Comparison of V2X based on 802.11p, LTE and 5G

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Outline

- Overview 802.11p
- Overview LTE-V2X
- Comparison 802.11p vs. LTE-V2X
- Outlook NR-V2X
802.11p – Overview

- DSRC = IEEE 802.11p WAVE

802.11p – Numerology

- Derived from 802.11a
  - Basically doubling all timings
  - → Better resilience against increased delay spread

- 802.11p parameters:
  - System bandwidth: 10MHz
  - Subcarrier spacing: 156.25kHz
  - Number of subcarriers: 52
    - Data: 48
    - Pilots: 4
    - (DFT length: 64)
  - Symbol duration: 8μs
  - Guard time: 1.6μs
  - Modulation and coding:
    - BPSK, QPSK, 16QAM, 64QAM
    - rate ½, 2/3, 3/4 convolutional code
    - → 3Mbps - 27Mbps

802.11p – Access Method

- CSMA/CA (Carrier Sense Multiple Access / Collision Avoidance)
- via DCF (Distributed Coordination Function)
- Principle
  - STAs monitor the channel for activity:
    - ED: Energy detection
    - CCA: Clear channel assessment
  - When channel becomes clear:
    - STAs enter a contention phase
  - When STA’s backoff timer ($n$ slots) expires:
    - STA transmits (typ. single frame)
802.11p – Access Method

Parameters
- DIFS 64μs
  - (SIFS / AIFS[i]: 32μs for use with QoS and for timing of signaling)
- Slot time: 13μs

IEEE WLAN MAC and PHY specification 802.11-2012.
802.11p – Access Method

- **Characterization**
  - TDMA with some residual risk of collision if backoff timers of different STAs expire simultaneously
  - Quite effective avoidance of collisions
    - depends on size of contention window
    - except for hidden source problem

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LTE-V2X – Overview

- Part of cellular communication system LTE
- Different options
  - Via network (Uu interface)
    - UL unicast + DL multicast
    - UL unicast + DL eMBMS
    - UL unicast + DL SC-PTM
  - Via D2D direct mode (PC5 interface)
    - Essential for delay critical communication
- Can be operated in
  - dedicated V2X spectrum (5.9GHz)
  - any LTE carrier
LTE-V2X – PC5 Numerology

- Derived from UL numerology
  - 2 additional pilot (DMRS) symbols
  - 1 OFDM symbol guard period

- LTE-V2X parameters:
  - System bandwidth: 10MHz
  - Subcarrier spacing: 15kHz
  - Number of subcarriers: 600
  - Symbol duration: \( \frac{1}{14} \text{ms} \approx 71\mu\text{s} \)
  - Guard time: \( \approx 5\mu\text{s} \)
  - Modulation and coding:
    - QPSK, 16QAM, (release 15: 64QAM)
    - Turbo code (various rates)
  - MIMO
    - Release 14: single Tx antenna
    - Release 15: option for small delay cyclic delay diversity (SD-CDD)
LTE-V2X – Access Method

Resource Allocation

Mode 3: Scheduled by eNB

- Limited to in-coverage
- eNB schedules every transmission
- Centralized control of resources
- UE must be in RRC Connected
  - UE sends eNB a scheduling request
- More suitable for licensed spectrum
  - E.g. coordination of Uu and PC5

Mode 4: Autonomous Mode

- Also supports out of coverage
- eNB configures resource pools
- Collisions are possible
  - \( \rightarrow \) Sensing!
- UE might be in RRC IDLE
  - Own resource selection from a pool
- More suitable for V2X spectrum
  - Limited range and high traffic load

Comparison of V2X based on 802.11p, LTE and 5G © Nomor Research GmbH
LTE-V2X – Sidelink Channels

- **PSCCH**: Control channel to carry SCI that indicates
  - use of corresponding PSSCH
  - transmission parameters of PSSCH (e.g. MCS)
  - whether next PSSCH (acc. to SPS scheduling) will also be used.
  - ...

- **PSSCH**: Carries transport block

LTE-V2X – Autonomous Resource Selection

- **Based on**
  - Sensing of channel
  - Semi-persistent subchannel selection

- **Principle**
  - **Subchannel selection**
    - UEs measure received signal power on different available PSSCH subchannels (with averaging over time)
    - Randomly select one out of the 20% best subchannels
  - **Update**
    - Selected subchannel is used periodically for \( n \) u.i.i.d. in [5,15] time instances
    - Then new subchannel is selected with probability \( 1-p \) (e.g. \( p=0.8 \)).
    - Otherwise same subchannel is used for another \( n \) u.i.i.d. in [5,15] time instances
    - Or when latency requirement for a packet would be exceeded
Characterization

- TTI grid imposes restrictions on collision avoidance
  - Also: UEs must be synchronized (eNB, GPS or by some UE acting as “sync source”)
- Sensing in combination with async. subchannel re-selection and SPS to have good subchannel selection based on reasonable subchannel quality measurements
- Problem: If two UEs close to each other happen to select the same subchannel, the collision will persist for a while.
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Simulation Assumptions

- Based on 3GPP TR 36.885 channel model and scenarios
  - Highway scenario
    - 2 x 3 lanes
    - Average inter-vehicle arrival time per lane 2.5s
  - Carrier frequency 5.9GHz
  - Dedicated carrier of 10MHz BW
  - Modulation and coding
    - $R_c \approx 0.5$
    - QPSK
  - CAM model
    - Message size: 300 bytes
    - Periodicity 100ms
  - LTE-V2X mode: 4 (autonomous)
Simulation Results

- LTE-V2X superior w.r.t. packet reception ratio (PRR)
  - Better link-level performance
- DSRC superior w.r.t. information age (IA)
  - Probability of large IA reduced
  - Semi-persistent scheduling in LTE-V2X
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Related to LTE, but many extensions

- OFDM(A) with 15kHz subcarrier spacing and 1ms subframe is one option, but there are others with 30kHz, 60kHz and 120kHz and sub-ms subframe length
- OFDM(A) is an additional option for the UL
- Subframes, slots, minislots, …
- Much more (massive) MIMO incl. hybrid beamforming also for mm-wave frequencies
- LDPC codes for data
- Polar codes for layer 1 control

... Longum est;-)
Scheduled transmission modes

1. Dynamic scheduling by gNB scheduler
   - Similar to LTE-V2X Mode 3

2. gNB configured sidelink grants
   - Similar to LTE Semi-Persistent Scheduling configured by RRC signalling
   - No need for scheduling requests by UE and dynamic scheduling by gNB

3. Grant-free transmission
Different modes of operation under discussion

a) Autonomous resource selection
   - Similar to LTE-V2X mode 4
   - Simplest scheme is random selection, but efficiency can be improved by short and long term sensing, resource reservation and listen-before-talk
   - The following schemes for resource selection are evaluated, including
     • Semi-persistent scheme: resource(s) are selected for multiple transmissions of different TBs
     • Dynamic scheme: resource(s) are selected for each TB transmission

b) UE assists resource selection of other UEs
   - Studied as a functionality that can be part of other Mode 2 operations, when one UE assists sidelink resources selection for other UE(s)
   - Not supported / studied as a standalone sidelink resource allocation mode
c) UE is configured with sidelink grants
   – Similar to LTE Semi-Persistent Scheduling for sidelink
   – Configuration of one or multiple transmission patterns in each sidelink resource pool
     – Out of coverage: pre-configuration
     – In coverage: configured by gNB
   – Sensing only if multiple patterns are configured for a UE.

d) NEW: UE schedules sidelink transmission of other UEs
   – Supported of advanced use cases like platooning.
   – Might require the election of a cluster head UE for scheduling of a group.
   – Functionality might be limited to some UEs.
   – In the context of Mode-2(d), NR V2X supports the following functionality:
     – A UE informs gNB about group members.
     – gNB provides individual resource pool configuration and / or individual resource configuration through the same UE to each group member UE within the same group.
     – No direct connection between other member UEs and gNB is required.
Resources for the retransmissions can be reserved in advance to reduce the impact of collisions in the system:

- The 1st transmission of a TB can reserve resources for subsequent transmissions.
- This reservation can be indicated through the control channel.

Source: 3GPP Tdoc R1-1902997 Qualcomm
NR-V2X – Beam Forming

- New functionality
  - Sidelink SSBO structure and beam sweeping
  - Fast and efficient beam management
  - Side-information assisted beam management
  - Resource allocation strategy considering beam-based transmission/reception

  - Allows vehicles to use the same sidelink resources without interference despite their proximity.

Source: 3GPP Tdoc R1-1903075 Huawei
NR-V2X – Beam Management

- Beam management is beneficial.
- In FR1 (cm-wave), it is feasible to support V2X use cases without beam management.
- In FR2 (mm-wave), it is feasible to support some V2X use cases without beam management in some scenarios.
  - Panel selection is necessary to improve the communication range in FR2.
- To enable beam sweeping for the sidelink in Mode 1, some signaling from the gNB will be needed.
- For Mode 2, beam sweeping for the sidelink can be based on (pre-) configured procedures / resources.
Summary

- DSRC vs. LTE-V2X: Two quite different systems for V2X
- 3GPP LTE-V2X pro’s
  - Better link-level performance
  - Option for collision avoidance based on centralized scheduling by eNodeB.
- 3GPP LTE-V2X con’s
  - Out of coverage: only mode 4 based on SPS approach can be used.
  - Inferior information-age performance compared to DSRC
- Enhancements to LTE-V2X being added
- NR-V2X in the process of being standardized
  - Further enhancements to link-level performance and probably also layer-2 procedures
  - To provide much lower delays and higher data rates for advanced use cases
- Open issue: coexistence between DSRC and LTE-V2X (and NR-V2X)
Company Facts

- Industry: IT Telecommunication
- Headquarter: Munich, Germany
- Founded: September 2004
- Spin off from Munich University of Technology
  - First real-time simulations GPRS/UMTS in 1999
  - Fully privately owned, always profitable from day one
  - Successful sale of LTE eNB Protocol Stack business in 2013
  - Today 18 highly qualified R&D engineers + admin staff
- Vendor independent research / consultancy services
- Service focussed around 4G/5G technology
  - Research/development projects and system simulation services
  - Demonstrators and HW/SW prototype development
  - Consultancy, standardisation and patents support
  - Technology training and knowhow transfer
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