (i.e. the nodes of the core network do not participate in the user plane transmissions), since the data traffic is localized

Extended RRC mechanisms to establish or manage of local e2e paths
Example configuration of Local e2e Paths

- UL and DL radio bearers and backhaul links (e.g., Xn) are connected to **enable fast and reliable transmission**
  - Multicast traffic
    - multiple unicast (Case 1) or
    - multicast e.g., SC-PTM (Case 2).

- No need of IP addresses and no need of MBMS to support the multicast/broadcast traffic,
  - benefit of lower latency
Evolution of 5G RAN for Localised V2X Traffic

New methods and signaling are introduced at the RAN for local e2e radio paths

In the case that **multiple cells** are involved then an inter-cell coordination is needed

Form the local end-to-end radio data paths among the involved vehicles through the configuration of the RBMT of the BS that connects UL and DL radio bearers

**Introduction of Radio Bearers Mapping Table (RBMT) at the BS**
Performance Improvement via Local e2e Paths

- Reduction of user plane latency of more than:
  - 45% for unicast communication
  - 52% for multicast communication (SC-PTM)
  - 73% for multicast communication (MBMS)

Local e2e Paths treat both unicast and multicast data packets with the same manner.
Multi-Link Communication: PC5 and Uu communication modes Integration

- There is **no predefined mapping** between V2X services and the communication interface that could be selected (i.e., NR-Uu or PC5 interface).

- Enable 5G systems to **select, combine and dynamically switch the best interface** in order to support the QoS requirements of demanding V2X services.
  - Increase **flexibility** of communication networks and V2X services
  - **Better coordination** of available Uu and Sidelink resources utilizing all communication modes
  - Increase **throughput**
  - Increase **reliability**
  - Maintain and **guarantee** the expected QoS by adapting selected modes
Multi-Link Communication: PC5 and Uu communication modes Integration

Dynamic selection of PC5 and Uu communication modes

- The application layer may not be the appropriate for making such a decision: too slow, not enough network layer information

- Enable the dynamic selection at the BS (e.g., via extended RRC methods) of appropriate communication mode at the BS (Uu, PC5, both methods), using
  - QoS requirements of the V2X service
  - current network conditions (e.g., network load)
Multi-Link Communication: PC5 and Uu communication modes Integration

Links redundancy to increase reliability

Send each packet of a V2X service/flow at both interface (Duplication)

Links aggregation (Dual connectivity model) to increase throughput and reduce latency

Send different packets of a V2X service/flow at both interface (Split)
Multi-Link Communication: PC5 and Uu communication modes Integration

For concurrent transmission on Uu+PC5 for same V2V application, a redundant scheduler is needed

**Option A** - UE’s Facilities level

**Option B** - UE’s Transport level

**Option C** - RAN level with RRC support

**Option D** – UE’s MAC Level

Source: 5GCAR D4.1” Deliverable D4.1 Initial design of 5G V2X system level architecture and security framework”, April 2018
Multi-Link Communication: PC5 and Uu communication modes Integration

Dynamic switching between links in the context of the same service, to maintain and guaranteed the expected QoS.

Reason of V2X Com: Cooperative collision Avoidance (CCA)

SL

UL

DL

UL

A vehicle can use both interfaces to communicate with different vehicles that participate in the same V2X service.
V2X Networks: Multi operator Environment

- Different vehicles will have **subscription to different operators**, while they need to communicate with each other in an ultra low delay and high reliability way. **Difficulties in**
  - multicast and broadcast sessions
  - PC5 mode 3 coordination
  - Interactions of MECs
Proposed Solution

Splitting the overall area in regions where only one operator is responsible:

a. Simplifies the multi-operator environment and enables efficient V2X communication
b. Is a good business model which splits the profit opportunities fairly among the operators
c. MEC coordination is handled
d. V2X mode 3 is handled since one operator undertakes resource management
Multi-PLMN Attach

Solution: attach to all operators that offer the V2X service

1. Attach

2. Forward and trigger multi-PLMN Attach

Depending on the region the UE will be active in the one or the other operator
Force Roaming

Solution: attach to all operators that offer the V2X service

1. Attach
2. Forward and trigger multi-PLMN Attach
3. Force Roaming
4. Switch to connected
Multi-PLMN connectivity

Challenge: How to handle the transition among the networks

Solution: Extend existing RRC operation so that the UE can be
a) either monitor and switch rapidly,
b) being dual connected in both operators
The previously described challenge is addressed if a dual operator area is defined. In this area the UEs will operate under both operators. This area is called **Dual Operator Area**.

When the UE is in the **Dual Operator Area** has the ability to communicate with UEs attached to both operators.
Conclusions

• V2X services leads to a redefinition of the concept of "end to end".

Source: 5GCAR D4.1 “Deliverable D4.1 Initial design of 5G V2X system level architecture and security framework”, April 2018
NR-V2X Requirements for Autonomous Driving

Uses Cases for Autonomous Driving Applications
- Vehicle Platooning
- Cooperative Operation, Sensor sharing
- Remote Driving
- Advanced Driving

NR-V2X Requirements defined in 3GPP SA1 (TS22.186) for

<table>
<thead>
<tr>
<th>Use Cases</th>
<th>E2E latency (ms)</th>
<th>Reliability (%)</th>
<th>Data rate (Mbps)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vehicle Platooning</td>
<td>10</td>
<td>99.99</td>
<td>65</td>
</tr>
<tr>
<td>Advanced Driving</td>
<td>3</td>
<td>99.999</td>
<td>53</td>
</tr>
<tr>
<td>Extended Sensors</td>
<td>3</td>
<td>99.999</td>
<td>1000</td>
</tr>
<tr>
<td>Remote Driving</td>
<td>5</td>
<td>99.999</td>
<td>UL:25, DL:1</td>
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<thead>
<tr>
<th>Lateral (m)</th>
<th>Longitudinal (m)</th>
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<tr>
<td>0.1</td>
<td>0.5</td>
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SOTA Solutions

➢ **Use current network**
  
  - **Drawbacks:**
    - Increased delay
    - Cannot treat local traffic
    - MEC coordination is not possible
    - Mode 3 PC5 is not possible due to
      - half duplex problem
      - synchronization

➢ **Single MNO will handle V2X**
  
  - **Drawbacks:**
    - Requires consensus among the stakeholders

➢ **Roaming schemes**
  
  - **Benefits:**
    - Limited extensions – national roaming has been proposed also in the past
  
  - **Drawbacks:**
    - Delay to register.
    - The decision to which operator a UE should roam is not easy → multiple UEs have to coordinate which will increase the delay

➢ **Use inter-PLMN handover solutions**
  
  - **Benefits:**
    - Does not require the excessive delay of the roaming schemes
  
  - **Drawbacks:**
    - Such solutions are extremely complex and require very good coordination among the actors