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# System Level Evaluation of Rel-14 LTE-V2X PC5 Mode 4 with SAE J3161 Congestion Control

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# Purpose

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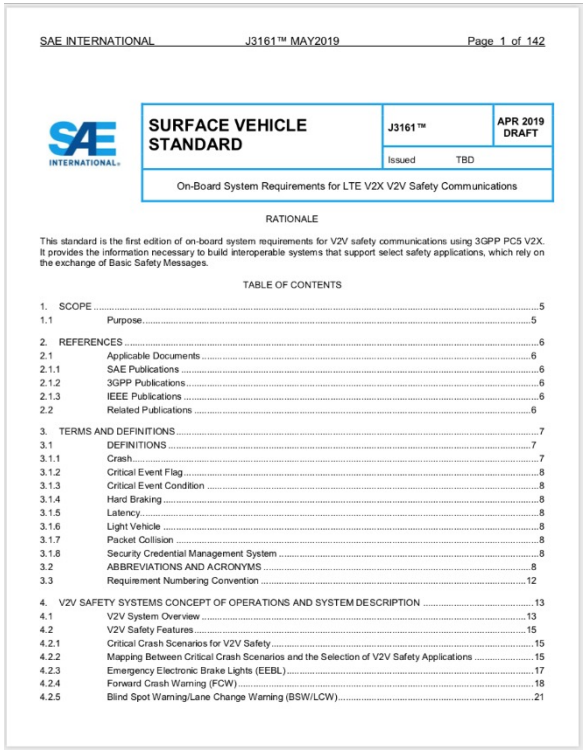
- Evaluate the system-level performance of Rel-14 LTE-V2X PC5 mode 4 with SAE J3161 congestion control and configuration

3GPP TS 36.321 V14.3.0 (2017-06)
*Technical Specification*

**3rd Generation Partnership Project;
Technical Specification Group Radio Access Network;
Evolved Universal Terrestrial Radio Access (E-UTRA);
Medium Access Control (MAC) protocol specification
(Release 14)**



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**SURFACE VEHICLE STANDARD** | J3161™ | APR 2019 DRAFT | Issued TBD

On-Board System Requirements for LTE V2X V2V Safety Communications

RATIONALE

This standard is the first edition of on-board system requirements for V2V safety communications using 3GPP PC5 V2X. It provides the information necessary to build interoperable systems that support select safety applications, which rely on the exchange of Basic Safety Messages.

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# SAE J3161 Configuration (1/2)

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- In the current draft J3161 (v1.0), the following configuration is being proposed:
  - Carrier frequency 5.915 GHz
  - Congestion control using J2945/1 rate control (without J2945/1 power control)
  - 23 dBm max Tx power
  - Antenna pattern same as J2945/1 (i.e., Ford's proposal was withdrawn)
  - 20 MHz system bandwidth
  - 10 subchannels per system bandwidth & 10 PRBs per subchannel
  - Always-on HARQ retransmission
  - 100ms fixed resource reservation (with resource skipping in case of congestion control)
  - 80% probability to keep the current resource
  - 5 consecutive skipped resources triggering resource reselection
  - Two priority class (PPPP 2 and 5, where PPPP 2 is higher priority)

# SAE J3161 Configuration (2/2)

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- In the current draft J3161 (v1.0), the following configuration is being proposed:
  - CBR&PDB-dependent resource selection window size
    - For CBR below 0.25, T2 = 20 ms
    - For 0.25<CBR<0.75, T2 = min(PDB-10,50) [ms]
    - For CBR above 0.75, T2 = PDB-10 [ms]
  - Vehicle-speed-dependent configuration (MCS range, min/max # of subchannels for PSSCH)
    - For below 120 km/h, MCS 5~11 (MCS 8~10 are excluded) & 1~2 subchannels for PSSCH transmission
    - For above 120 km/h, MCS 0~7 & 1~5 subchannels for PSSCH transmission
  - CBR-CRlimit table
    - For CBR<0.65, no CR-limit
    - For CBR>=0.65, 4% CR-limit

# Key Questions



- What's the performance difference between LTE-V2X with SAE 3161 and DSRC with SAE J2945/1?
- What's the performance difference between 10 MHz bandwidth and 20 MHz bandwidth?
- What's the performance difference between with and without HARQ retransmission?
- What's the performance difference between with and without J2945/1 power control?
- What's the performance impact of the resource selection window size?
- What's the performance impact of the probability to keep the current resource?

# To Do



- Implementation of LTE-V2X PC5 mode 4 simulator (ns-3)
  - Implement SAE J3161 congestion control
  - Implement configuration of the latest draft SAE J3161 (v1.0)
  - Implement in-band emission interference
  - Implement PHY link abstraction by cooperating with Javier
- System-level evaluation in freeway scenarios with various vehicle densities
  - 20 MHz bandwidth vs. 10 MHz bandwidth
  - With HARQ retransmission vs. without HARQ retransmission
  - CBR-dependent resource selection window vs. fixed T2 (e.g., 20, 50, 100 ms)
  - Without J2945/1 power control vs. with J2945/1 power control
  - 80% probability to keep the resource vs. 20% probability
- Documentation on how to use the simulators
- Final presentation at the end of internship

# Detailed Procedure of LTE-V2X PC5 Mode 4 (UE Autonomous Mode)

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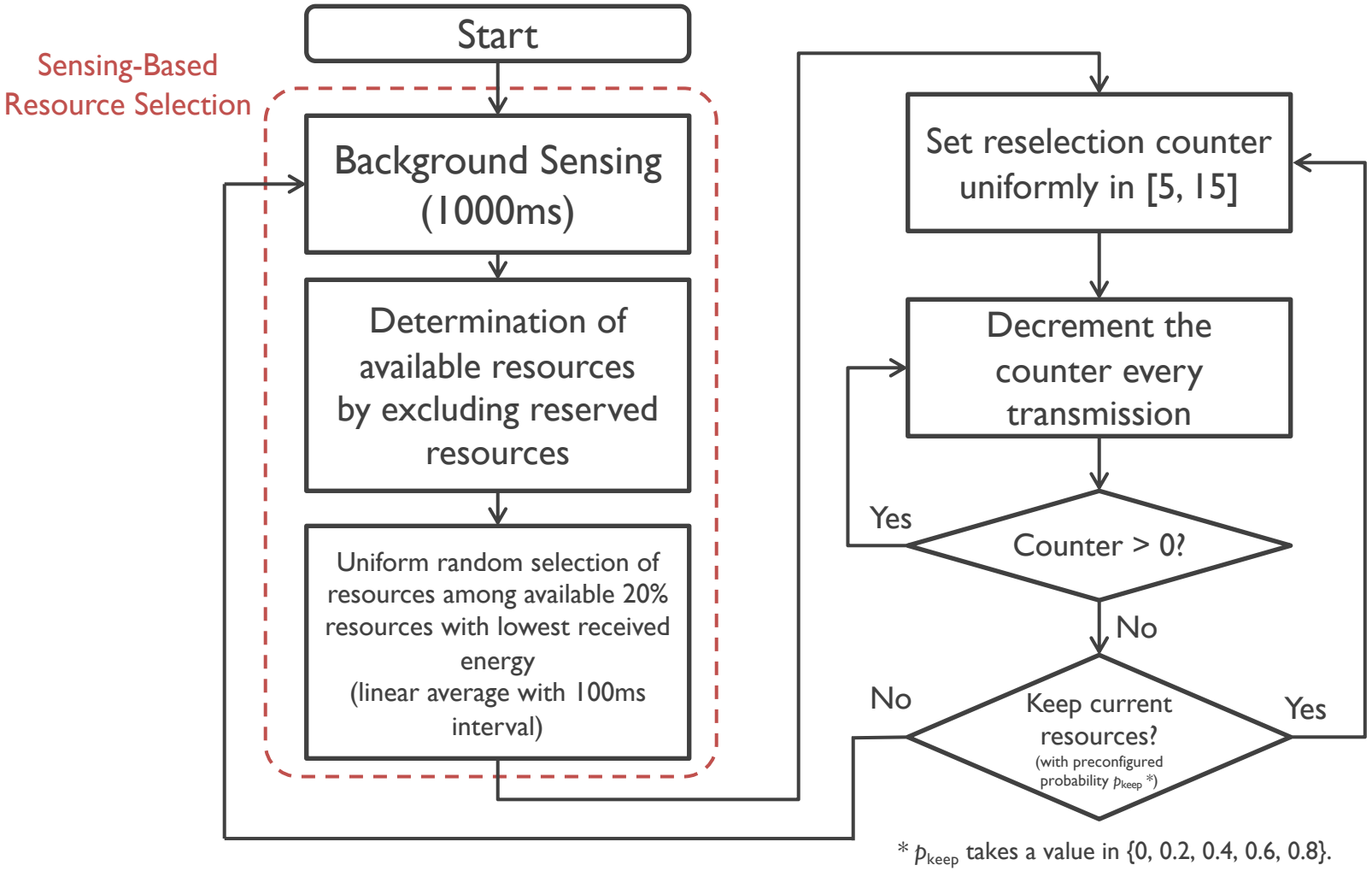

# Rel-14 LTE-V2X PC5 Mode 4: Sensing-Based Resource Selection

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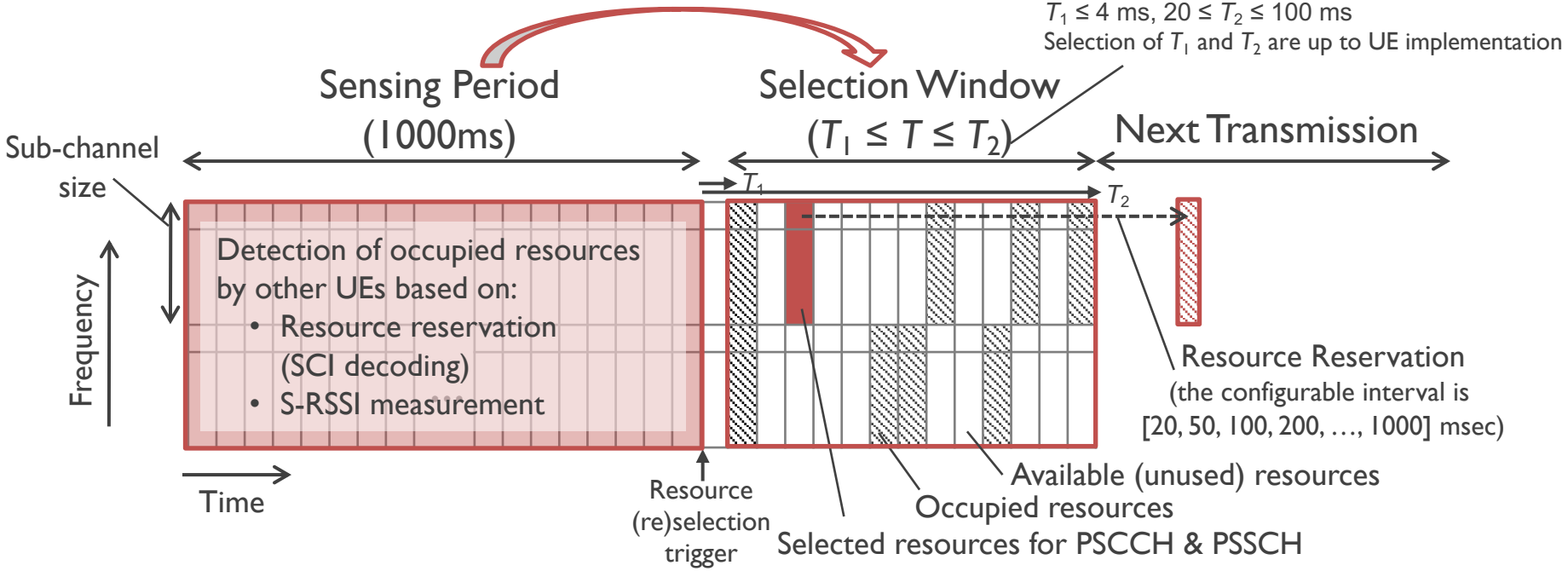
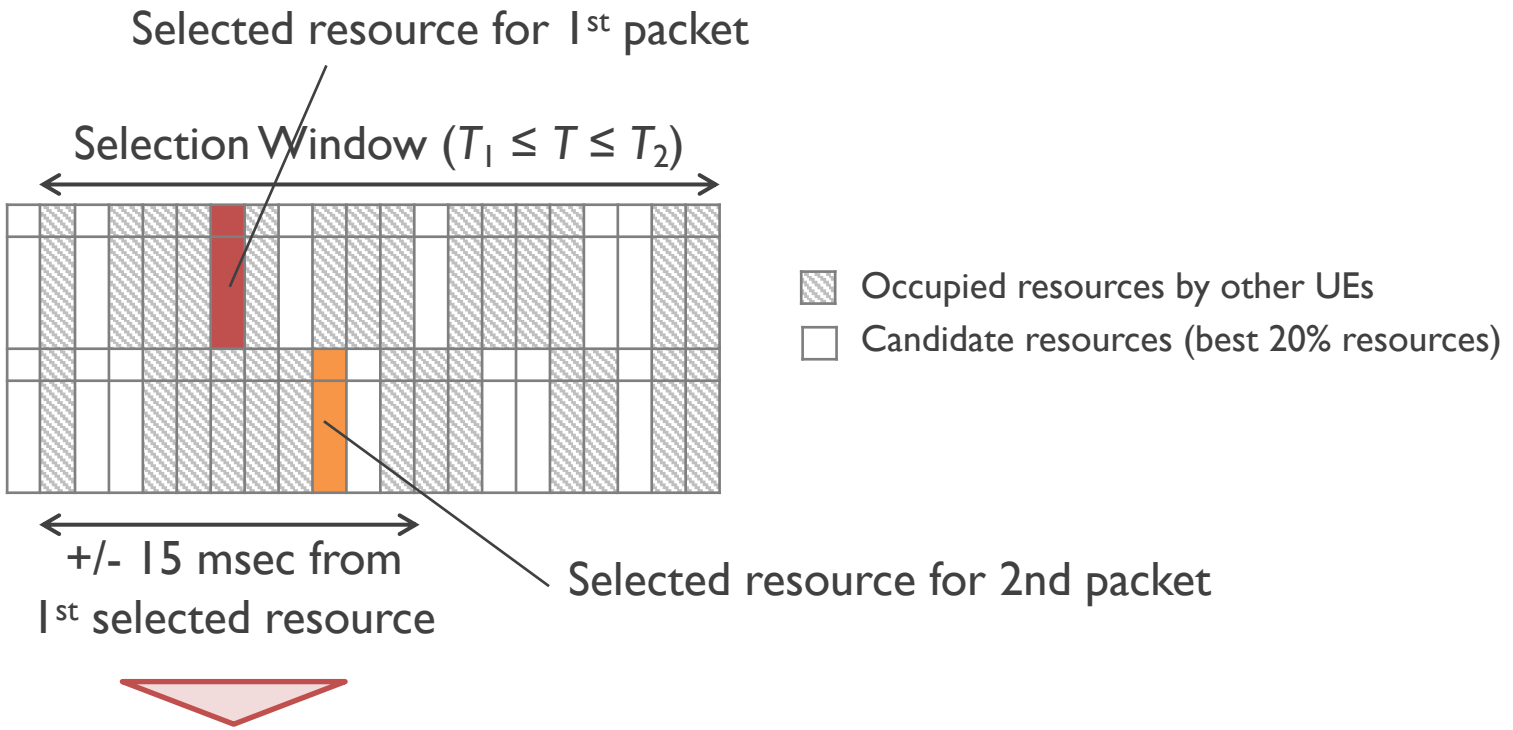
Background Sensing (1000ms) → Determination of available resources by excluding occupied resources → Uniform random selection of resources among available 20% resources with lowest received energy (linear average with 100ms interval)




In case that the retransmission feature is enabled, if some resources (same frequency resources) are available within 15ms from the initial transmission, resources for retransmission are randomly selected among available resources.

# Resource Selection for HARQ Retransmission





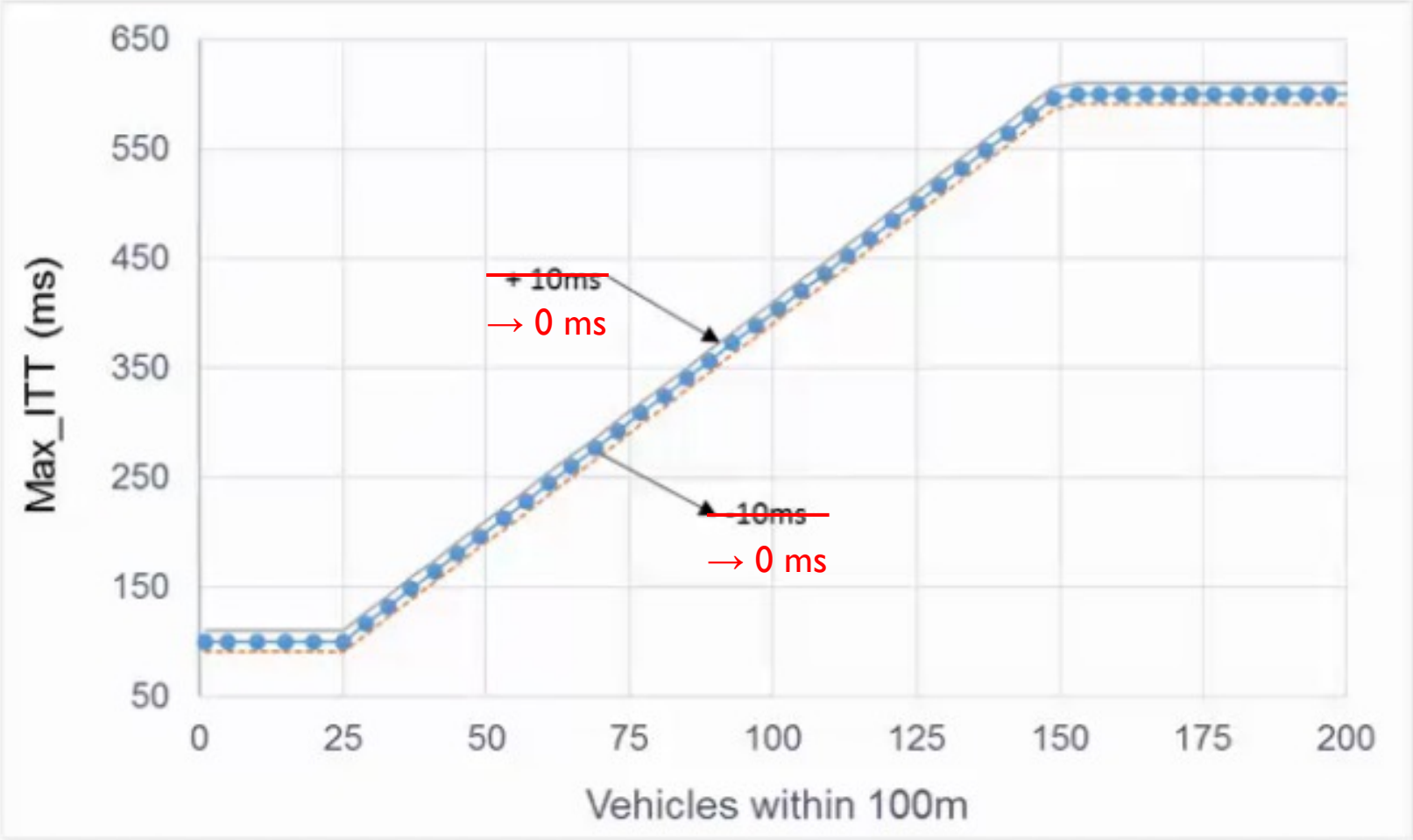

Randomly select a resource among the best 20% resources within +/- 15ms for 2nd packet*

* If no resource available within +/-15 ms window is available, no resource for 2nd packet is selected.

# SAE J3161 Rate Control

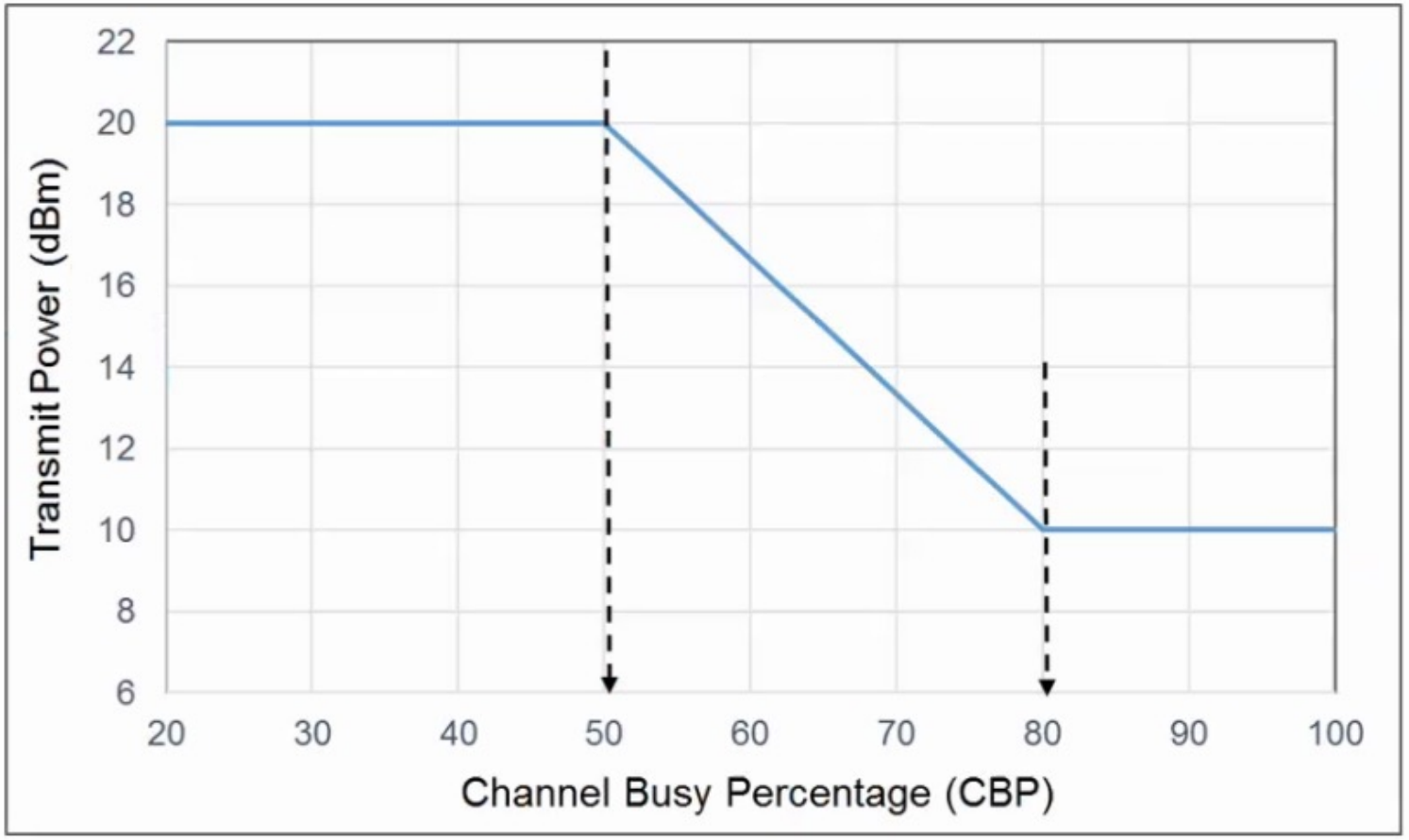


Same as SAE J2945/1 rate control except the random offset
(in our simulation, we remove the random offset)



# SAE J2945/1 Power Control





# Simulation Scenarios & Channel Model

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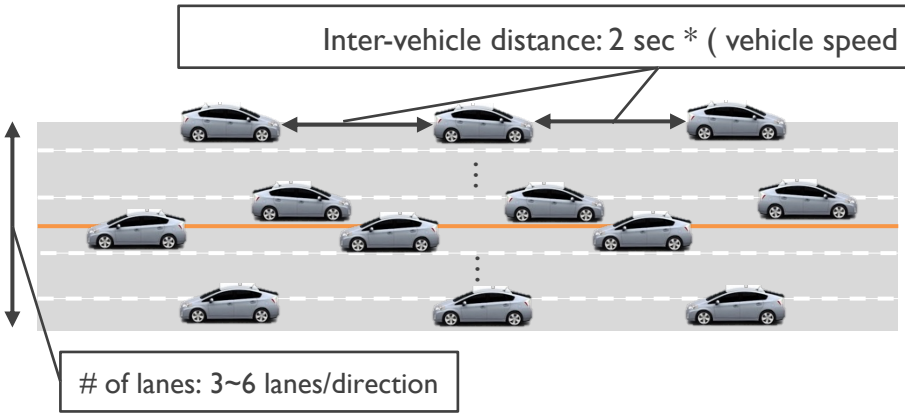
- Congested Freeway Scenarios

## Simulation Scenario: Congested Freeway




Change the inter-vehicle distance to evaluate different vehicle density.

## Channel Model

| Parameter | Value |
|---|---|
| **Scenario** | Freeway (5 km long, 3~6 lanes/direction, and 4 m lane width) |
| **Vehicle speed** | 10 km/h ~ 100 km/h |
| **Inter-vehicle distance** | 2 sec × vehicle speed [m/s] |
| **Path loss** | ITU-R P.1411-9 UHF street canyon LOS (median) |
| **Shadowing** | No |
| **Fast fading** | Nakagami-m fading (same as last year) |
| **In-band emission (for LTE-V2X)** | 3GPP TR 36.885 |

# Simulation Parameters

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| Parameter | Value |
|---|---|
| Carrier frequency | 5.9 GHz |
| System bandwidth | 20 MHz (J3161), 10 MHz |
| # of subchannel | 10 for 20 MHz (J3161), 5 for 10 MHz BW |
| Tx power | 20 dBm fixed (J3161), 10-20 dBm with J2945/1 power control |
| Tx and Rx antenna gains | 0 dBi |
| Noise figure | 9 dB |
| Number of Tx and Rx antennas | 1 Tx antenna and 2 Rx antennas with maximum ratio combining |
| Antenna pattern | Omni 2D |
| Tx and Rx antenna heights | 1.5 m |
| Message traffic | Periodic traffic (default: 10 Hz) |
| PHY payload size | 300 bytes (if possible, 300 byte packet, followed by four 190 byte packets) |
| # of subchannels per PSSCH | 2 |
| Modulation and coding scheme | MCS 5~11 (MCS 8~10 are excluded)<br>(MSC11 for 300 byte, MSC5 for 190 byte) |
| Congestion control | J3161 rate control with/without J2945/1 power control<br>(CBR threshold is -94 dBm per subchannel) |
| HARQ retransmission | Always-on HARQ (J3161), no HARQ |
| Probability to keep the current resource | 0.8 (J3161), 0.2 |
| Packet Delay Budget (PDB) | 100 ms |
| Resource selection window | CBR-dependent T2 (J3161), fixed T2 (e.g., 20, 50, 100 ms)<br>(T1 = 4 ms) |
| Resource reservation | 100 ms fixed |
| # of consecutive skipped resources triggering resource reselection | 5 |

# CBR and CR in LTE-V2X

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- CBR is measured every 100 ms
- CR is not used in our simulation

| Metric | Definition |
|---|---|
| Channel busy ratio (CBR) | Channel busy ratio (CBR) measured in subframe *n* is defined as follows:<br>• For PSSCH, the portion of sub-channels in the resource pool whose S-RSSI measured by the UE exceed a (pre-)configured threshold (e.g., -94dBm per subchannel *) sensed over subframes [*n-100, n-1*];<br>• For PSCCH, in a pool (pre)configured such that PSCCH may be transmitted with its corresponding PSSCH in non-adjacent resource blocks, the portion of the resources of the PSCCH pool whose S-RSSI measured by the UE exceed a (pre-)configured threshold sensed over subframes [*n-100, n-1*], assuming that the PSCCH pool is composed of resources with a size of two consecutive PRB pairs in the frequency domain. |
| Channel occupancy ratio (CR) | Channel occupancy ratio (CR) evaluated at subframe *n* is defined as the total number of sub-channels used for its transmissions in subframes [*n-a, n-1*] and granted in subframes [*n, n+b*] divided by the total number of configured sub-channels in the transmission pool over [*n-a, n+b*]. |

NOTE 1: *a* is a positive integer and *b* is 0 or a positive integer; *a* and *b* are determined by UE implementation with *a+b+1 = 1000, a >= 500*, and *n+b* should not exceed the last transmission opportunity of the grant for the current transmission.
NOTE 2: CR is evaluated for each (re)transmission.
NOTE 3: In evaluating CR, the UE shall assume the transmission parameter used at subframe *n* is reused according to the existing grant(s) in subframes [*n+1, n+b*] without packet dropping.
NOTE 4: The subframe index is based on physical subframe index.
NOTE 5: CR can be computed per priority level

Source: 3GPP TS36.214 v14.2.0

* 3GPP R1-1611594, R1-1702526

# In-Band Emission (IBE) Model for LTE-V2X



- IBE model for PC5 LTE-V2X is defined in TR 36.885:
  - Based on IBE model in PC5 LTE-D2D (TR 36.843):

### A.2.1.5 In-band emissions model

A modified version of in-band emissions defined in Section 6.5.2.3 of 3GPP TS 36.101 [5] should be used for simulation purposes for SC-FDMA waveforms. Table 6.5.2.3.1-1 in [5] is modfied to:

**Table A.2.1.5-1: In-band emissions for simulations**

| Parameter description | Unit | | Limit (Note 1) | Applicable Frequencies |
|---|---|---|---|---|
| General | dB | | $\max\{ -25-10\cdot\log_{10}(N_{RB}/L_{CRB})-X,$ $\max\{20\cdot\log_{10} EVM-3-5\cdot(\lvert\Delta_{RB,i}\rvert-1)/L_{CRB,i}\}-W, i=1,\ldots,num\_clusters,$ $-57\,dBm/180kHz-P_{RB}-X\}$ | Any non-allocated (Note 2) |
| IQ Image | dB | -28-Y | Image frequencies when carrier center frequency < 1 GHz and Output power > 10 dBm | Image frequencies (Notes 2, 3) |
| | | -25-Y | Image frequencies when carrier center frequency < 1 GHz and Output power ≤ 10 dBm | |
| | | -25-Y | Image frequencies when carrier center frequency ≥ 1 GHz | |
| Carrier leakage | dBc | -28-Z | Output power > 10 dBm and carrier center frequency < 1 GHz | Carrier frequency (Notes 4, 5) |
| | | -25-Z | Output power > 10 dBm and carrier center frequency ≥ 1 GHz | |
| | | -25-Z | 0 dBm ≤ Output power ≤10 dBm | |
| | | -20-Z | -30 dBm ≤ Output power ≤ 0 dBm | |
| | | -10-Z | -40 dBm ≤ Output power < -30 dBm | |

NOTE 1: An in-band emissions combined limit is evaluated in each non-allocated RB. For each such RB, the minimum requirement is calculated as the higher of $P_{RB}$ - 30 dB-X and the power sum of all limit values (General, IQ Image or Carrier leakage) that apply. $P_{RB}$ is defined in Note 10.

NOTE 2: The measurement bandwidth is 1 RB and the limit is expressed as a ratio of measured power in one non-allocated RB to the measured average power per allocated RB, where the averaging is done across all allocated RBs.

NOTE 3: The applicable frequencies for this limit are those that are enclosed in the reflection of the each allocated RB, based on symmetry with respect to the centre carrier frequency, but excluding any allocated RBs.

NOTE 4: The measurement bandwidth is 1 RB and the limit is expressed as a ratio of measured power in one non-allocated RB to the measured total power in all allocated RBs.

NOTE 5: The applicable frequencies for this limit are those that are enclosed in the RBs containing the DC frequency if $N_{RB}$ is odd, or in the two RBs immediately adjacent to the DC frequency if $N_{RB}$ is even, but excluding any allocated RB.

NOTE 6: $L_{CRB,i}$ is the number of allocated RBs of the $i^{th}$ cluster in case of multi-cluster transmission. The overall transmission bandwidth $L_{CRB}$ is given as the sum of the number of allocated RBs of all clusters

NOTE 7: $N_{RB}$ is the Transmission Bandwidth Configuration

NOTE 8: $EVM$ is the limit specified in Table 6.5.2.1.1-1 for the modulation format used in the allocated RBs.

NOTE 9: $\Delta_{RB}$ is the starting frequency offset between the allocated RB and the measured non-allocated RB (e.g. $\Delta_{RB}=1$ or $\Delta_{RB}=-1$ for the first adjacent RB outside of the any allocated RB.

NOTE 10: $P_{RB}$ is the transmitted power per 180 kHz in allocated RBs, measured in dBm.

Assumptions on value of W,X,Y, Z for single cluster transmissions, i.e., *num_cluster = 1*: [0,0,0,0] dB and [3,6,3,3] dB.

  - For PC5 LTE-V2X, {*W, X, Y, Z*} = {3, 6, 3, 3} and single-cluster SC-FDMA.

# Example of In-band Emission

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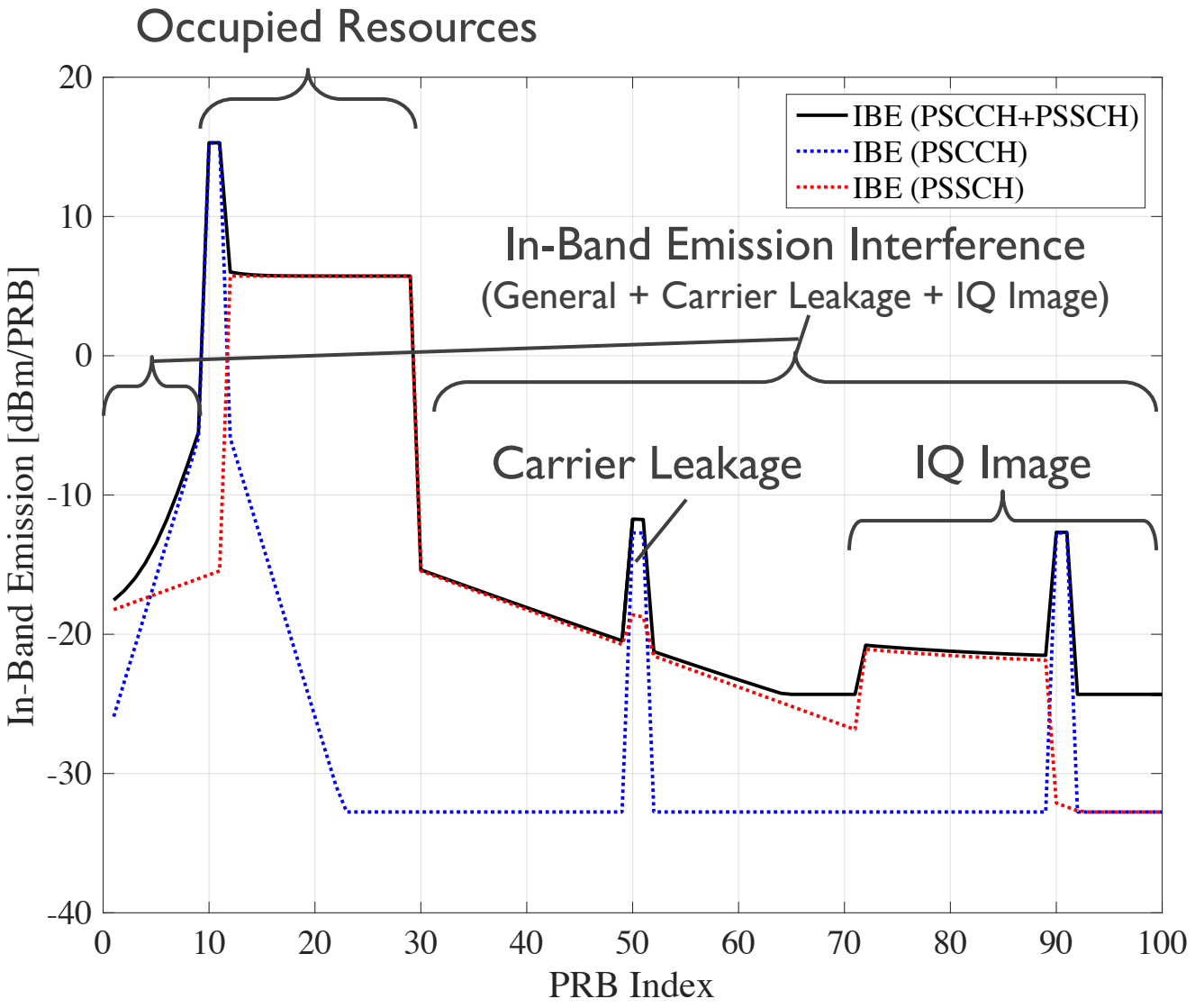


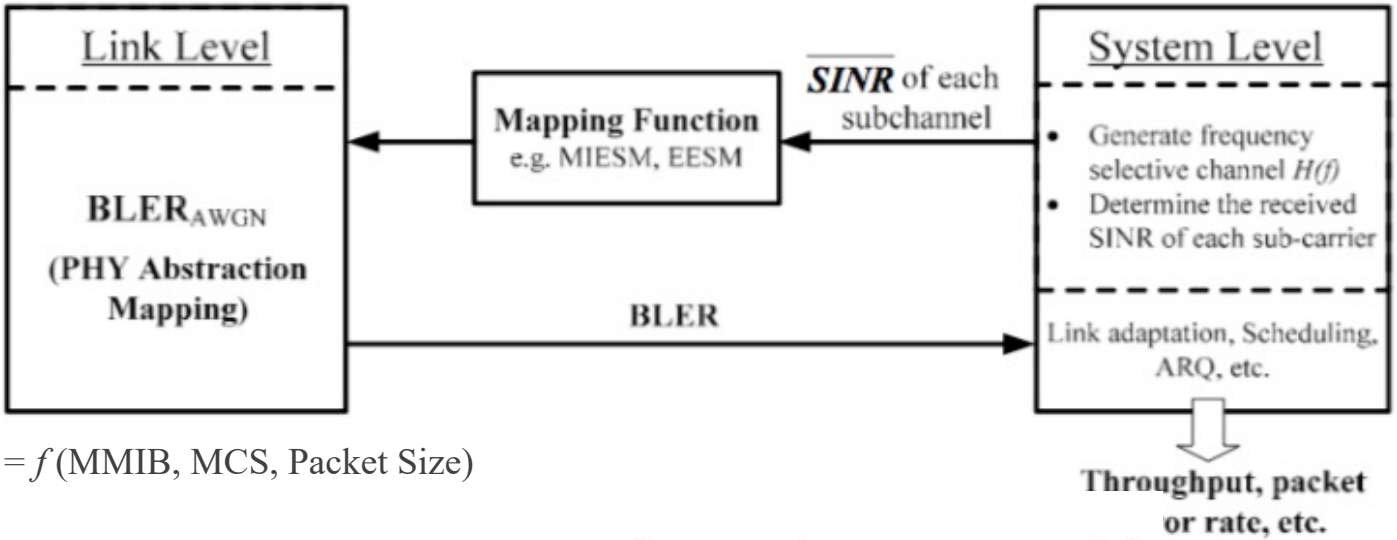
# PHY Abstraction



- PHY abstraction based on MIESM

MIESM: Mutual Information Effective SINR Metrics
MMIB: Mean Mutual Information per coded Bit

$$MMIB = \frac{1}{N}\sum_{n=1}^{N} I_m(SINR_n)$$




$BLER = f(\text{MMIB, MCS, Packet Size})$

$$BLER_{MCS} = \frac{1}{2}\left[1 - erf\left(\frac{MMIB - b_{MCS}}{\sqrt{2}\cdot c_{MCS}}\right)\right]$$

http://www.dei.unipd.it/~rossi/papers/MSWiM_long_version.pdf
https://core.ac.uk/download/pdf/37831602.pdf
http://ieee802.org/16/tgm/docs/80216m-08_004r5.zip

# Performance Metrics: Definition



- Packet Reception Ratio (PRR)
  - For one Tx packet, the PRR is calculated by $X / Y$, where $Y$ is the number of vehicles that located in the range $(a, b)$ from the Tx, and $X$ is the number of vehicles with successful reception among $Y$. The average PRR is calculated as $(X_1+X_2+X_3+....+X_n) / (Y_1+Y_2+Y_3+....+Y_n)$ where $n$ denotes the number of generated messages in simulation.
- Packet Inter-Reception (PIR)
  - Time elapsed between two successive successful reception of two different packets transmitted from vehicle A to vehicle B.
- Information Age (IA)
  - Time between the current measuring timestamp ($i * t_{\text{period}}$) and the packet generation timestamp $t_i$ at a transmitter for last successfully received packet transmitted from vehicle A to vehicle B, where $i = 0, 1,...,$ and $t_{\text{period}} = 100$ ms
- End-to-End Latency
  - Time difference between the time that a packet generated are delivered from the application layer to MAC layer at the transmitter side and the time that the packet is received by the receiver (for successfully received packets)

# Performance Metrics



- Packet Reception Ratio (PRR)
  - V2V distance vs. average PRR (for V2V distance bins of $a=i*20$ meters, $b=(i+1)*20$ meters for $i=[0, 40]$)
- Packet Inter-Reception (PIR)
  - CDF of PIR for different V2V distance bins (samples within range $[i*20, (i+1)*20]$m with for $i = [0, 15]$)
  - V2V distance vs. 95-percentile PIR (for V2V distance bins of $a=i*20$ meters, $b=(i+1)*20$ meters for $i=[0, 40]$)
- Information Age (IA)
  - CDF of IA for different V2V distance bins (samples within range $[i*20, (i+1)*20]$m with for $i = [0, 15]$)
  - V2V distance vs. 95-percentile IA (for V2V distance bins of $a=i*20$ meters, $b=(i+1)*20$ meters for $i=[0, 40]$)
- End-to-End Latency
  - CDF of E2E latency (samples within range $[i*20, (i+1)*20]$m with for $i = [0, 15]$)

ICDF: Inverse Cumulative Distribution Function

# 3GPP Technical Specifications



- 3GPP Technical Specifications for Rel-14 LTE

| Number | Title |
|---|---|
| 3GPP TS 36.201 | Evolved Universal Terrestrial Radio Access (E-UTRA); LTE physical layer; General description |
| 3GPP TS 36.211 | Evolved Universal Terrestrial Radio Access (E-UTRA); Physical channels and modulation |
| 3GPP TS 36.212 | Evolved Universal Terrestrial Radio Access (E-UTRA); Multiplexing and channel coding |
| 3GPP TS 36.213 | Evolved Universal Terrestrial Radio Access (E-UTRA); Physical layer procedures |
| 3GPP TS 36.321 | Evolved Universal Terrestrial Radio Access (E-UTRA); Medium Access Control (MAC) protocol specification |
| 3GPP TS 36.322 | Evolved Universal Terrestrial Radio Access (E-UTRA); Radio Link Control (RLC) protocol specification |
| 3GPP TS 36.323 | Evolved Universal Terrestrial Radio Access (E-UTRA); Packet Data Convergence Protocol (PDCP) specification |
| 3GPP TS 36.331 | Evolved Universal Terrestrial Radio Access (E-UTRA); Radio Resource Control (RRC); Protocol specification |

Note: These specifications includes the features of Rel-14 LTE-V2X PC5 mode 4

# 3GPP Technical Report



- 3GPP Technical Reports for LTE-V2X and NR-V2X

| Number | Title |
|---|---|
| 3GPP TR 36.885 | Study on LTE-based V2X Services |
| 3GPP TR 37.885 | Study on evaluation methodology of new Vehicle-to-Everything (V2X) use cases for LTE and NR |
| 3GPP TR 38.885 | Study on NR Vehicle-to-Everything (V2X) |