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Rel-14 LTE-V2X Overview

Network Division

TOYOTA InfoTechnology Center, U.S.A., Inc.

LTE-V2X (Rel-14) Overview

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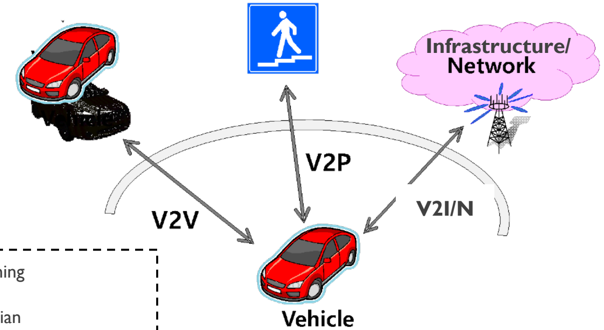
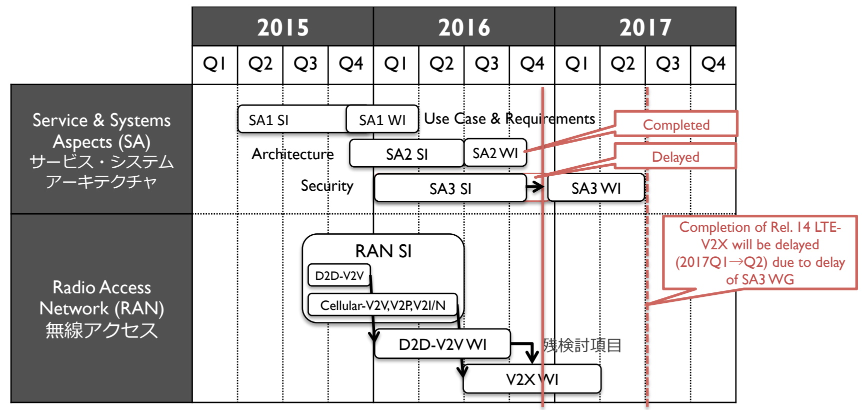
LTE-V2X will support V2V,V2P,V2I/N and safety and non-safety use cases
→ Direct competitor of DSRC

- 3GPP started the standardization of LTE-V2X from April 2015 (planned completion in Q1 in 2017)

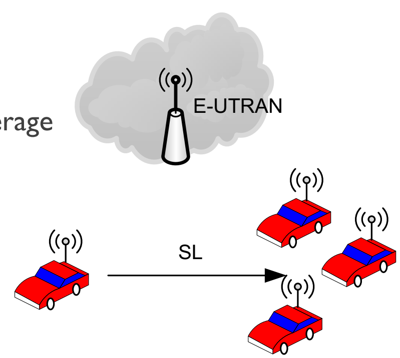


V2X: Vehicle-to-Everything
V2V: Vehicle-to-Vehicle
V2P: Vehicle-to-Pedestrian
V2I/N: Vehicle-to-Infrastructure/Network



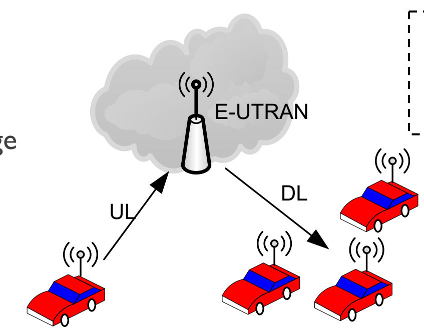
- LTE-V2X = D2D-based V2X + Network-based V2X

Available both inside coverage & outside of coverage



D2D-based LTE-V2X (a.k.a PC5-based LTE-V2X)

Available only inside of coverage



Network-based LTE-V2X (a.k.a Uu-based LTE-V2X)

D2D: Device-to-Device
DL: Down Link
UL: Up Link
SL : Side Link

LTE-V2X (Rel-14) Standardization Timeline in 3GPP

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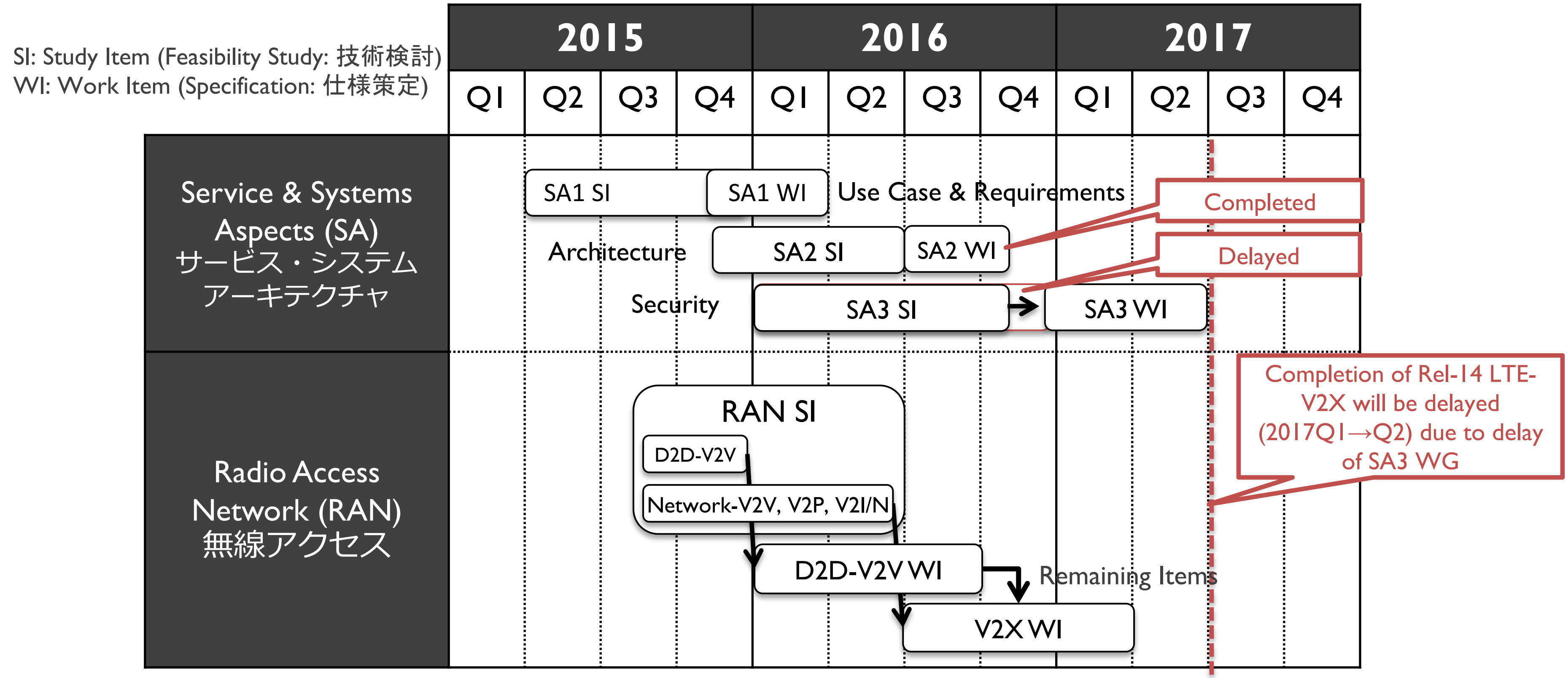

- Current status of LTE-V2X (Rel-14) standardization in 3GPP WGs
  - **RAN WGs:** Discussed remaining items for D2D-V2V, V2P, coexistence with DSRC in V2X WI
  - **SA2 WG:** Completed V2X architecture WI
  - **SA3 WG:** The feasibility study of V2X security is behind the schedule
    → Causes the delay of the completion of Rel-14 LTE-V2X standardization (2017 Q1→Q2)

LTE-V2X (Rel-14) Use Cases

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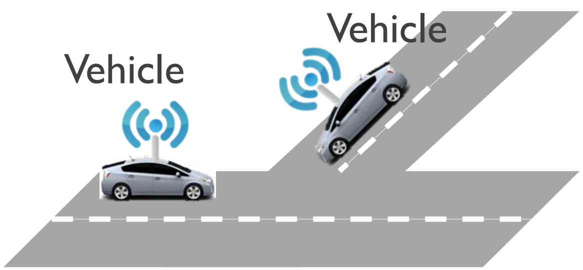
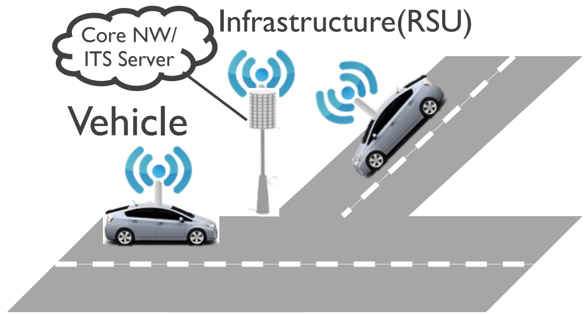
V2V Road Safety/ Cruise Control



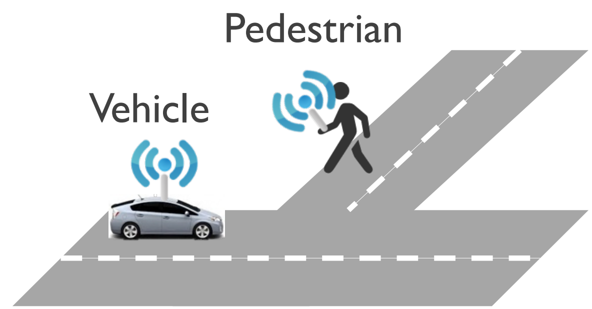
- Forward collision warning
- Control loss warning
- Emergency vehicle warning
- Emergency stop
- Wrong way driving warning
- Pre-crash sensing warning
- Cooperative adaptive cruise control (C-ACC)

V2I/N Road Safety/ Traffic Optimization



- Emergency stop
- Queue warning
- Road safety services
- Curve speed warning
- Providing overview of traffic
- Traffic flow optimization
- Automated parking system
- Enhancing Positional Precision
- Remote diagnosis / just-in-time repair notification

V2P Road Safety



- Warning to pedestrian against pedestrian collision
- Vulnerable road user (VRU) safety
- Pedestrian road safety via V2P awareness messages

Red: Safety
Green: Safety, Traffic Efficiency
Blue: Non Safety

- The safety use cases are the almost same as the ETSI and SAE for DSRC
- C-ACC, automated parking, traffic flow optimization are also considered

LTE-V2X (Rel-14) Use Cases and Requirements

No	Use Case	Type	Safety/Non-safety	Periodic/Event-Driven	Broadcast/Multicast/Unicast	Max. Latency [ms]	Max. Message Rate [Hz]	Message Size [byte]
1	Forward Collision Warning	V2V	Safety	Periodic	Broadcast	100	10	50-300 (max. 1200)
2	Control Loss Warning	V2V	Safety	Event-Driven	Broadcast	100	10	50-300 (max. 1200)
3	V2V Use case for emergency vehicle warning	V2V	Safety	Periodic	Broadcast	100	10	50-300
4	V2V Emergency Stop Use Case	V2V	Safety	Event-Driven	Broadcast	100	10	400 (max. 1200)
5	Cooperative Adaptive Cruise Control	V2V	Safety, Efficiency	Periodic	Broadcast	1000	1	-
6	V2I Emergency Stop Use Case	V2I	Safety	Event-Driven	Broadcast	100	10	400 (max. 1200)
7	Queue Warning	V2V, V2I	Safety	Periodic	Broadcast	100	-	50-400 (max. 1200)
8	Road safety services	V2I	Safety	Periodic, Event-Driven	Broadcast	100	10	Max. 1200
9	Automated Parking System	V2I, V2N	Safety, Efficiency	Event-Driven	Unicast	100	-	50-400
10	Wrong way driving warning	V2V	Safety	Event-Driven	Broadcast	-	-	-
11	V2V message transfer under MNO control	V2V, V2N	Safety, Non-safety	Periodic, Event-Driven	Broadcast	N/A	N/A	N/A
12	Pre-crash Sensing Warning	V2V	Safety	Event-Driven	Broadcast	20	-	50-300
13	V2X in areas outside network coverage	V2V	Safety, Non-safety	Periodic, Event-Driven	Broadcast	N/A	N/A	N/A
14	V2X Road safety service via infrastructure	V2I, V2N	Safety	Event-Driven	Broadcast	500	-	-
15	V2N Traffic Flow Optimisation	V2N	Safety, Efficiency	Periodic	Unicast	1000	1 (Min. 0.1)	50-300
16	Curve Speed Warning	V2I	Safety	Periodic	Broadcast	1000	1	50-400
17	Warning to Pedestrian against Pedestrian Collision	V2P	Safety	Periodic, Event-Driven	Broadcast	Varied	-	50-300 (max. 1200)
18	Vulnerable Road User (VRU) Safety	V2P	Safety	Periodic	Broadcast	100	1	50-300 (max. 1200)
19	V2X by UE type RSU	V2I	Safety, Non-safety	Event-Driven	Unicast	N/A	N/A	N/A
20	V2X Minimum QoS	V2V	Safety, Non-safety	Periodic, Event-Driven	Broadcast, Unicast	N/A	N/A	N/A
21	Use case for V2X access when roaming	V2V, V2I, V2P	Safety, Non-safety	Periodic, Event-Driven	Broadcast	N/A	N/A	N/A
22	Pedestrian Road Safety via V2P awareness messages	V2P	Safety	Periodic, Event-Driven	Broadcast	-	-	-
23	Mixed Use Traffic Management	V2I	Safety	Periodic, Event-Driven	Broadcast	N/A	Varied	N/A
24	Enhancing Positional Precision for traffic participants	V2N	Non-safety	Periodic	Unicast	N/A	N/A	N/A
25	Privacy in the V2V communication environment	V2V	Safety, Non-safety	Periodic, Event-Driven	Unicast	N/A	N/A	N/A
26	V2N Use Case to provide overview to road traffic participants and interested parties	V2N	Non-safety	Periodic	Broadcast	500	0.01-10	50-1200
27	Remote diagnosis and just in time repair notification	V2N	Non-safety	Periodic	Unicast	-	-	-

Summary of use cases and potential requirements in "3GPP TR 22.885 V2.0.0 (2015-12)"

- 3GPP SA1 WG completed the study of LTE-V2X use cases and requirements in Dec. 2015
- The use cases and requirements are the almost same as the ETSI and SAE
- C-ACC, automated parking, traffic flow optimization are also considered

Key Players in LTE-V2X Standardization

- LTE-V2X standardization is led by base station vendors, chip vendors, and mobile device companies

	Automotive	Mobile Network Operator	Base Station/ Core Network Vendor	Chip Vendor	Mobile Device	R&D Organization
Active (Leading standardization)		• NTT DoCoMo	• Huawei • Nokia • Ericsson	• Qualcomm • Intel	• LG • Samsung	• CATT
Less active (few comments/contribution papers)	• GM	• China Mobile • Vodafone • Deutsche Telekom	• NEC • Fujitsu		• Panasonic • Sony • Sharp • OPPO • ZTE • Kyocera	• ITRI
Just monitoring	• Toyota ITC • Continental • Denso New! • VW New!					

Note: BMW and Honda are not 3GPP members but seems have some interests on LTE/5G

LTE-V2X Operation Mode

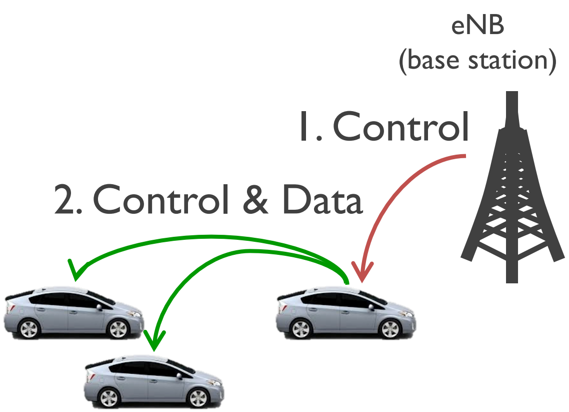
* Modes 1 & 2 are specified for Rel-12/13 LTE-D2D.

- LTE-V2X has 3 operation modes: D2D-based modes 3 & 4*, and network-based.

D2D-based LTE-V2X (a.k.a PC5-based LTE-V2X)

Sidelink
Uplink
Downlink

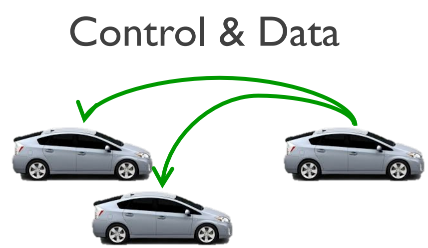
Mode 3: eNB Scheduled Resource Allocation



This mode is only available inside NW coverage.

1. eNB allocates resources to UE
2. UE broadcasts V2X message using allocated resources

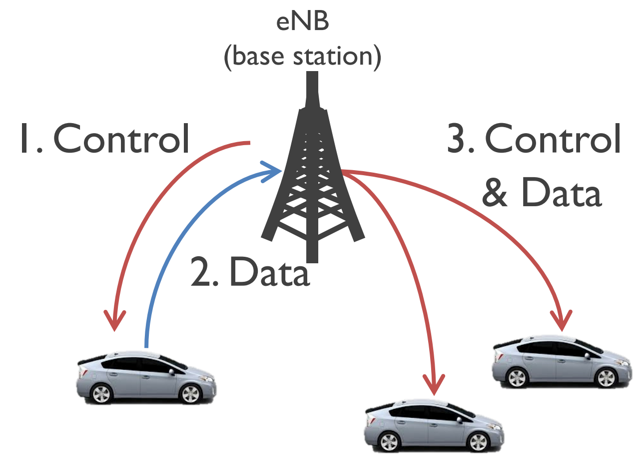
Mode 4: UE Autonomous Resource Selection



This mode is available both inside and outside NW coverage.

1. UE selects resources by itself
2. UE broadcasts V2X message using selected resources

Network-based LTE-V2X (a.k.a Uu-based LTE-V2X)



This mode is only available inside NW coverage.

1. eNB allocates resources to UE
2. UE sends V2X message to eNB using allocated resources
3. eNB forwards the received V2X message to other UEs inside NW

PC5-Based LTE-V2X

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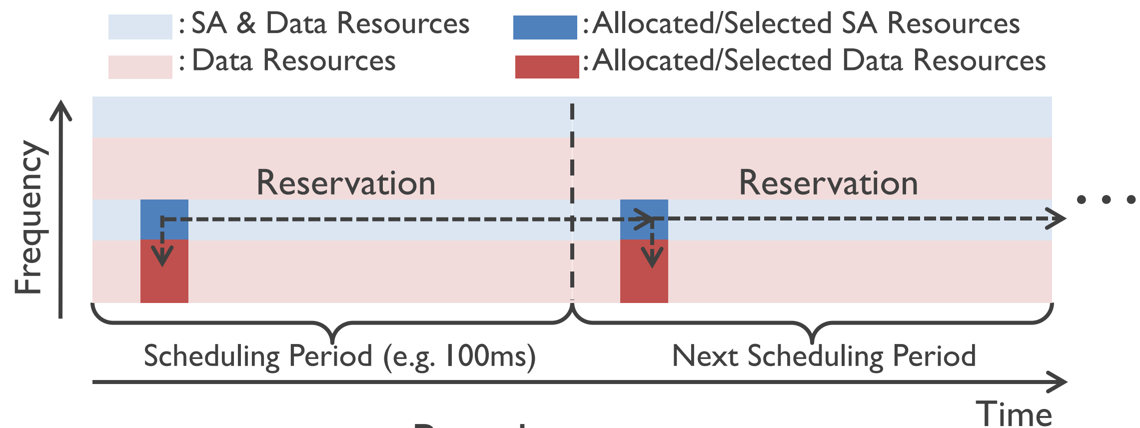
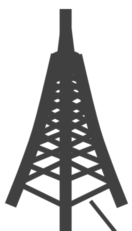
- Use sidelink to transmit V2X data for direct communication

eNB: Evolved Node B
UE: User Equipment
SA: Scheduling Assignment



eNB
(base station)



eNB Scheduled Resource Allocation (Mode 3):

- eNB allocates the resources for SA and data transmission for transmit devices using downlink
- Used <u>inside network coverage</u>

Resource Allocation

UE (Tx)

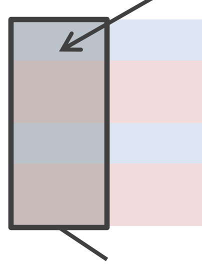
Broadcast
(over sidelink)

UEs (Rx)

Resource Selection

UE Autonomous Resource Selection (Mode 4):

- Each transmit devices autonomously selects the resources for control and data transmission from predefined resource pools
- Can operate both <u>inside and outside of network coverage</u>



Resource Pools
(pre-configured or configured by eNB)

Transmit devices send SA and data over sidelink using allocated/selected resources

SA is used to identify data resources, coding scheme (MCS) for data transmission, and reserve resources for subsequent SA & data transmission

Receive devices receive SA and data, using sidelink

Source: [3GPP]

Transmission Procedure of PC5-Based LTE-V2X

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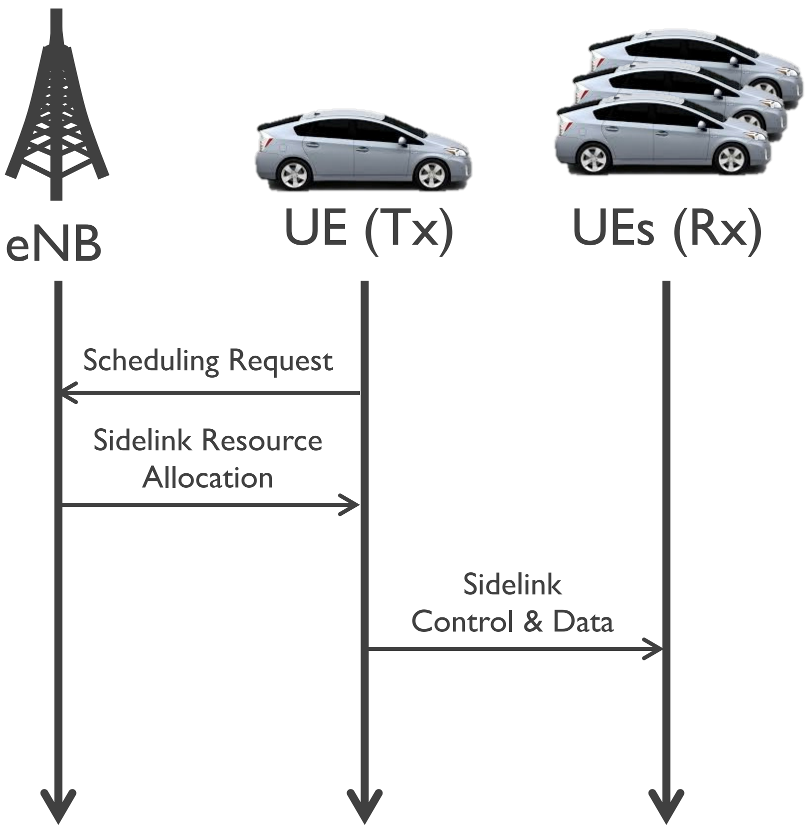
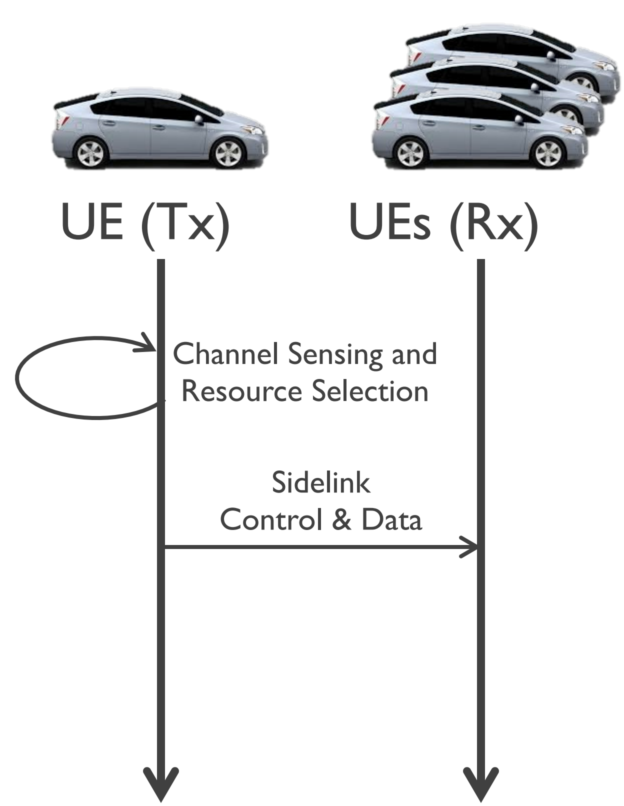
Mode 3: eNB Scheduled Resource Allocation



This mode is only available inside NW coverage.

Mode 4: UE Autonomous Resource Selection

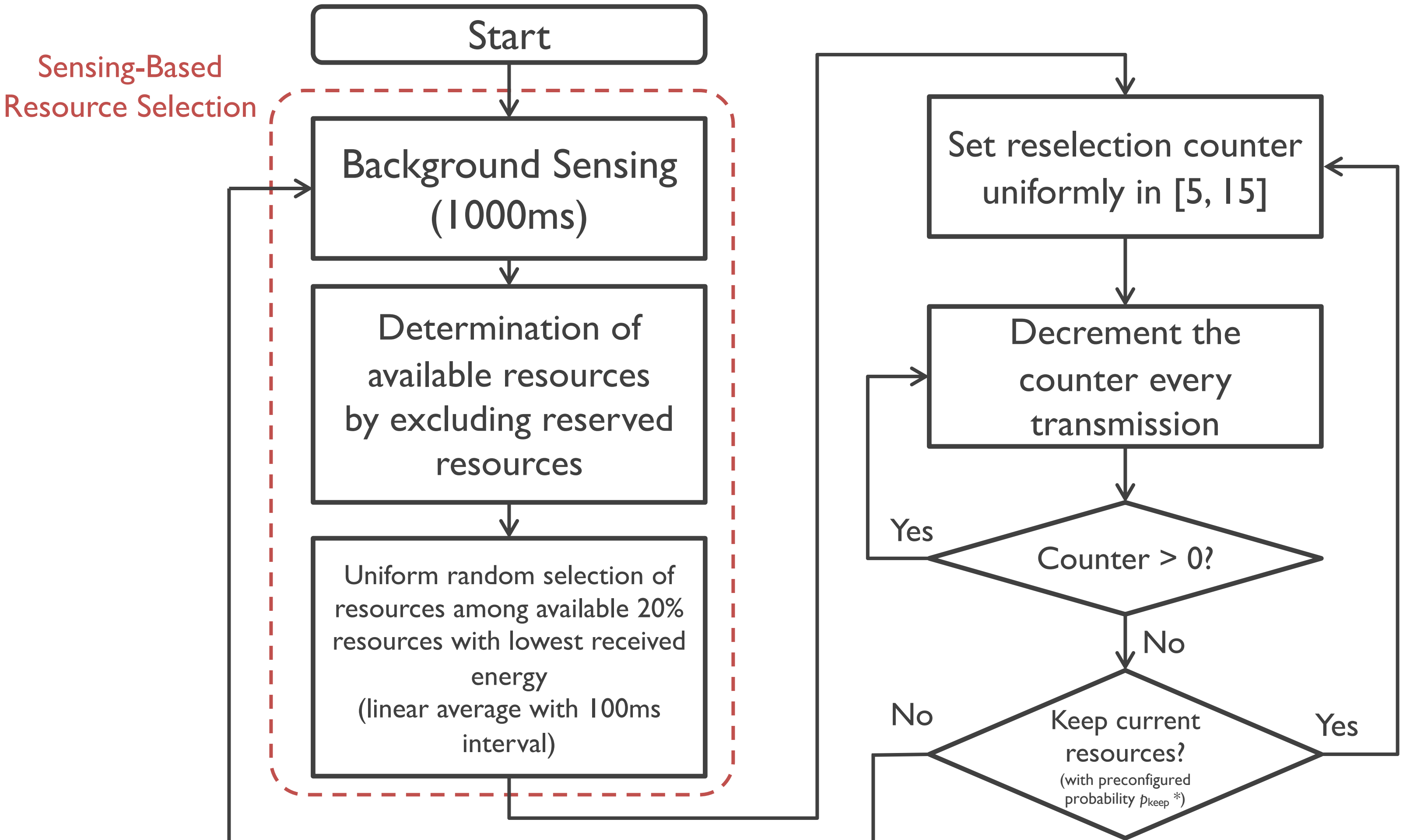


This mode is available both inside and outside NW coverage.

eNB: Evolved Node B (base station)
UE: User Equipment (mobile terminal)

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

- Procedure of Semi-Persistent Resource Selection

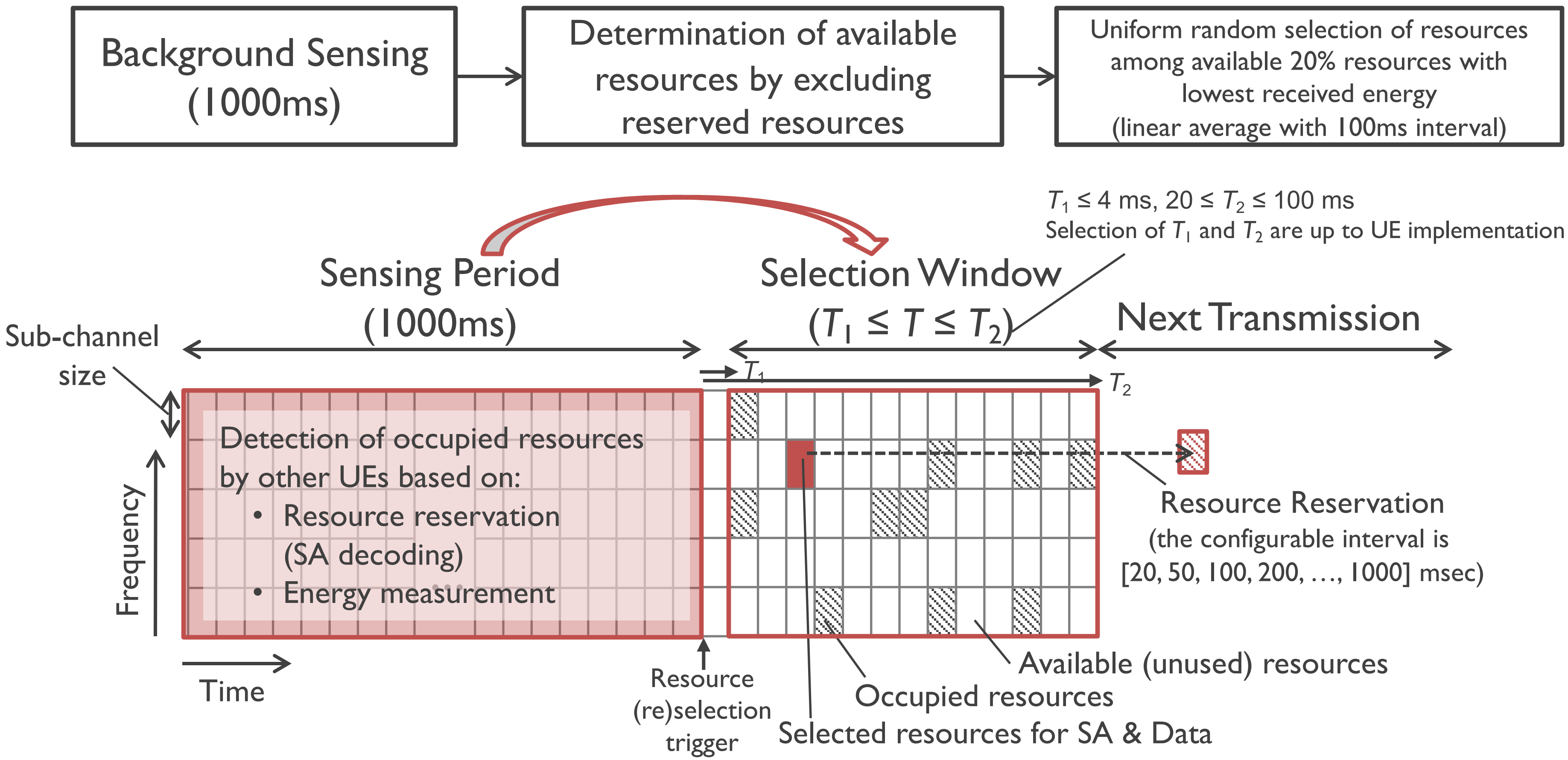


* p_{keep} takes a value in {0, 0.2, 0.4, 0.6, 0.8}.

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

SA: Scheduling Assignment

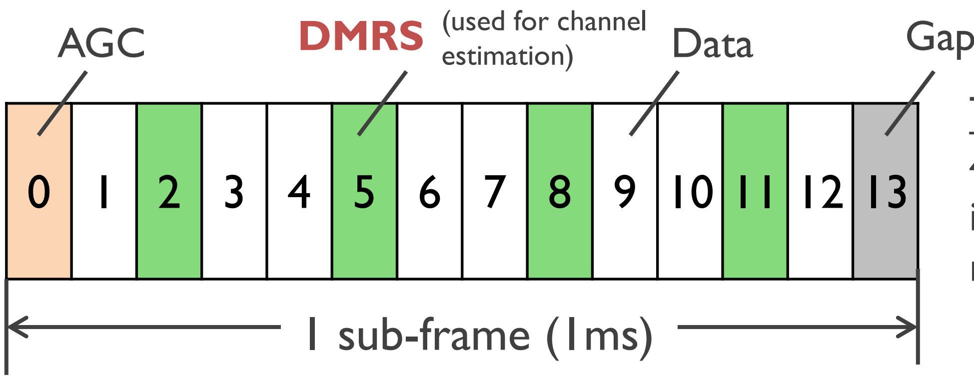
- Sensing-Based Resource Selection



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

PHY Parameters of V2X Sidelink

- The PHY parameters are the same as Rel-12/13 sidelink except DMRS density.



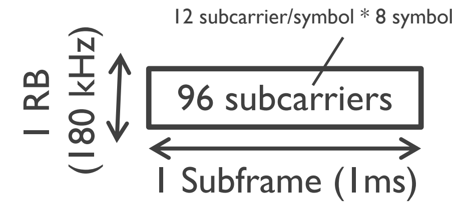
<u>The density of DMRS</u> is increased from 2 to 4 per sub-frame for better channel tracking in high vehicle mobility (up to 250km/h relative speed).

AGC: Automatic Gain Control
DMRS: DeModulation Reference Signal
SC-FDMA: Single-Carrier Frequency Division Multiple Access

Access Scheme	SC-FDMA
Modulation	QPSK, 16QAM
Channel Coding	Turbo Coding
Bandwidth	10, 20 MHz
Sub-Carrier Spacing	15 kHz
Cyclic Prefix Length	Normal: 4.7 μs
	Long: 16.7 μs
# of MIMO streams	1

Example of Packet Size in Rel-14 LTE-V2X

- The packet size that can be transmitted depends on # of resources, modulation and coding rate.

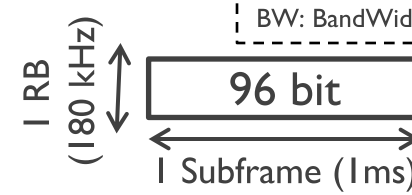


RB: Resource Block
BW: BandWidth

Case 1

For 180 kHz (1 RB) BW, QPSK, and 1/2-rate:
96 bit * 1 user can be transmitted in a subframe (1ms).

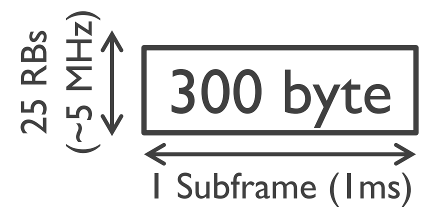
96 subcarrier * 2 bit/subcarrier * 1/2 rate = 96 bit



Case 2

For 5 MHz (25 RBs) BW, QPSK, and 1/2-rate:
300 byte * 1 user can be transmitted in a subframe (1ms).

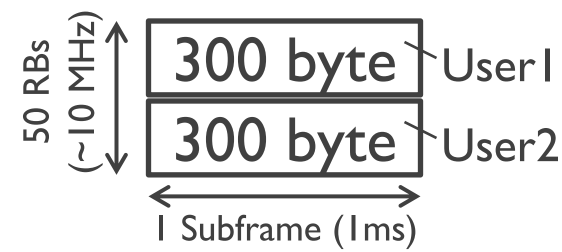
25 RB * 96 bit/RB = 2400 bit = 300 byte



Case 3

For 10 MHz (50 RBs) BW, QPSK, and 1/2-rate:
300 bytes * 2 users can be transmitted in a subframe (1ms).

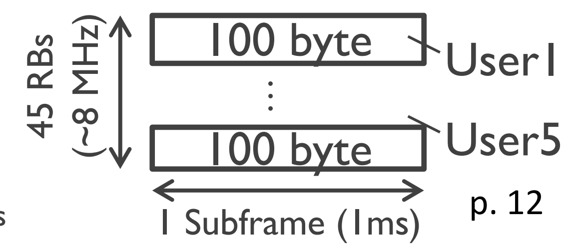
2400 [bit/user] / 96 [bit/RB] = 25 [RB/user], 50 [RB] / 25 [RB/user] = 2 users



Case 4

For 10 MHz (50 RBs) BW, QPSK, and 1/2-rate:
100 bytes * 5 users can be transmitted in a subframe (1ms).

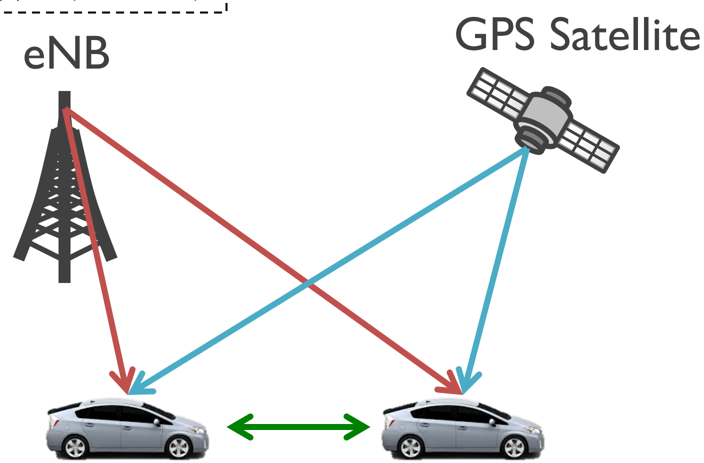
ceil(800 [bit/user] / 96 [bit/RB]) = 9 [RB/user], floor(50 [RB] / 9 [RB/user]) = 5 users



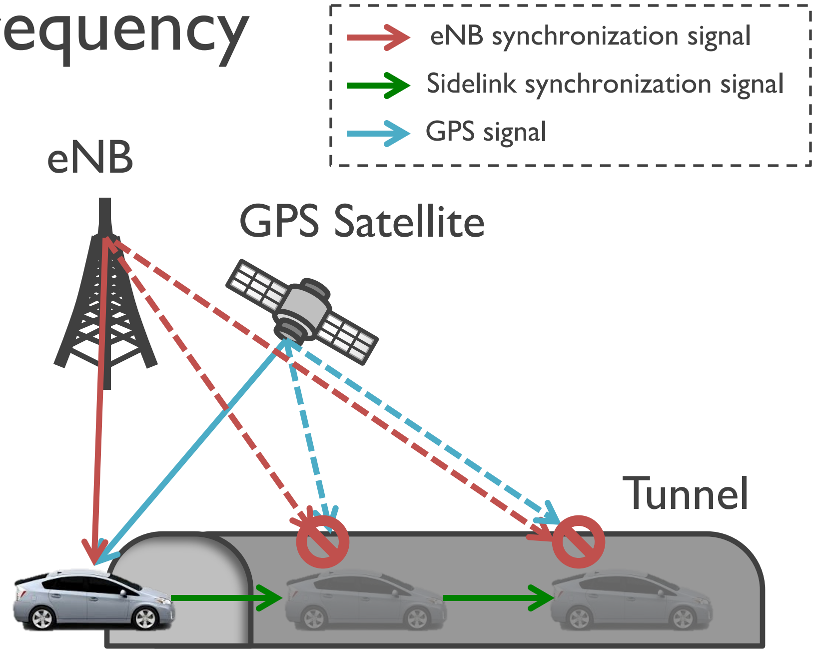
Synchronization in PC5 LTE-V2X

- Enhancement allows to use GPS signals for synchronization for time and frequency

eNB: Evolved Node B (base station)
UE: User Equipment (mobile terminal)



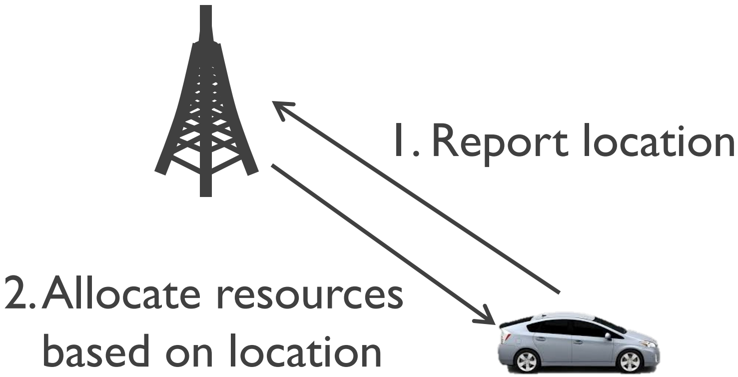
Use of GPS signal as synchronization source, in addition to eNB/UE sync. signal

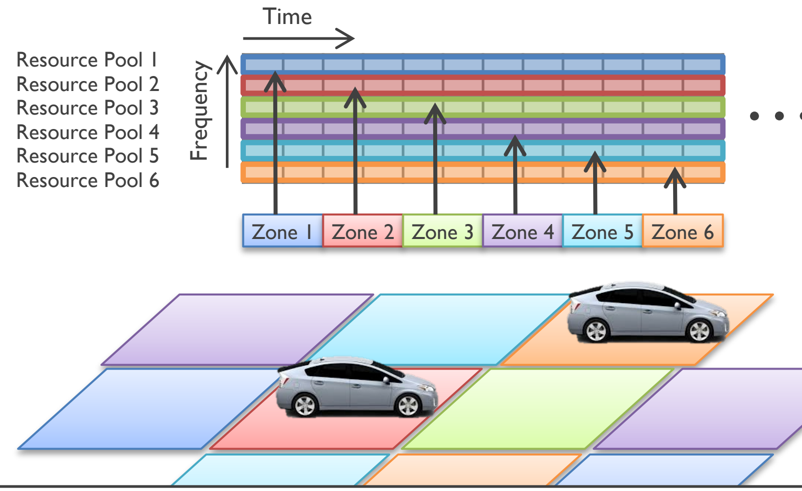


Relay of synchronization signal

These enhancements enable synchronization among UEs <u>even when they are outside NW coverage</u>

Geo-Based Scheduling for PC5 LTE-V2X





Each vehicle autonomously selects resources in the resource pool corresponded to the zone where the vehicle is located in.

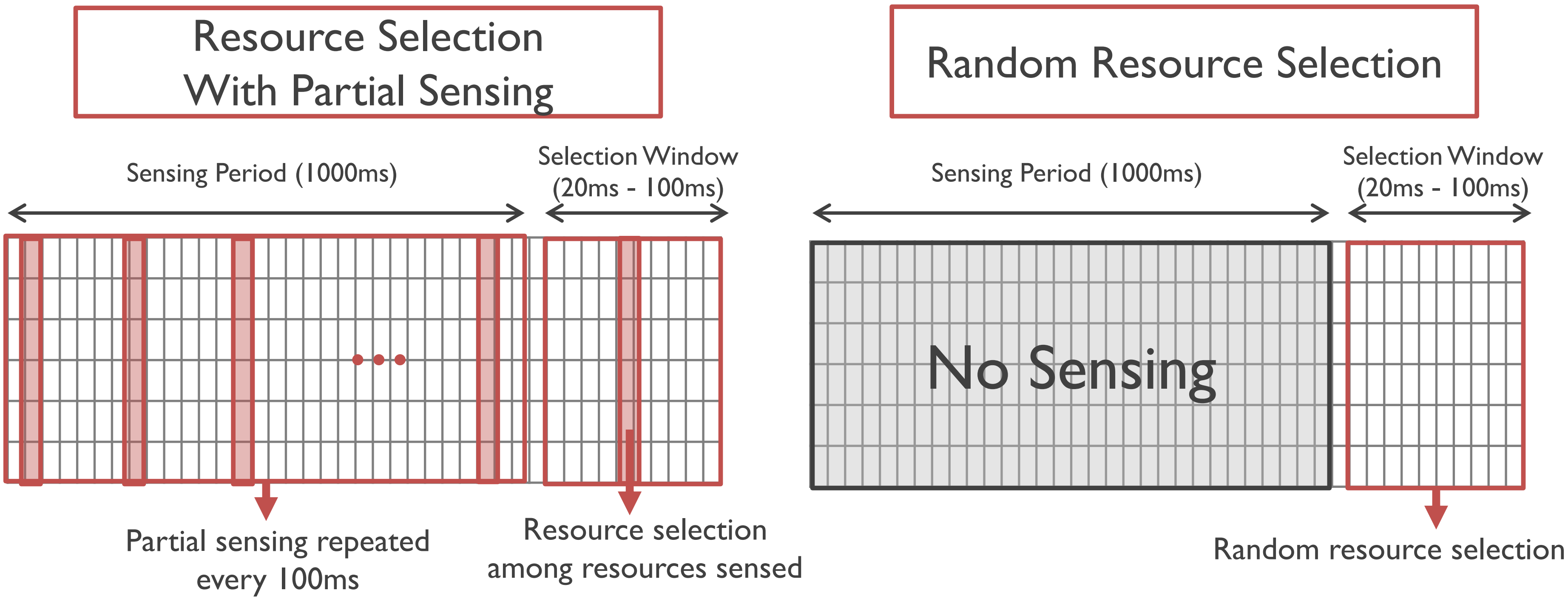
Mode 1: eNB Scheduled Resource Allocation

Mode 2: UE Autonomous Resource Selection

- Vehicle location information can be used for resource management.
  - eNB scheduling mode: Reporting of vehicle location to eNB
    Use different resource pools for each base station sector to reduce inter-sector interference
  - UE autonomous mode: Geo-zoning
    Use different resource pools for each zone to reduce inter-zone interference / packet collision

eNB: Evolved Node B (base station)
UE: User Equipment (mobile terminal)

Resource Selection for Pedestrian UE in PC5 LTE-V2P



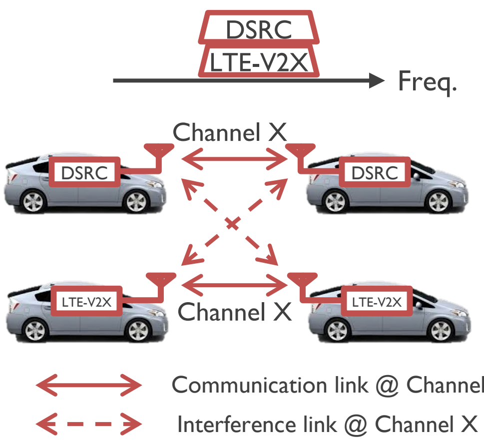
- Two resource selection options were introduced for pedestrian UEs (P-UEs) for battery efficiency
  - Resource selection with partial sensing
  - Random resource selection without sensing

Note: (Pre)configuration instructs whether a P-UE uses partial sensing only, random selection only, or either of the two.

Coexistence between DSRC and D2D LTE-V2X

- In Mar. 2016, 3GPP RAN TSG agreed* to study coexistence between DSRC and LTE-V2X, which was proposed by Ericsson, to deploy LTE-V2X in Europe in addition to China.
- ETSI decided to study this co-channel coexistence based on cellular industry's proposal.
  ➔ ITC carefully monitors these activities on this coexistence topic

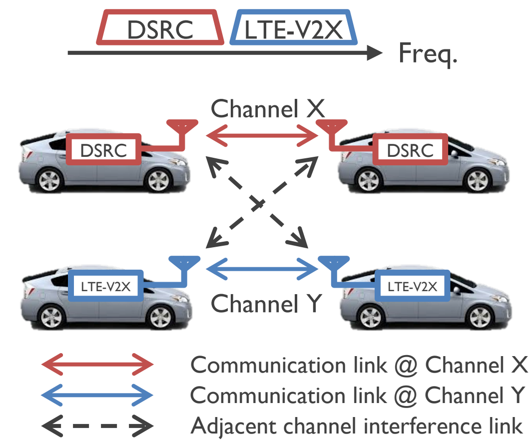
Scenario1: Same Channel



➔ Study high-level coexistence schemes

- Geo-location and database (similar to TV whitespace)
- Time sharing based on GNSS timing
  (would require modification to DSRC)
- Sensing-based vacate/switching approaches
  (would require modification to DSRC)

Scenario2: Adjacent Channel



➔ Study the effect of adjacent interference

* http://www.3gpp.org/ftp/meetings_3gpp_sync/ran/Inbox/RP-160657.zip
http://www.3gpp.org/ftp/meetings_3gpp_sync/ran/Inbox/RP-160649.zip

This would cause the negative impact to DSRC operation due to the potential loss of DSRC transmission and potential interference. → ITC carefully monitors their movement.

Potential Solutions for Co-Channel Coexistence Between DSRC and D2D LTE-V2X (1/2)

- In 3GPP RAN1 WG, some companies proposed potential solutions on co-channel coexistence
- Ericsson is very aggressive on co-channel coexistence to deploy LTE-V2X in Europe

Company	Proposals
Ericsson	• Detect-and-vacate based on mutual detection
LG Electronics	• Geo-location and database (like TVWS) • Detect-and-vacate based on mutual detection
Huawei	• Long-term channel splitting (not co-channel) • Detect-and-vacate based on mutual detection • LBT-based coexistence based on mutual detection
Samsung	• LBT-based coexistence based on mutual detection

Qualcomm	• LBT-based coexistence based on mutual detection with interoperability between LTE-V2V and DSRC
	  • Both LTE-V2V and DSRC vehicles able to decode messages from both technologies but transmit using only its respective technology
	  • LTE-V2V vehicles able to both transmit and received DSRC messages

All these solutions potentially cause interference to DSRC
due to a possibility that LTE-V2X signals are transmitted in the same channel

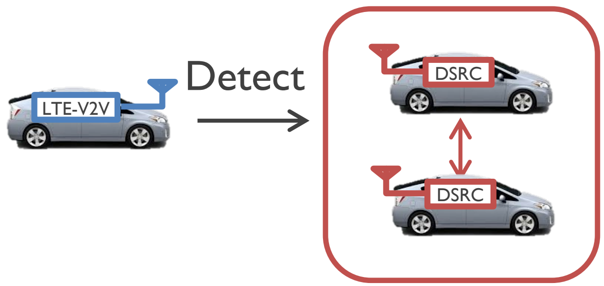
TVWS: TV White Space
LBT: Listen Before Talk

Potential Solutions for Co-Channel Coexistence Between DSRC and D2D LTE-V2X (2/2)

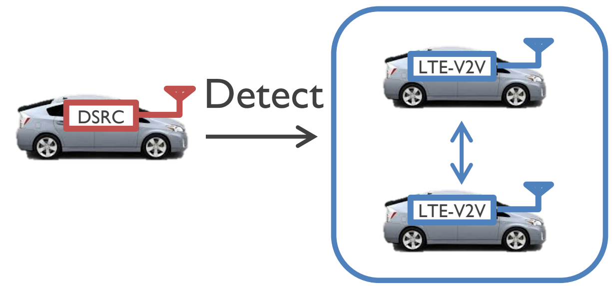
Scenario 1:
LTE-V2V devices detect DSRC communication

Channel X
Assumed co-channel coexistence

Scenario 2:
DSRC devices detect LTE-V2V communication



RAN1 WG also concluded that DSRC can detect D2D LTE-V2V signals with following techniques with necessary modifications to DSRC.



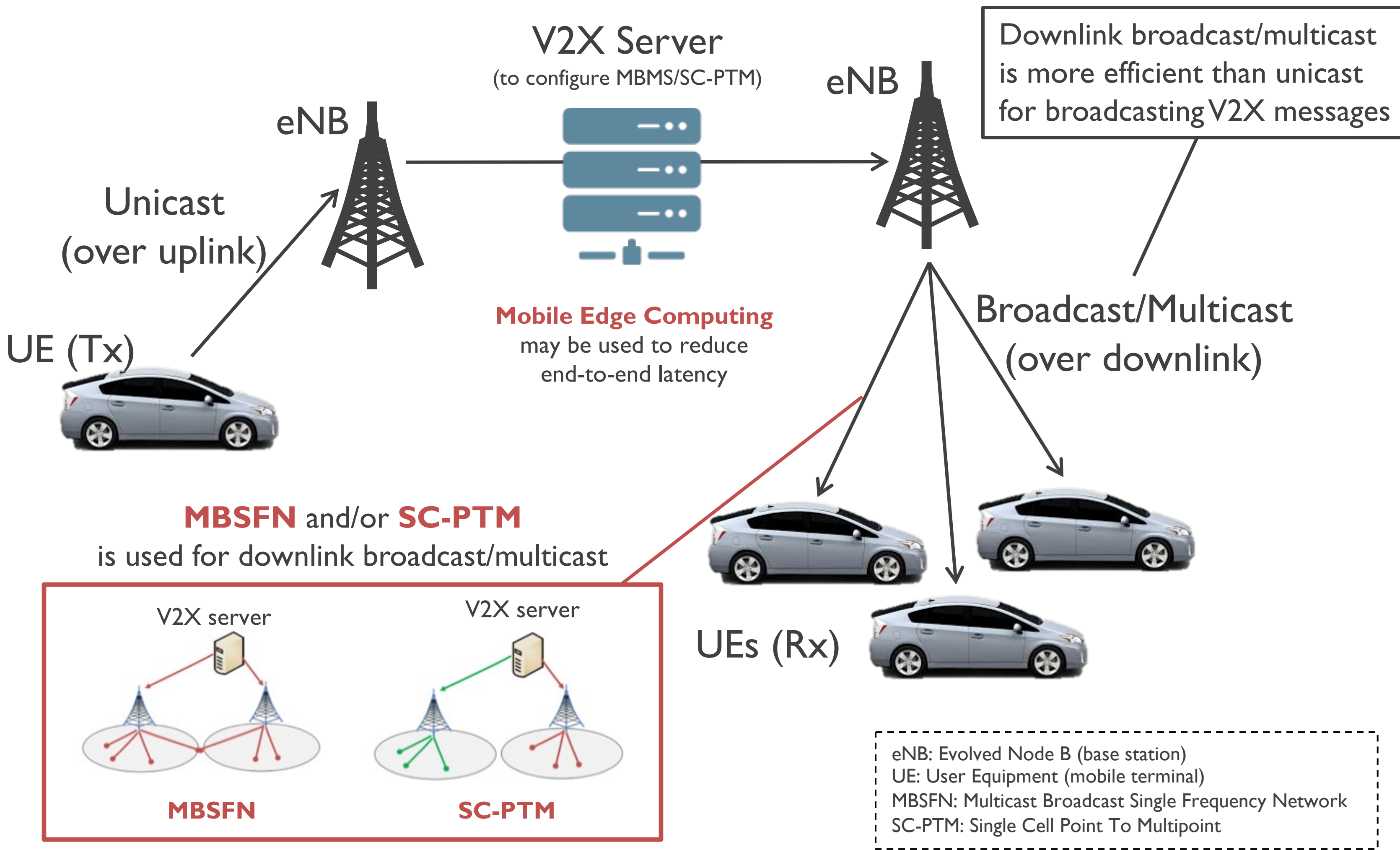
RAN1 WG concluded that LTE-V2V devices can detect DSRC signals via preamble detection and/or energy detection.

- 3GPP RAN1 WG studies the detection schemes of different V2X technology for co-channel coexistence between D2D LTE-V2V and DSRC:
  - Option 1: Detection using LTE-V2V signal's cyclic prefix
  - Option 2: Detection using a symbol for detection that can be added to LTE-V2V signal
  - Option 3: Detection of synchronization symbols of LTE-V2V signal
  - Option 4: Energy detection of LTE-V2V signal

→Any techniques require modification to the current DSRC radios, which causes additional radio development/testing/cost. Therefore, we cannot support such ideas without regulator's guidance.

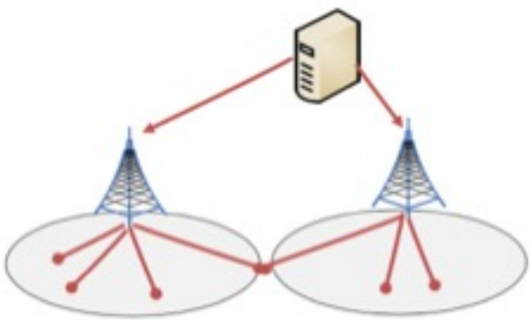
Network-Based LTE-V2X

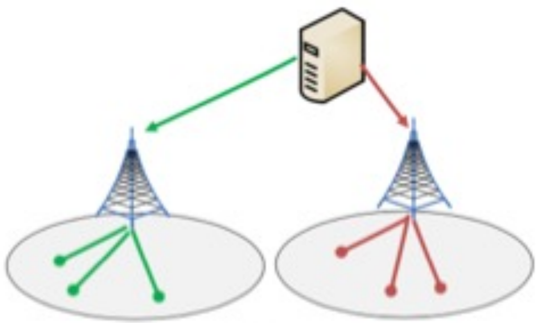
- Use the LTE uplink and downlink to exchange V2X data



MBSFN and SC-PTM in Network-Based LTE-V2X

Downlink multicast technologies: MBSFN and SC-PTM

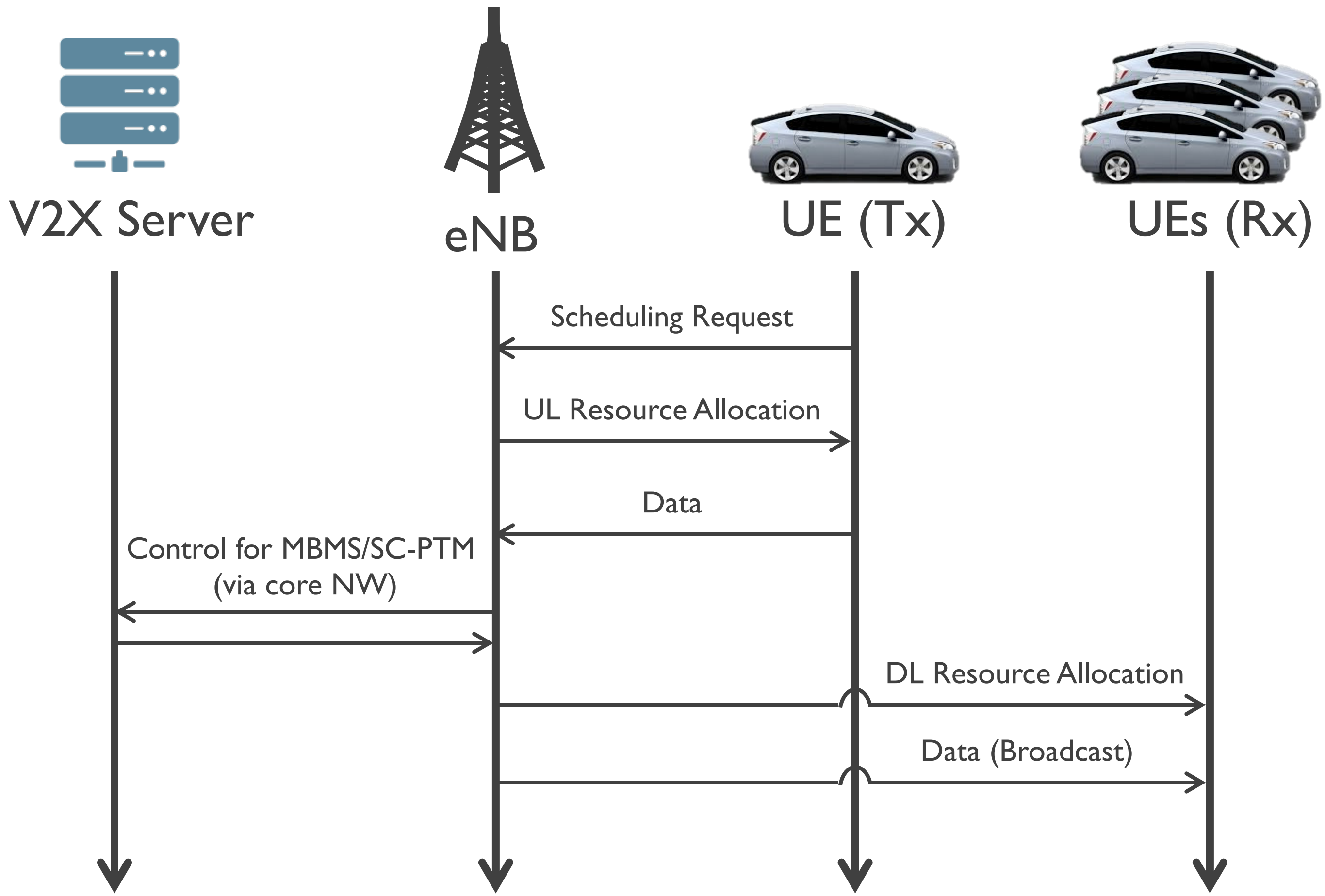




- MBSFN
  - Standardized in Rel-9
  - Multicast by all eNBs in a MBSFN area
  - Semi-static resource allocation
- SC-PTM
  - Standardized in Rel-13
  - Multicast by an eNB in each cell
  - Dynamic resource allocation

eNB: Evolved Node B (base station)
UE: User Equipment (mobile terminal)
MBSFN: Multicast Broadcast Single Frequency Network
SC-PTM: Single Cell Point To Multipoint

Transmission Procedure of Network-Based LTE-V2X



This mode is only available inside NW coverage.

eNB: Evolved Node B (base station)
UE: User Equipment (mobile terminal)
MBSFN: Multicast Broadcast Single Frequency Network
SC-PTM: Single Cell Point To Multipoint

PHY Parameters of V2X Uplink/Downlink

- The PHY parameters are the same as the existing uplink/downlink parameters

DL: Downlink
UL: Uplink
OFDMA: Orthogonal Frequency Division Multiple Access
SC-FDMA: Single Carrier Frequency Division Multiple Access
FDD: Frequency Division Duplex
TDD: Time Division Duplex
MIMO: Multiple Input Multiple Output

Access Scheme	DL: OFDMA UL: SC-FDMA
Duplex Scheme	FDD or TDD
Modulation	DL: QPSK, 16QAM, 64QAM, 256QAM (option) UL: QPSK, 16QAM, 64QAM (option)
Channel Coding	Turbo Coding
Bandwidth	1.4, 3, 5, 10, 15, 20 MHz
Sub-Carrier Spacing	15 kHz
Cyclic Prefix Length	Normal: 4.7 µs
	Long: 16.7 µs
# of MIMO streams	DL: up to 8 UL: up to 4

Overhead at Layer 2

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関係社外秘(Protected)

802.11p

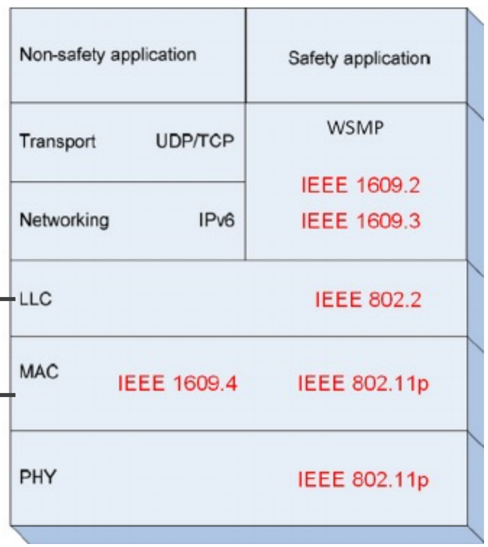
Total Overhead at Layer 2: **32 byte**

Overhead:

2 byte — LLC

26 byte — MAC

4 byte (FCS) — PHY



http://andi.flowrider.ch/research/public/meier2005a.pdf
http://www.ijcce.org/papers/250-OC0016.pdf

For 313-byte MAC PDU, Layer 2 overhead is:

$$\left(1 - \frac{313 - 32\ [\text{byte}]}{313\ [\text{byte}]}\right) \times 100 = \mathbf{10.22}\%$$

PC5 LTE-V2X

Total Overhead at Layer 2: **19 byte**

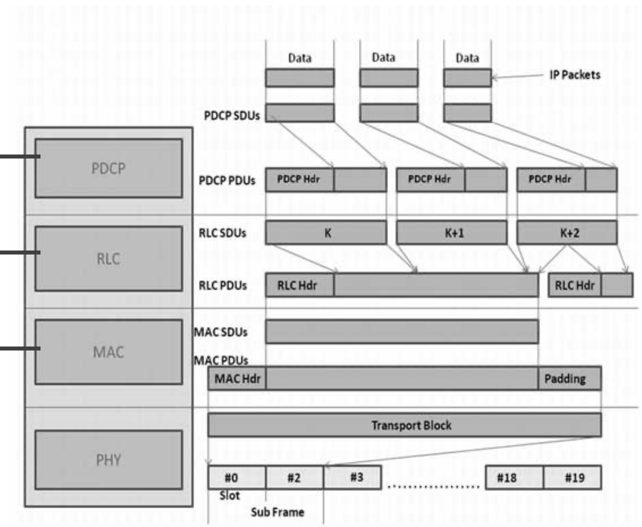
Overhead:

5 byte — PDCP

1 byte — RLC

10 byte — MAC

3 byte (CRC) — PHY



3GPP TS36.323 Packet Data Convergence Protocol (PDCP) specification V14.3.0
3GPP TS36.322 Radio Link Control (RLC) protocol specification V14.0
3GPP TS36.321 Medium Access Control (MAC) protocol specification V14.3.0

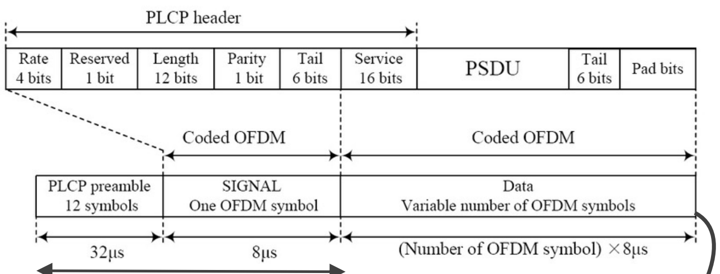
For 300-byte MAC PDU, Layer 2 overhead is:

$$\left(1 - \frac{300 - 19\ [\text{byte}]}{300\ [\text{byte}]}\right) \times 100 = \mathbf{6.33}\%$$

- The overhead of 802.11p at Layer 2 is 13-byte larger than PC5 LTE-V2X

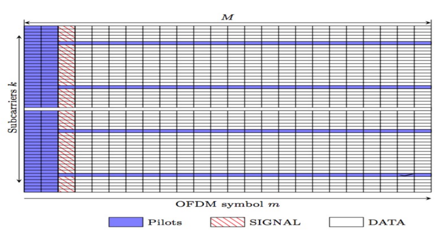
Overhead at Layer 1

802.11p



Preamble+SIGNAL overhead

H. Wen, P. H. Ho and G. Gong, "A Novel Framework for Message Authentication in Vehicular Communication Networks," *GLOBECOM 2009 - 2009 IEEE GLOBECOM*, Honolulu, HI, 2009, pp. 1-6.



4 pilot subcarriers (overhead) out of 52 subcarriers in Data

http://publications.lib.chalmers.se/records/fulltext/225073/225073.pdf

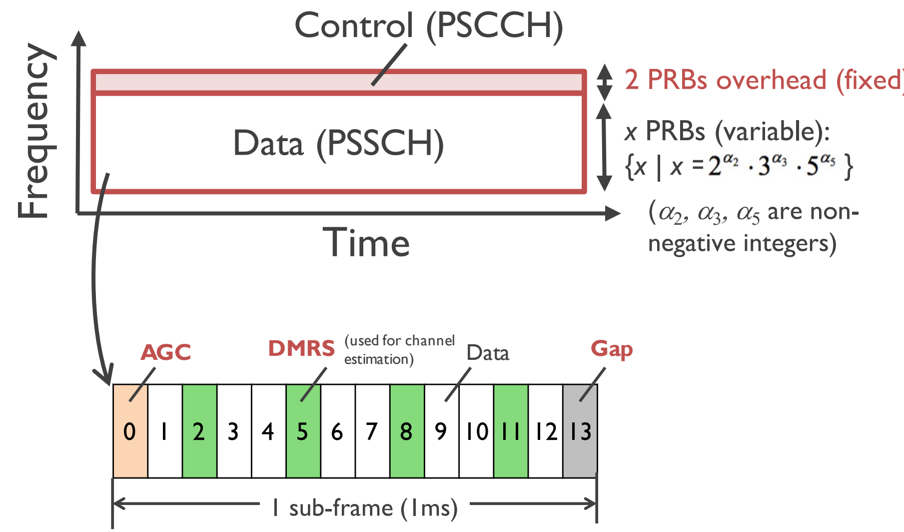
Cyclic Prefix overhead: 1.6 µs out of 8-µs total OFDM symbol

For 313-byte PHY payload, PHY overhead is:

Preamble+SIGNAL overhead | Pilot symbol overhead | Cyclic prefix overhead

$$\left(1-\frac{464-40\,[\mu s]}{464\,[\mu s]}\times\frac{52-4\,[\text{Subcarrier}]}{52\,[\text{Subcarrier}]}\times\frac{8-1.6\,[\mu s]}{8\,[\mu s]}\right)\times 100=\mathbf{32.52}\%$$

PC5 LTE-V2X



Cyclic Prefix overhead: 4.7 µs out of 71.4-µs total SC-FDMA symbol

For 300-byte PHY payload (20 PRBs for data and 2 PRBs for control), PHY overhead is:

PSCCH overhead | AGC, DMRS, Gap overhead | Cyclic prefix overhead

$$\left(1-\frac{22-2\,[\text{PRB}]}{22\,[\text{PRB}]}\times\frac{14-6\,[\text{Symbol}]}{14\,[\text{Symbol}]}\times\frac{71.4-4.7\,[\mu s]}{71.4\,[\mu s]}\right)\times 100=\mathbf{51.47}\%$$

- The overhead of 802.11p at Layer 1 is ~19-point smaller than PC5 LTE-V2X.

Total Overhead (Layer 1 and 2) Comparison

- The overhead of 802.11p at Layer 1&2 is ~15-point smaller than PC5 LTE-V2X.

	802.11p	PC5 LTE-V2X
Layer 2 overhead	10.22%	6.33%
Layer 1 overhead	32.52%	51.47%
Total Overhead	**39.42%**	**54.54%**

This is calculated based on the assumption that ~300byte MAC PDU and QPSK and ~1/2 code rate.

Technical Problems in Rel-14 PC5 LTE-V2X

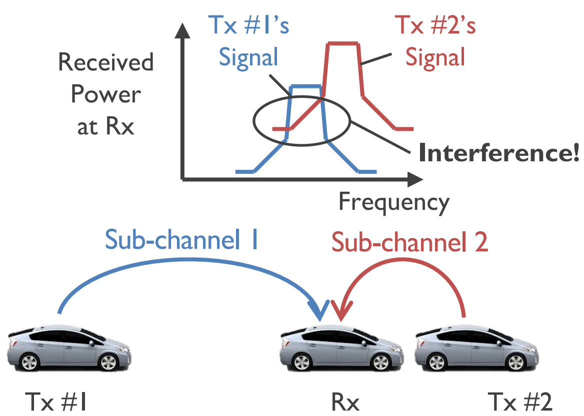
- For both modes 3 and mode 4:
  - In-band emission interference
  - No resource coordination between mode 3 and mode 4
  - Inflexibility for variable message sizes
  - Inflexibility for variable message interval
  - Higher PHY overhead
- For mode 3 only:
  - Inter-cell interference
  - Resource coordination/sharing among multiple operators
- For mode 4 only:
  - Persistent packet collision
  - Half duplex problem

Note that DSRC doesn't have any of the problems above.

Technical Problems in Rel-14 PC5 LTE-V2X (Both Mode 3 and Mode 4) (1/3)

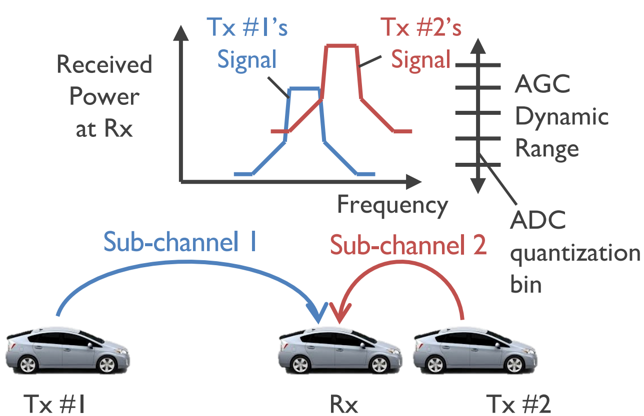
TOYOTA
InfoTechnology Center, U.S.A., Inc.
関係社外秘(Protected)

Near-far problem 1: in-band emission interference



- Since LTE-V2X uses FDMA, IBE interference occurs due to imperfect receiver filters, which allow signals at adjacent sub-channel to leak into the pass band.
- IBE interference severely degrades the communication performance when there are two Txs using adjacent resources, one close to Rx, the other far away from Rx (i.e., near-far effect).
- One way to mitigate this problem is to apply geo-based resource allocation/selection so that distant Tx don't use the same resource pool. However, it leads inefficient use of resources when the user density is not uniform in space.

Near-far problem 2: AGC & ADC impact



- Since AGC has limited dynamic range and ADC has limited quantization bits, when there are two Txs using adjacent resources, one close to Rx, the other far away from Rx (i.e., near-far effect), the impact of ADC quantization error degrade the reception of weaker signals because AGC dynamic range is adjusted based on the stronger signal and weaker signal is affected by ADC quantization error.

IBE: In-Band Emission
AGC: Automatic Gain Control
ADC: Analog-to-Digital Converter
FDMA: Frequency Division Multiple Access

Technical Problems in Rel-14 PC5 LTE-V2X (Both Mode 3 and Mode 4) (2/3)

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InfoTechnology Center, U.S.A., Inc.
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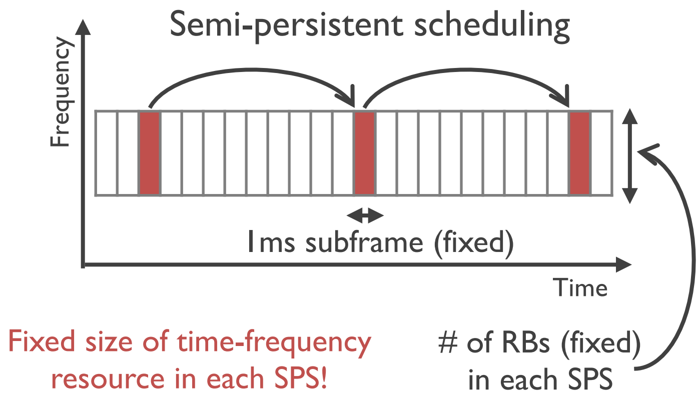
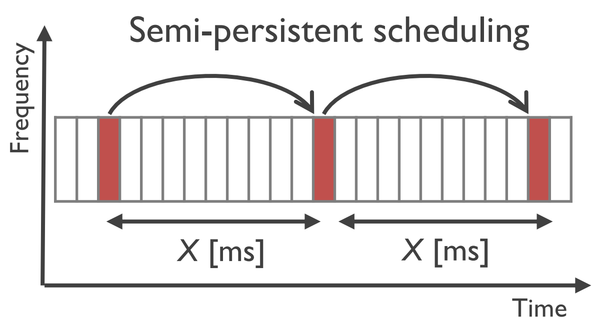
Inflexibility for variable message sizes



- In semi-persistent scheduling, # of allocated RBs is fixed in each SPS until the next resource allocation/reselection (i.e., fixed time-frequency resource size). Therefore, it has less flexibility to support variable message sizes.
- It's possible to change MCS in each transmission even in SPS to support different message sizes. However, it causes different communication performance in each transmission.
- Since V2X message size is not necessarily the same in each transmission due to different security overhead (digest and full certificate) and optional fields (e.g., path history), it's not trivial how to support variable message sizes.

Inflexibility for variable message interval



The allowed resource interval X [ms] is limited to: {20, 50, 100, 200, 300, …, 1000} [ms]

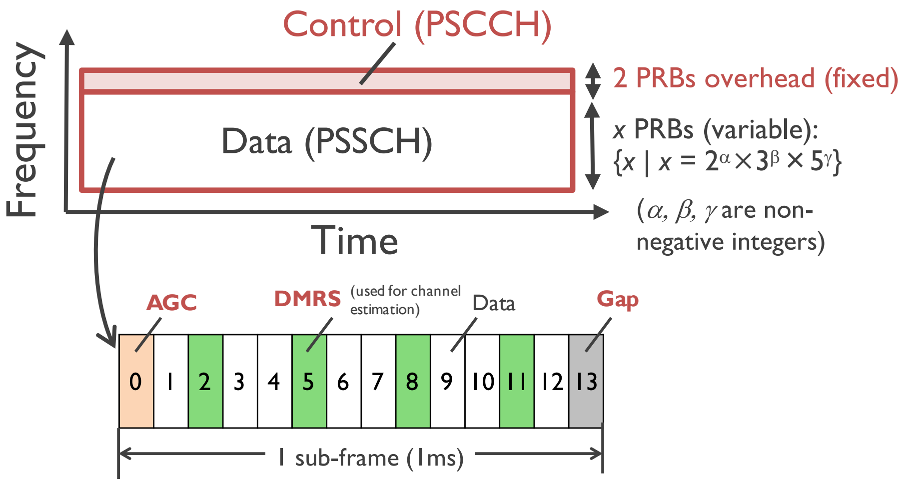
- In semi-persistent scheduling, the message interval X [ms] is limited to {20, 50, 100, 200, 300, …, 1000} [ms]. Therefore, it has less flexibility on message interval.
- Since ETSI CAM message interval depends on vehicle dynamics and thus it is not perfectly periodic, it's not trivial how to support such message traffic.
- This imposes a restriction on the granularity of message rate control in congestion control.

RB: Resource Block
SPS: Semi-Persistent Scheduling
MCS: Modulation and Coding Scheme
CAM: Cooperative Awareness Message

Technical Problems in Rel-14 PC5 LTE-V2X (Both Mode 3 and Mode 4) (3/3)

PSCCH: Physical Sidelink Control CHannel
PSSCH: Physical Sidelink Shared Channel
PRB: Physical Resource Block
DMRS: DeModulation Reference Signal

- Higher PHY overhead



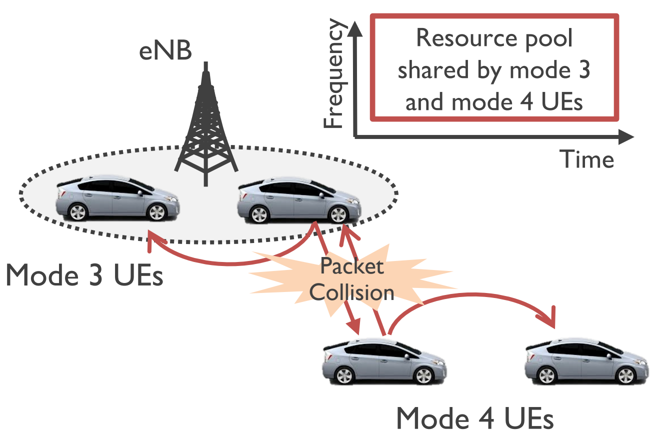
PSCCH, AGC, DMRS, Gap are overhead

- In order to support high mobility, PHY overhead is increased and thus total overhead at Layer 1 and 2 is higher than 802.11p.

	802.11p	PC5 LTE-V2X
Layer 2 overhead	10.22%	6.33%
Layer 1 overhead	32.52%	51.47%
Total Overhead	**39.42%**	**54.54%**

Note: this is calculated based on the assumption that ~300byte MAC PDU and QPSK and ~1/2 code rate.

- No resource coordination between mode 3 and mode 4



- Since eNB cannot know which sidelink resources are used by mode 4 UEs and resource reservation is always disabled in mode 3, if sidelink resources are shared by mode 3 and mode 4 UEs, packet collision between mode 3 and mode 4 UEs could happen.
- One way to mitigate this problem is to allocate separate resource pools for mode 3 and mode 4. However, it leads inefficient use of resources when the traffic of mode 3 and mode 4 is not comparable.

➔ In Rel-15, 3GPP will define enhancements for resource pool sharing between mode 3 and mode 4.

Technical Problems in Rel-14 PC5 LTE-V2X (Mode 3 Only)

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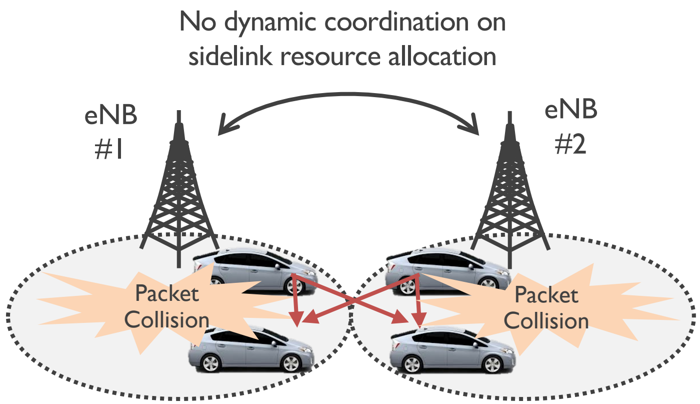
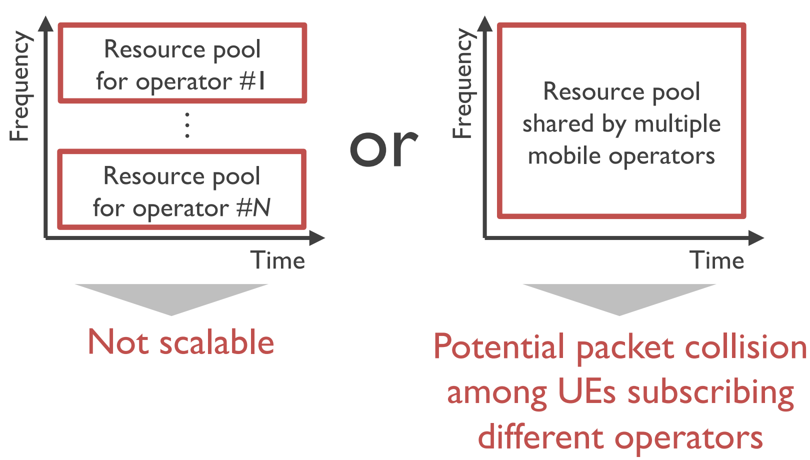
Inter-cell interference



- For multiple eNBs that don't coordinate with each other on sidelink resource allocation, if two UEs camping on different eNBs at cell edge are accidentally allocated the same time-frequency resources, it causes inter-cell interference to surrounding UEs.
- One way to mitigate this problem is to apply geo-based resource allocation/selection so that UEs camping on different eNBs at cell edge don't use the same resource pool. However, it leads inefficient use of resources when the user density is not uniform in space.

Resource coordination/sharing among multiple operators



- If multiple mobile operators provide PC5 V2X mode 3 services, it's not trivial on how to coordinate or share sidelink resources between multiple operators.
- If dedicated resource pool is allocated to each operator, it's inefficient use of spectrum and not scalable.
- If multiple operators share the sidelink resources, it causes packet collision among UEs subscribing different operators as different operators don't coordinate on sidelink resource allocation.

Technical Problems in Rel-14 PC5 LTE-V2X (Mode 4 Only)

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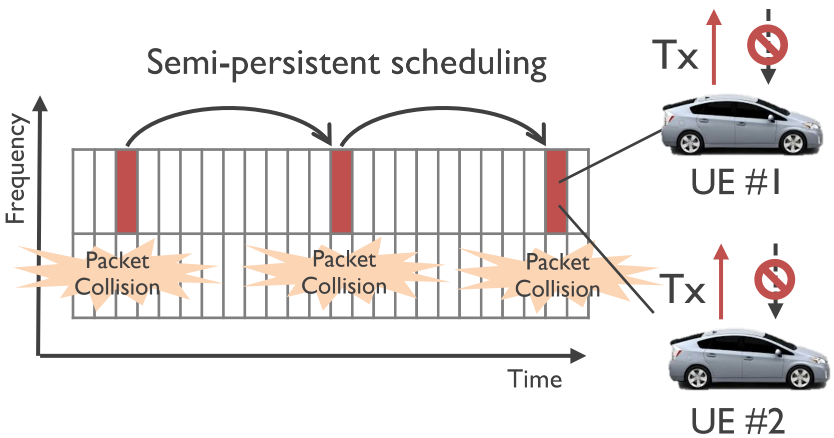
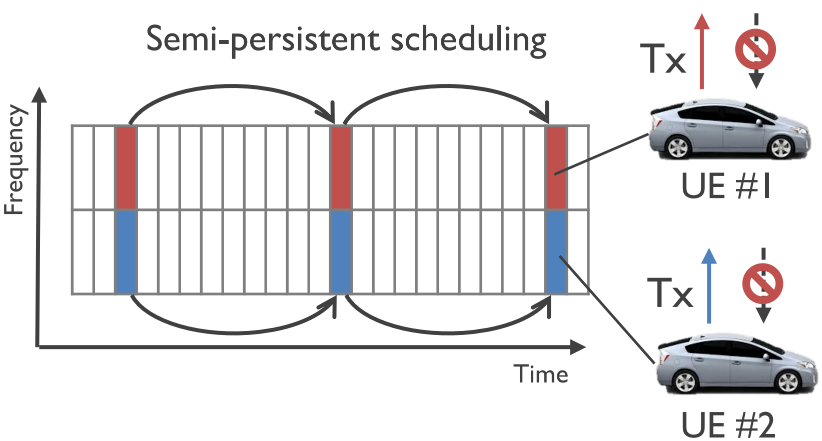
• Persistent packet collision

p_{RK}: Probability in the interval [0, 1] with which UE keeps the current resources when the resource reselection counter is zero.



- Due to semi-persistent scheduling, if UE #1 and UE #2 select the same time-frequency resources, their packets collide with each other consecutively until one of the UEs performs resource reselection ($10/(1-p_{RK})$ transmissions on average). Also, due to half duplex limitation, they cannot detect those packet collisions.
- One way to mitigate this problem is to use retransmission with random interval (optional function in Rel-14). However, it reduces the system capacity by half. Also, retransmission is not available in case of lack of resources in congested scenarios.

• Half duplex problem



- Due to half duplex limitation and semi-persistent scheduling, if UE #1 and UE #2 select the same resource in time but without overlap in frequency, they cannot receive the other's messages consecutively until one of the UEs performs resource reselection ($10/(1-p_{RK})$ transmissions on average)..
- One way to mitigate this problem is to use retransmission with random interval (optional function in Rel-14). However, it reduces the system capacity by half. Also, retransmission is not available in case of lack of resources in congested scenarios.

List of 3GPP Technical Specification

- 3GPP Technical Specification related to LTE-V2X

Number	Title
3GPP TS 22.185	Service requirements for V2X services
3GPP TS 23.285	Architecture enhancements for V2X services
3GPP TS 33.185	Security aspect for LTE support of Vehicle-to-Everything (V2X) services
3GPP TS 36.101	E-UTRA; UE radio transmission and reception
3GPP TS 36.201	E-UTRA; LTE physical layer; General description
3GPP TS 36.211	E-UTRA; Physical channels and modulation
3GPP TS 36.212	E-UTRA; Multiplexing and channel coding
3GPP TS 36.213	E-UTRA; Physical layer procedures
3GPP TS 36.214	E-UTRA; Physical layer; Measurements
3GPP TS 36.321	E-UTRA; MAC protocol specification
3GPP TS 36.322	E-UTRA; RLC protocol specification
3GPP TS 36.323	E-UTRA; PDCP specification
3GPP TS 36.331	E-UTRA; RRC; Protocol specification

http://www.3gpp.org/DynaReport/22-series.htm
http://www.3gpp.org/DynaReport/23-series.htm
http://www.3gpp.org/ftp/Specs/html-info/33-series.htm
http://www.3gpp.org/ftp/Specs/html-info/36-series.htm

List of 3GPP Technical Reports

TOYOTA
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- 3GPP Technical Reports for LTE-V2X

Number	Title
3GPP TR 22.885	Study on LTE support for Vehicle to Everything (V2X) services
3GPP TR 23.785	Study on architecture enhancements for LTE support of V2X services
3GPP TR 33.885	Study on security aspects for LTE support of V2X services
3GPP TR 36.885	Study on LTE-based V2X services
3GPP TR 36.785	Vehicle to Vehicle (V2V) services based on LTE sidelink; User Equipment (UE) radio transmission and reception
3GPP TR 36.786	V2X Services based on LTE; User Equipment (UE) radio transmission and reception
3GPP TR 36.787	Vehicle-to-Everything (V2X) new band combinations

http://www.3gpp.org/DynaReport/22-series.htm
http://www.3gpp.org/DynaReport/23-series.htm
http://www.3gpp.org/ftp/Specs/html-info/33-series.htm
http://www.3gpp.org/ftp/Specs/html-info/36-series.htm

Global Situation of V2X Safety

- Only China has a high possibility of the deployment of LTE-V2X because of national policy
- Europe might be another region that LTE-V2X is deployed

Country / Region	Situation	Deployment Possibility for Safety	
		700MHz ITS / 5.9 GHz DSRC	LTE-V2X
Japan	• Toyota started the commercial service of 760MHz DSRC "ITS Connect" in Oct. 2015 • LTE V2X Ad Hoc was established in ARIB	Deployed	Low
USA	• NHTSA NRPM for V2V DSRC published in late 2016 • Expected that US government mandates 5.9GHz DSRC for V2V around 2020 • GM's Cadillac CTS with DSRC (Model 2017) is now in production • Ford, AT&T, and Delphi teamed up for LTE-V2X R&D	To be deployed	Low
Europe	• C2C-CC expects the initial deployment of ITS-G5 (802.11p) in 2019 • VW announced they will deploy ITS-G5 in 2019 • ITS-G5 (802.11p) will not be mandated • Some auto companies (e.g., BMW, Audi, Daimler, Ford) are interested in LTE-V2X • 5GAA becomes aggressive to deploy LTE-V2X in 5.9GHz in Europe	To be deployed	Some possibility
China	• Chinese government strongly promotes LTE-V2X • China plans to conduct LTE-V2X trial in Shanghai with up to 1000 cars in 2016-2019 • GM and NXP promote DSRC in China	?	High
Asia / Mid. East	• ITC-JP promotes 700MHz DSRC in Asian / Mideastern countries	Under discussion	?

NHTSA: National Highway Traffic Safety Administration
C2C-CC: Car 2 Car - Communication Consortium

Automotive OEMs' Positions on V2X Solutions

- Major OEMs (Toyota, Honda, GM, VW) keep support DSRC
- Some European OEMs (BMW, Daimler, Audi) and Ford support Cellular-V2X

	Pro-DSRC	Neutral	Pro-C-V2X
Toyota TOYOTA	✓		
Honda HONDA The Power of Dreams	✓		
GM	✓		
Volkswagen	✓		
Ford		✓	✓ ?
BMW			✓
Daimler DAIMLER			✓
Audi			✓

5G Automotive Association (5GAA)

TOYOTA InfoTechnology Center, U.S.A., Inc.
関係社外秘(Protected)

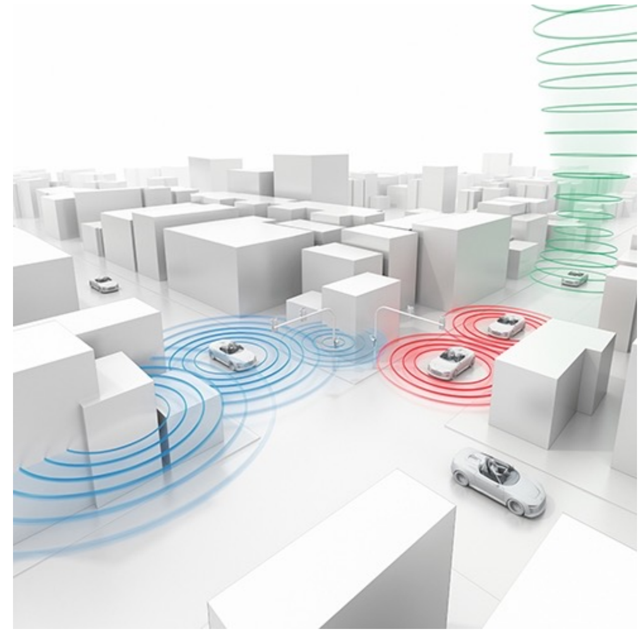
5GAA Automotive Association

PRESS RELEASE

www.5GAA.org

Telecommunications and automotive players form global cross-industry 5G Automotive Association

- AUDI AG, BMW Group, Daimler AG, Ericsson, Huawei, Intel, Nokia and Qualcomm Incorporated team up to evolve, test and promote communications solutions for connected mobility.
- Next generation mobile networks will help to address society's mobility and road safety needs with applications like connected infotainment features and connected automated driving.
- The association is open to further partners.



- Audi, BMW, Daimler, Ericsson, Huawei, Intel, Nokia, Qualcomm established 5G Automotive Association (5GAA) on Sept. 28, 2016
- The main focus is activities for the deployment of Cellular-V2X (i.e., LTE/5G-V2X) (e.g., architecture, spectrum, interoperability, testing/trial, regulation, business model)

Source: 5GAA

Member Companies of 5GAA

- Major automotive and cellular companies joined 5GAA

AT&T | Audi | BMW GROUP | Rolls-Royce | 北汽集团 BAIC GROUP | BOSCH Technik fürs Leben | 中国移动 China Mobile | Continental The Future in Motion

DAIMLER | DANLAW AUTOMOTIVE MADE SMART | DENSO | ERICSSON | FEV | FICOSA | Ford | gemalto security to be free

Hirschmann Car Communication A VOXX INTERNATIONAL COMPANY | HUAWEI | infineon | intel | INTERDIGITAL | JAGUAR | LAND ROVER | Designing The Future KDDI

KEYSIGHT TECHNOLOGIES | kt | Laird | LG | NOKIA | NTT docomo | P3 | Panasonic | QUALCOMM

ROHDE&SCHWARZ | SAIC 上汽集团 SAIC MOTOR | SAKO TECHNOLOGIES LIMITED | SAMSUNG | SAVARI™ | SK telecom

SoftBank | Telefónica | T · · | Valeo | verizon | VIAVI | vodafone | ZF

ZTE

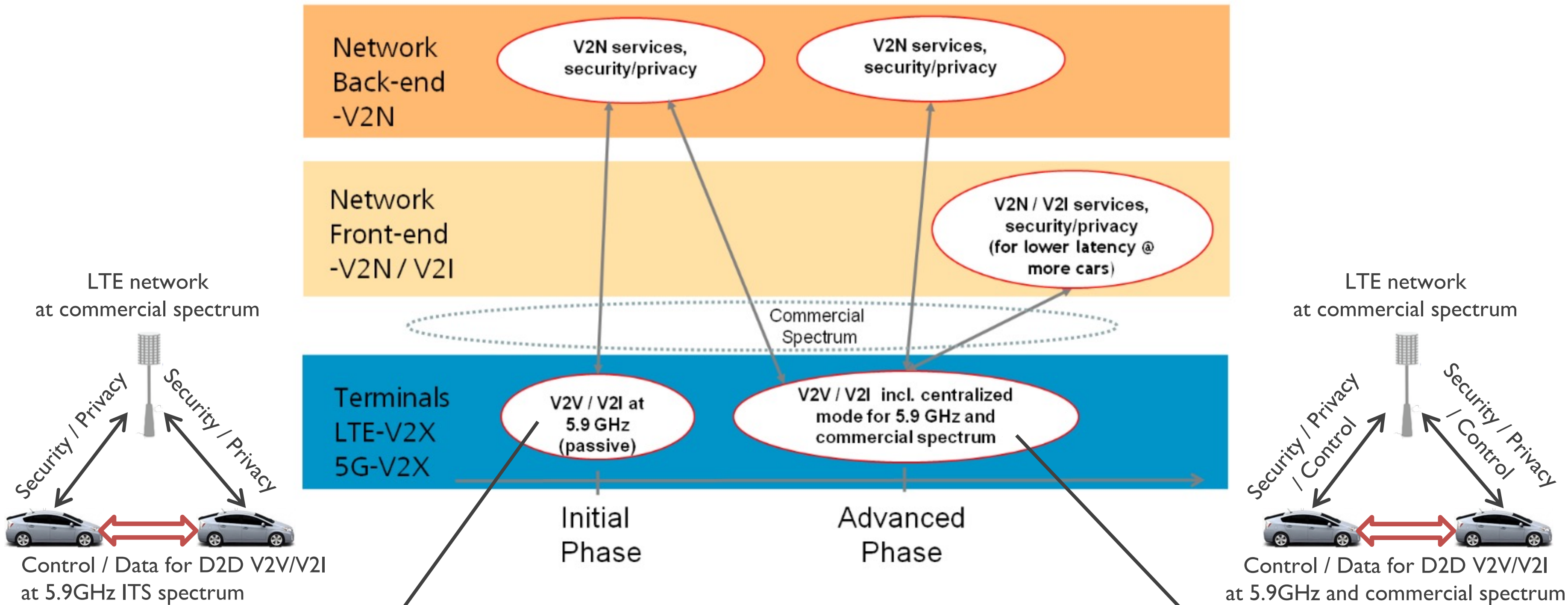
List of member companies as of May. 2017

Source: 5GAA

5GAA's Views on Possible Deployment Scenarios of Cellular-V2X

- 5GAA published a white paper to explain 5GAA's perspective on Cellular-V2X
- The white paper includes several important information on the possible deployment scenarios of Cellular-V2X:

Source: 5GAA Whitepaper



D2D LTE-V2V/V2I (UE autonomous mode) is used at 5.9GHz ITS spectrum <u>without V2X service fee</u>
➔ No upgrade of LTE network is required
➔ <u>Same as 802.11p-DSRC deployment model</u>

D2D LTE-V2V/V2I (both UE autonomous mode and eNB control mode) is used at 5.9GHz ITS spectrum <u>without V2X service fee</u> and commercial LTE spectrum (with V2X service fee?)
➔ Upgrade of LTE network is required

Challenges for Deployment of LTE-V2X

- We identified several potential challenges for deployment of LTE-V2X

Challenge	Description
Spectrum	Currently there is no available dedicated spectrum for LTE-V2X (except Europe), which is required when we use it for safety applications.
Business Model	Business model is unclear (Who will pay communication fee? Who will pay the cost of infrastructure?).
Operation	It is unclear who will deploy and operate LTE-V2X infrastructure (particularly for safety applications).
Testing	It requires large-scale comprehensive testing which will take several years (particularly for safety applications) until real deployment.
Engagement with Auto OEMs	Consensus of Auto OEMs is required to deploy LTE-V2X services (This may not be so easy!).
Unique Use Cases	When we use LTE-V2X in addition to DSRC, LTE-V2X must provide unique use cases that cannot be supported by DSRC.

5GAA's Views for LTE-V2X Challenges

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- 5GAA's white paper includes some directions to solve the challenges for LTE-V2X deployment.
- There are still some challenges to be solved until the commercial deployment of LTE-V2X such as spectrum allocation, regional regulation/standards, large-scale testing.

Challenge	Direction in 5GAA White Paper
Spectrum	5GAA plans to use 5.9GHz ITS spectrum (for initial phase) and both 5.9GHz and commercial LTE spectrum (for advanced phase). ➔ ITC view: Currently, regional regulation/standards to deploy LTE-V2X at 5.9GHz ITS spectrum is under discussion in China. In Europe, ETSI EN 302 571 (5.9GHz ITS device spec) needs to be technology agnostic.
Business Model	V2V/V2I for safety at 5.9GHz ITS spectrum can be used without V2X service fee (for initial phase). Advanced V2X service (e.g. low latency) can be provided using commercial V2V/V2I network. ➔ ITC view: It is still unclear whether V2V/V2I service over commercial LTE network is successful or not.
Operation	In initial phase, V2V/V2I (UE autonomous mode) can be supported without base stations. In advanced phase, V2V/V2I (eNB control mode) can be also supported ➔ ITC view: It is still unclear who will deploy and operate LTE-V2X infrastructure for V2V/V2I (eNB control mode) in advanced phase.
Testing	5GAA and ConVeX consortium plan to conduct testing of LTE-V2X. ➔ ITC view: Large scale testing is required to ensure the performance of LTE-V2X, but it will take several years.
Engagement with Auto OEMs	Some automakers (mostly German OEMs) joined 5GAA. ➔ ITC view: some engagement from auto OEMs are expected, though we don't know the motivation and expectation of auto OEMs in 5GAA.
Unique Use Cases	Cellular-V2X provides better communication performance than 802.11p-DSRC. ➔ ITC view: It is not verified that cellular-V2X really provides better performance than 802.11p-DSRC. Also, it is still unclear which unique use cases can be realized by LTE-V2X, compared with 802.11p-DSRC.

Source: 5GAA Whitepaper

ITC's Views on V2X Technologies

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- IEEE802.11p/DSRC is the only proven technology for safety applications
- Ad-hoc V2X communication requires a single protocol for interoperability for the maximum benefit
- Emerging technologies (e.g., LTE-V2X, 5G mmWave V2X) can complement DSRC
  - E.g. applications requiring longer communication ranges or very high data rate
- We recognize deployment of ITS Connect/DSRC/ITS-G5 in JP and US, imminent in EU.
  - Encourage on-going deployments to move forward
  - Delays due to protocol competition will be damaging to public benefits
- We notice that other regions might have different choices
  - Global harmony could be beneficial for OEMs
- Technical comparison between DSRC and LTE-V2X is interesting
  - However, many details of LTE-V2X for actual deployment are not decided, challenging a detailed comparison
  - Expect advantages for each protocol and total performance difference to be modest, which should not delay deployment of DSRC