5G C-V2X 표준 및 기술현황

2018. 11. 30

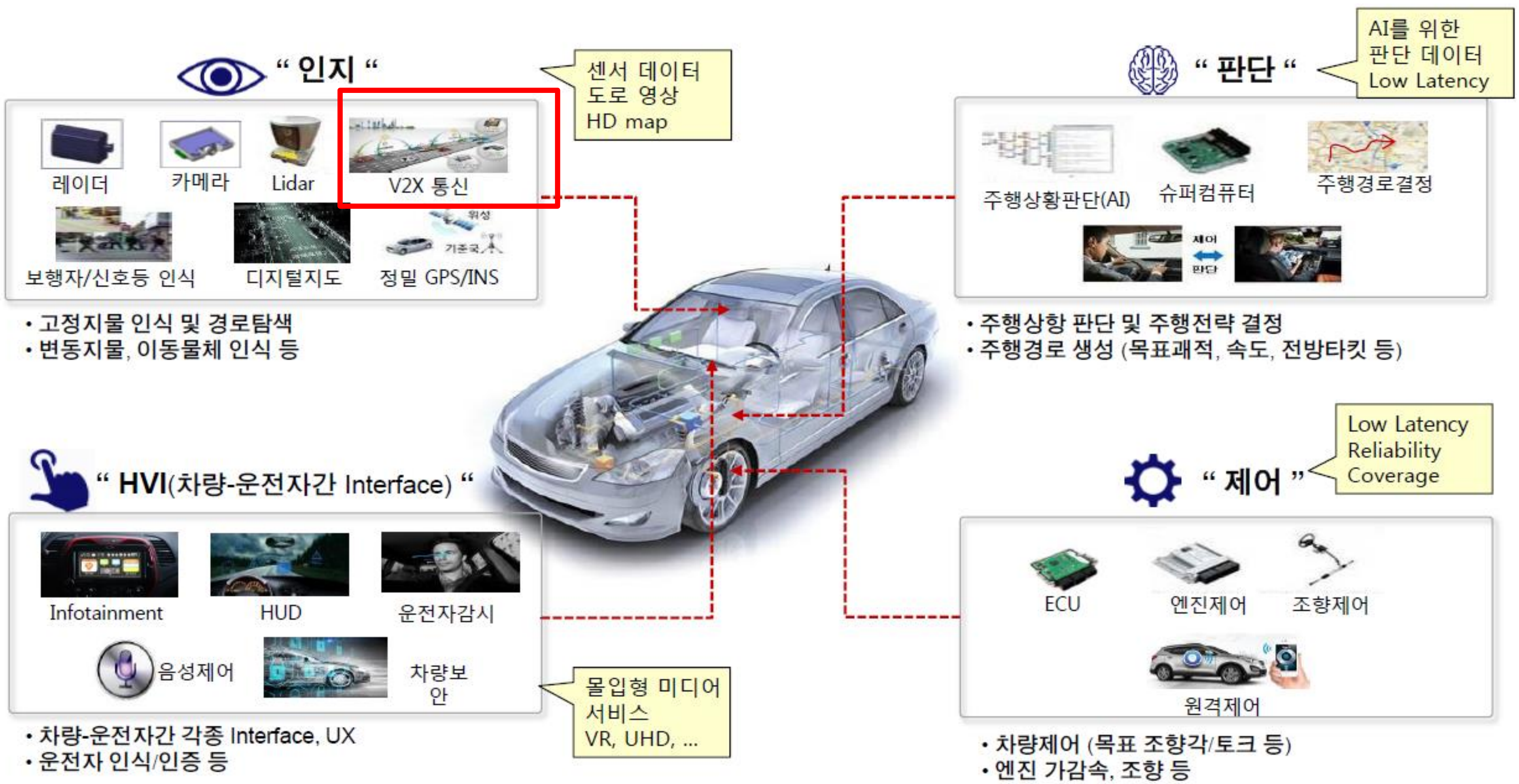
인하대학교 김 덕 경

인하대학교
INHA UNIVERSITY

Wireless
Communication
Research Laboratory

자율주행 차량

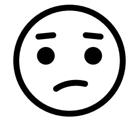
자율주행차는 주행 환경, 위치 등을 인식하는 인지, 주행상황 판단 및 경로 생성을 위한 판단, 가감속, 조향 등을 담당하는 제어, 그리고 자동차와 운전자간 소통을 위한 HVI 기술로 구성



<SKT>

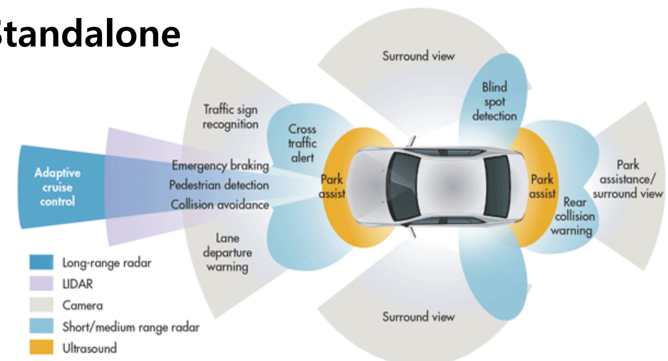
자율주행은 어떻게..

- Standalone : “Vehicle resident”, 주변 환경을 운전자가 직접 관측하는 방식
  - ➔ 제한된 기능 수행 (LoS 아닌 경우)
  - ➔ 기상상황에 따른 성능 열화
  - ➔ 고가 장비 장착으로 인한 차량 가격 상승



항목	Standalone
사각지대 관측	어려움
타 차량 관측	어려움
주변 차량의 경로 예측	불가
차내 센서 및 날씨 상태 등에 주행 안전 위험도	높음
운전자의 주변 상태 인지도	낮음
미래 기술 지원 위한 정보력	제한적
유효 통신 거리	단거리

Standalone



- Camera
- Radar
- LiDAR(Light Detection and Ranging)
- Sensors
- Computing

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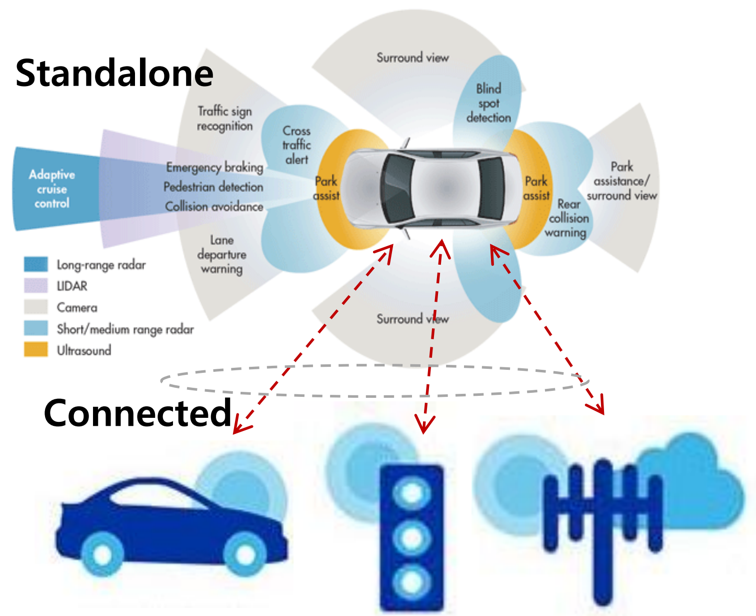
자율주행을 어떻게..

- Standalone : “Vehicle resident”, 주변 환경을 운전자가 직접 관측하는 방식
- Connected : 주변 차량 및 차도 내 설치된 기지국으로부터 정보 수신
  - ➔ 더 많은 기능을
  - ➔ 더 많은 서비스를
  - ➔ 더 적은 비용으로
  - ➔ 더 신뢰성있게

☺

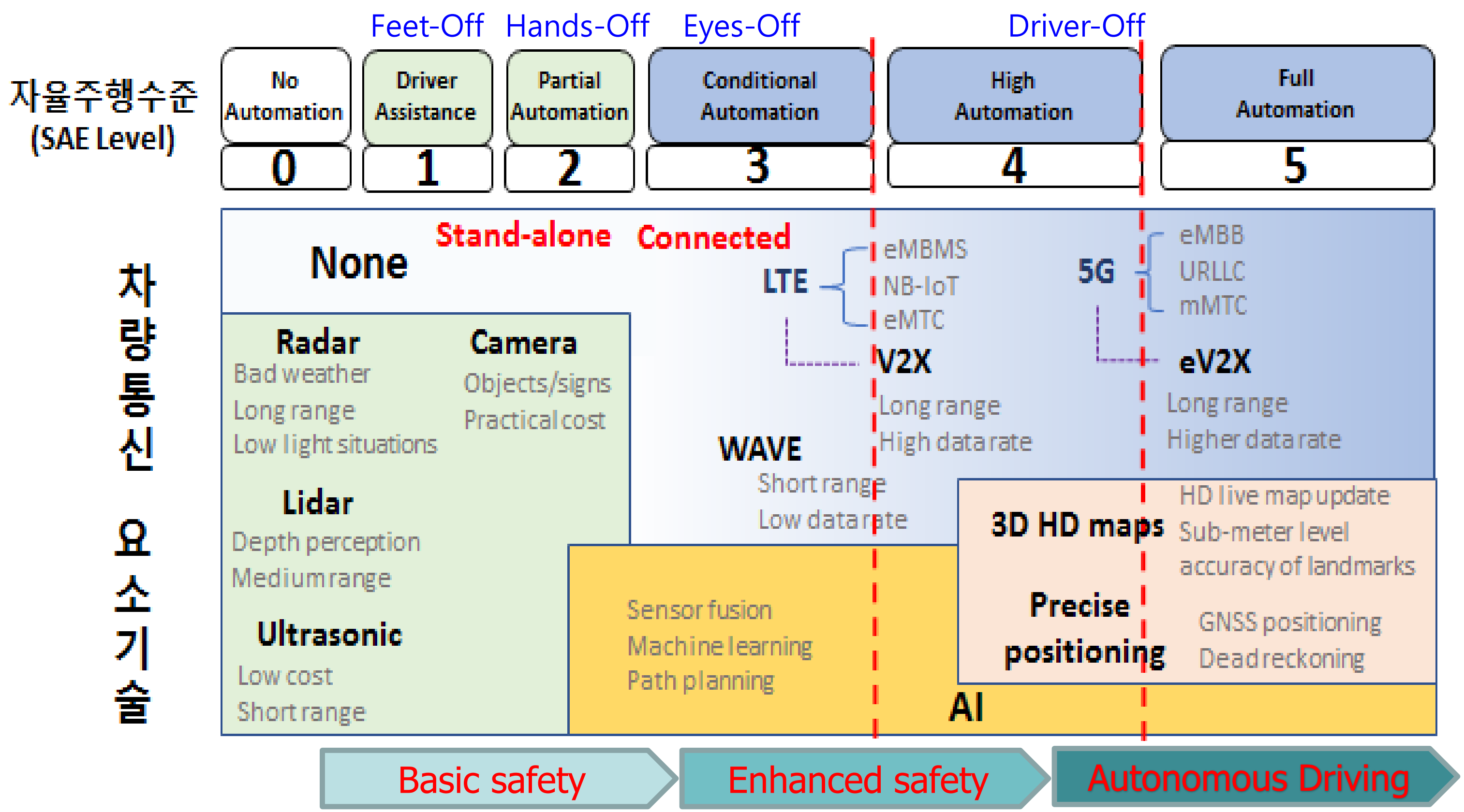
항목	Standalone	Connected
사각지대 관측	어려움	용이
타 차량 관측	어려움	용이
주변 차량의 경로 예측	불가	가능
차내 센서 및 날씨 상태 등에 주행 안전 위험도	높음	낮음
운전자의 주변 상태 인지도	낮음	높음
미래 기술 지원 위한 정보력	제한적	충분
유효 통신 거리	단거리	장거리



자율주행수준에 따른 차량통신 및 요소기술

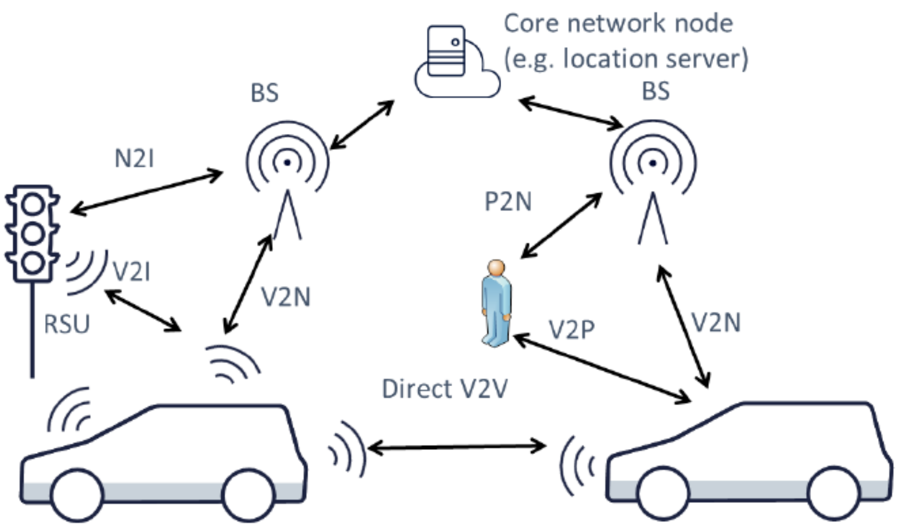
자율주행은 자동화 정도에 따라 레벨5까지 정의되며, 레벨3 이상의 높은 수준의 자율주행을 위해서는 인지능력을 향상 시키는 차량통신 기능이 필수적임

특히, 고정밀 (HD) 지도, 고정밀 위치 추정, 차량 센서 데이터 공유를 통한 협력 자율주행 기술 구현을 위해서는 초고속/초저지연 데이터 전송을 지원하는 5G/eV2X의 도입이 필수적임.



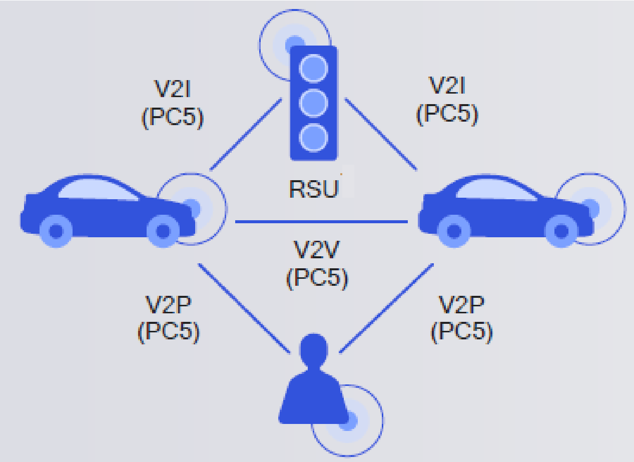
V2X는 무엇인가?

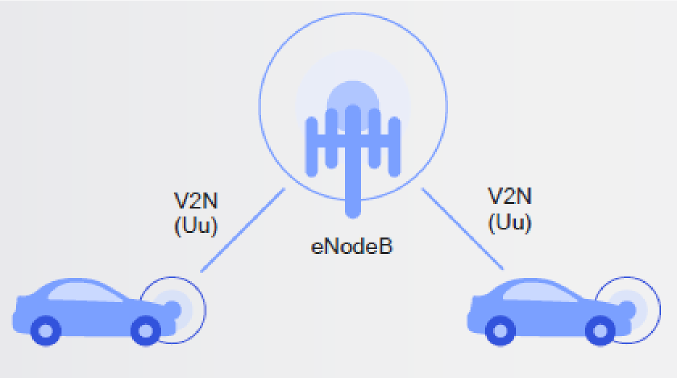
- **Vehicle-to-Everything**
  - **V2V**: vehicle exchanges safety-related messages with each other
  - **V2I**: vehicle exchanges information with road infrastructures, e.g., at road intersections
  - **V2P**: vehicle exchanges information with vulnerable road users, e.g., pedestrians, cyclists, motorcycles, etc.
  - **V2N**: vehicle exchanges information with a serving entity, e.g., an application server



<5GCAR>

Two Types of Communication Links





	Sidelink	Uplink & downlink
Pros	- Shorter latency - Local communication with spatial resource reuse - <u>Operation even outside network coverage</u>	- Larger coverage - Reuse existing infrastructure (V2I or V2N) - <u>More efficient centralized control</u>
Cons	- Limited coverage - Limitation in controlling multiple devices	- Longer latency in V2V and V2P - No support for out-coverage operations

V2X Messages

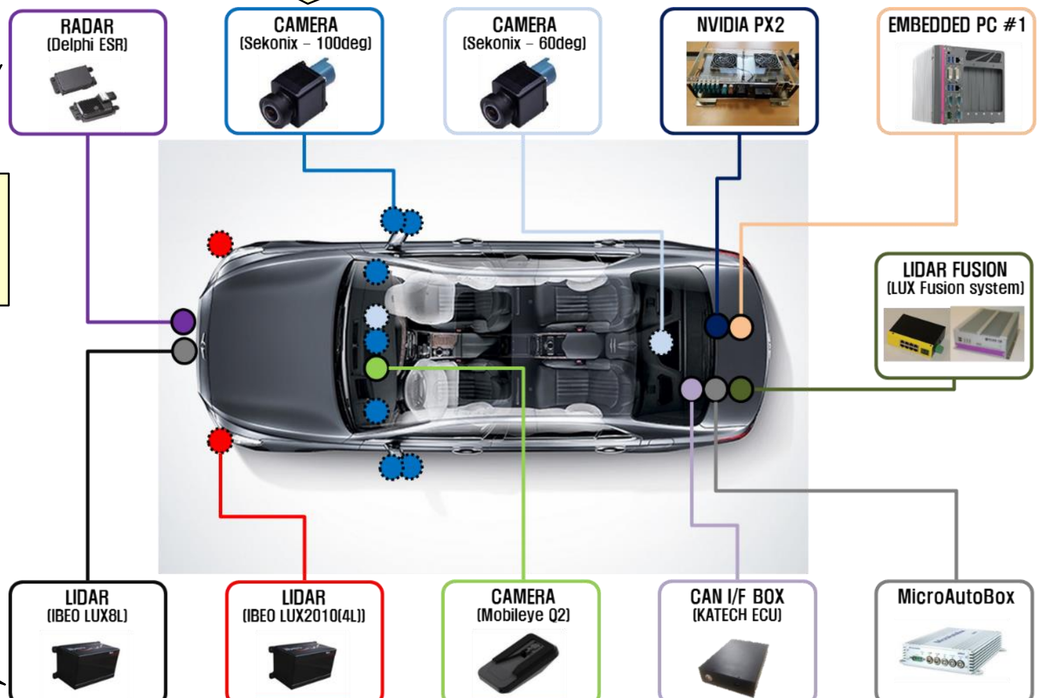
- BSM (Basic Safety Message)
  - 다중 V2V 안전 응용을 위한 메시지로 송신 차량의 상태 정보 포함
- CAM (Cooperative Awareness Message)
  - 주변 차량의 존재, 위치, 속도 등과 같은 기본적인 상태정보를 주기적으로 제공
  - 차량의 방향, 속도, 위치에 따라 CAM 생성 주기가 달라짐
- DEMN (Decentralized Environmental Notification Message)
  - 이벤트 중심의 위험 경고 메시지
  - 이벤트(사건 : 도로 공사, 교통 정체, 사고 등) 시작 시 전송

분류	기본 전송 주기	평균 메시지 크기
BSM	10Hz	320 바이트
CAM	1-10Hz	50~300 바이트
DENM	-	50~400 바이트

차량에서 발생하는 정보는..

HD/Full HD resolution: > 1M pixel
30~60 frame/s
6~9 cameras
> 48~144Mbps (compressed)
> 4.3~17.2Gbps (uncompressed)

Single Radar: **50kbps~6Mbps**
Array Radar: **> 100Mbps**



1 million point per sec
140 bytes per point
50Mbps average
> 1.1Gbps (Max)

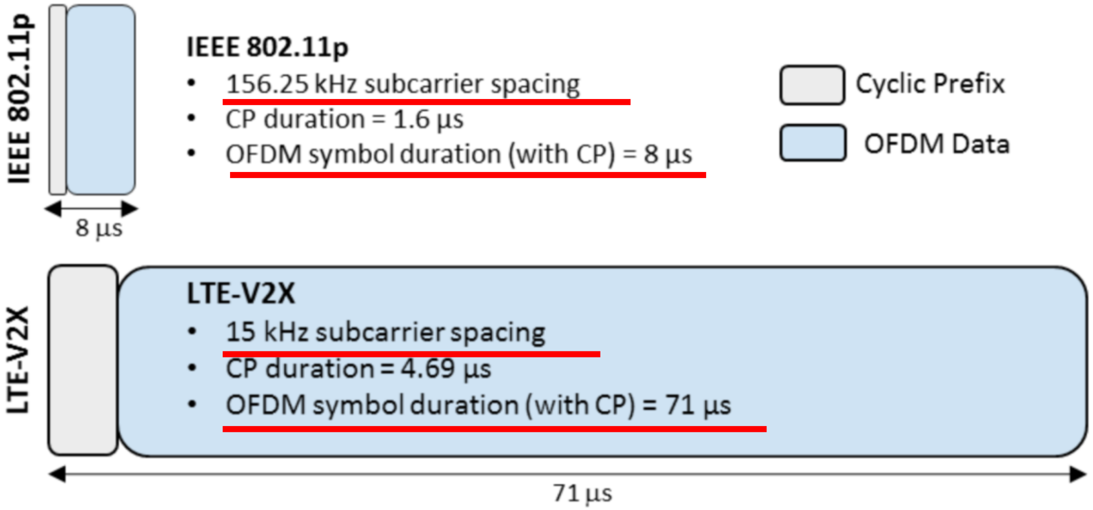
In-Vehicle Network
CAN/CAN FD: **1~12Mbps**
Automotive Ethernet: **100M~1Gbps**

Cellular V2X vs. WAVE – Brief Overview

Item	C-V2X (Rel. 14)	DSRC (WAVE)
Overview	• **LTE를 차량통신에 적합하도록 개선**	• **무선랜 기술을 차량통신에 적합하도록 개선**
Specification	• Rel.14 완료(17.3월), • Rel.15 진행 중(18.6월 완료예정)	• **완료** (2010~2012년)
Eco system	• 기존 통신장비/ 단말 제조사, 이통사	• 교통인프라, 무선랜 제조사
Data rate	• V2I: ~75Mbps • V2V: ~25Mbps (통상 1.4~6Mbps)	• ~ 27Mbps (통상 1~5.4Mbps)
Latency	• V2I(Uu): 20~30ms • V2V(PC5): 10ms 내외	• 10ms 내외
Coverage	• 1~5km (LTE 기지국 전국망)	• 최대 1km (별도 기지국 구축)

WAVE: wireless access in vehicular environments
DSRC: dedicated short-range communication system

WAVE vs. LTE-V

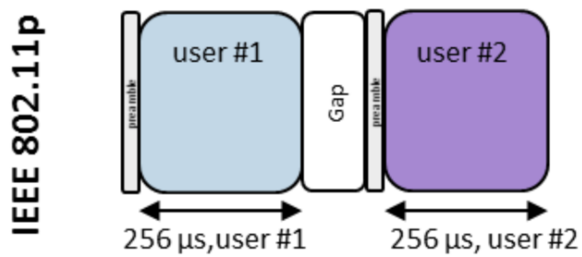


IEEE 802.11p
- 156.25 kHz subcarrier spacing
- CP duration = 1.6 µs
- OFDM symbol duration (with CP) = 8 µs

LTE-V2X
- 15 kHz subcarrier spacing
- CP duration = 4.69 µs
- OFDM symbol duration (with CP) = 71 µs

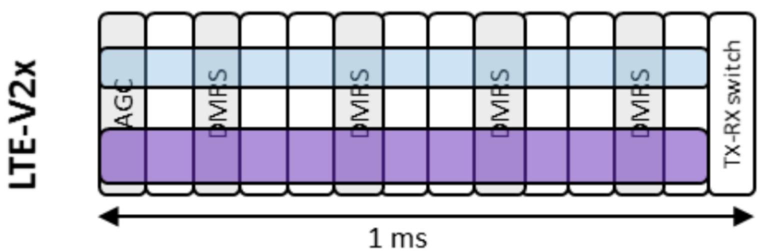
Cyclic Prefix
OFDM Data

- Shorter symbol duration
  = Larger subcarrier spacing
  – synchronization, doppler (higher velocity)에 유리



IEEE 802.11p
- 48 data subcarriers
- Flexible number of OFDM symbols
- Typical message duration = 256 µs
- No users-multiplexing

Overhead (preambles / pilots ...)
Data, user #1
Data, user #2
Gap / Unused resource



LTE-V2X
- 600 data subcarriers total (all users)
- 9 OFDM data symbols (out of 14 per subframe)
- Message duration fixed to 1 ms
- Users-multiplexing possible in frequency domain
- Number of subcarriers per user flexible

<Two users transmitting a CAM message of 192 bytes with QPSK and coding rate 1/2>

WAVE 기술 - PHY

- Based on IEEE 802.11a
- Modifications to fit into Vehicular environments
- Further enhancement in IEEE802.11px
  - e.g., LDPC, MIMO as in WiFi

	IEEE 802.11a	IEEE 802.11p
Data rate	6, 9, 12, 18, 24, 36, 48, 54 Mbps	3, 4.5, 6, 9, 12, 18, 24, 27 Mbps
Modulation	BPSK OFDM QPSK OFDM 16-QAM OFDM 64-QAM OFDM	BPSK OFDM QPSK OFDM 16-QAM OFDM 64-QAM OFDM
Error Correction Coding	Convolutional Coding with K=7	Convolutional Coding with K=7
Coding Rate	1/2, 2/3, 3/4	1/2, 2/3, 3/4
# of subcarriers	52 net	52 net
OFDM Symbol Duration	4.0 µs	8.0 µs
Guard Period	0.8 µs	1.6 µs
Occupied bandwidth	20 MHz	10 MHz
Frequency	5 GHz ISM band	5.850-5.925 GHz

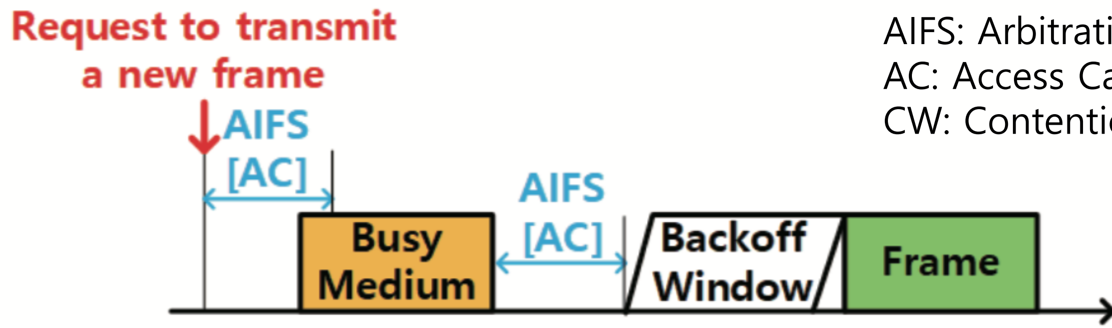
Longer symbol duration

Longer guard period
- Less ISI

Dedicated frequency band

WAVE 기술 - MAC+

- EDCA (Enhanced Distributed Channel Access)



AIFS: Arbitration Inter-Frame Spacing
AC: Access Category
CW: Contention Window

  - CSMA/CA기반
  - 패킷 우선순위에 따라 AC (Access Category) 부여
  - No Ack 시 CW 증가

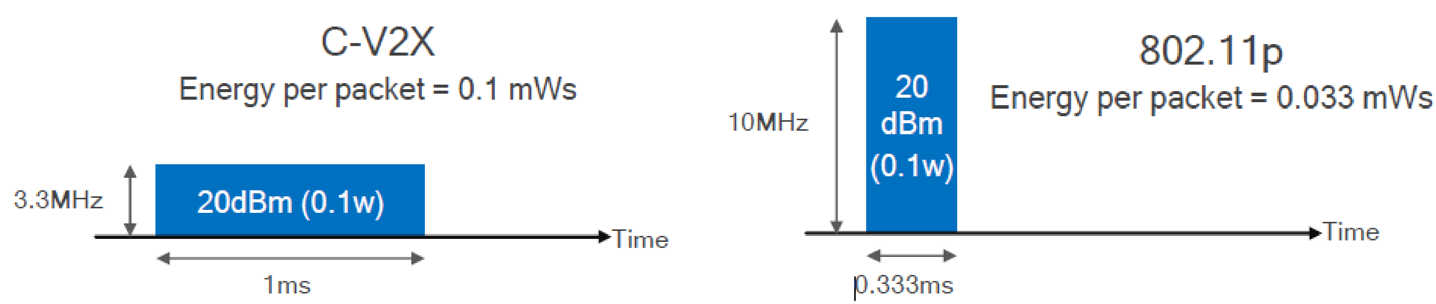
Access Category(AC)	CWmin	CWmax	AIFS (μs)
AC_BK(Background)	31	1023	149
AC_BE(Best effort)	31	1023	110
AC_VI(Video)	15	31	71
AC_VO(Voice)	7	15	58

  - 안전메세지는 Broadcast 방식으로 전송

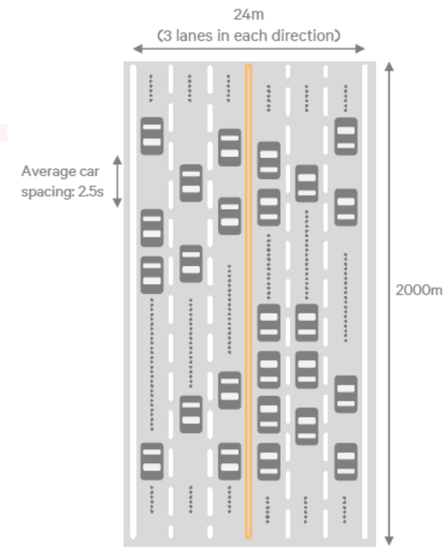
<KICS, 2018.3>

WAVE 한계점들

- CSMA/CA based MAC protocol of 802.11p
  → 단말 밀도가 증가함에 따라 지연이 급격히 증가, 채널 효율 감소
  → 일정 지연을 보장하지 못함 (Unbounded delay)
  → Hidden node 문제 : RTS/CTS 적용 시 추가적인 지연 발생
  → Congestion problems
- Link budget issue for supporting larger coverage
  → 10 MHz full band 전송: 4.8dB gain per packet
  → Channel coding: TC provides ~2dB coding gain over CC

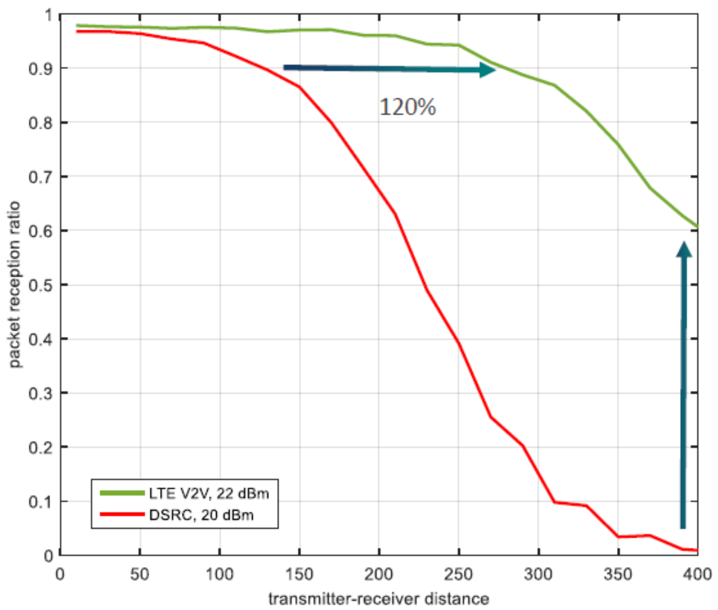


IEEE 802.11p와 LTE-V2X의 PRR 성능

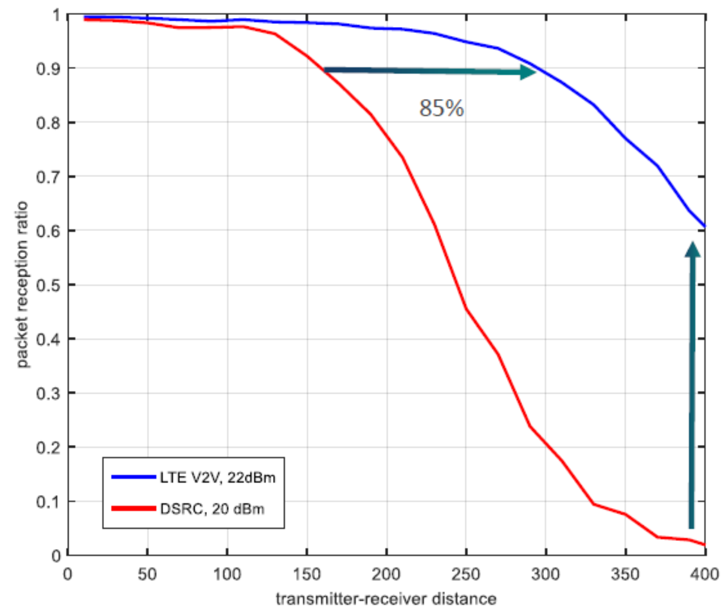


- ~100% gain in distance @ 0.9 PRR
- @ 400m, PRR is 0.02 to 0.6

Freeway 250 km/hr, 69 cars

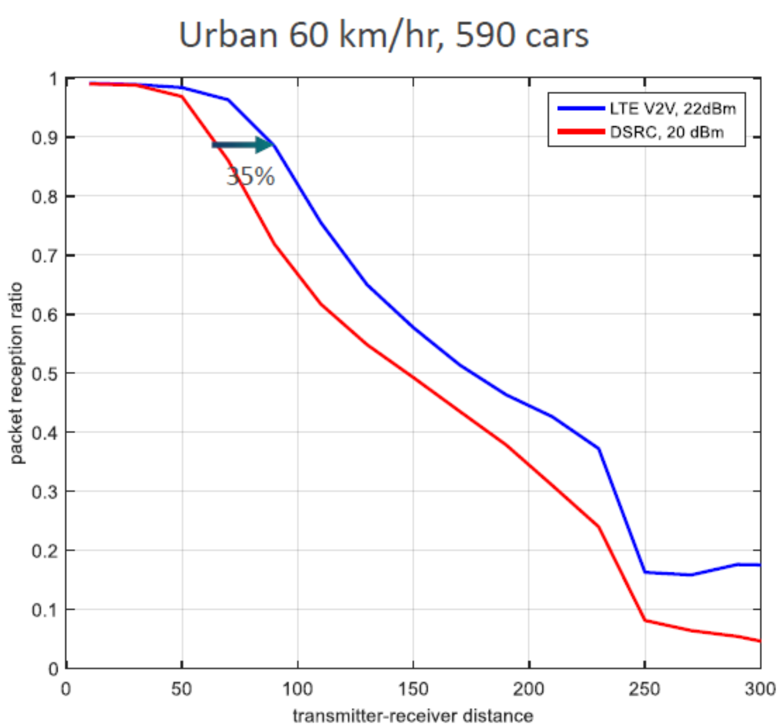


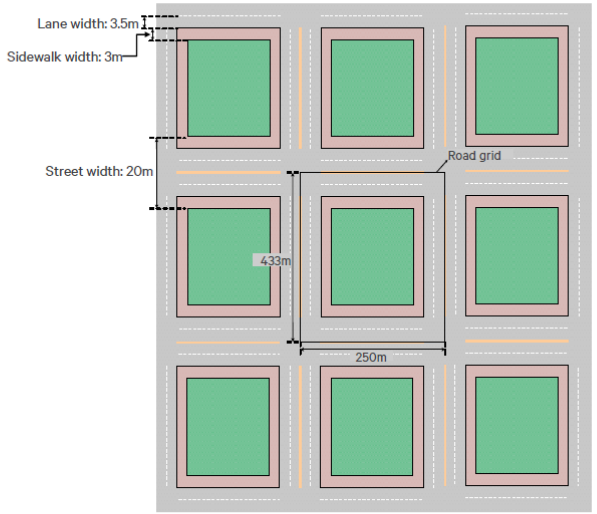
Freeway 140 km/hr, 123 cars



IEEE 802.11p와 LTE-V2X의 PRR 성능

- ~30% gain @ 0.9 PRR
- Gain is reduced due to challenging PL model
  - LoS on same road, NLoS on cross roads





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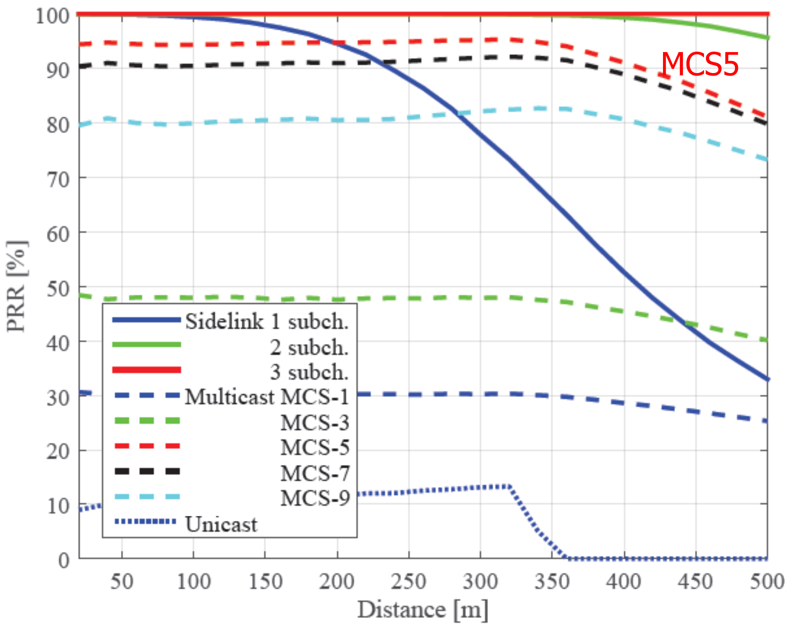
Simulation in German A9 Highway

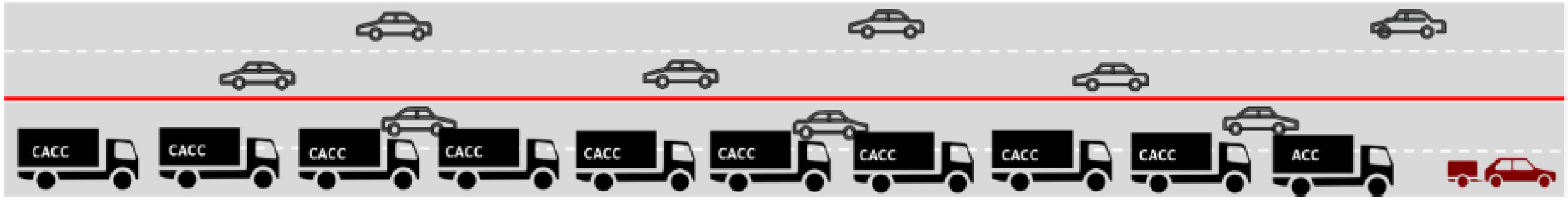
PRR vs. Distance for CAM



	CAM	DENM	Platooning	
Sidelink	O	O	O	# sub-ch. No feedback
Multicast	O	O	△	MCS No feedback
Unicast	X	X	X	Congestion

Bandwidth	10 MHz
BS TX power	46 dBm
BS number of antennas	2
BS antenna gain	17 dBi
BS antenna downtilt	6 deg
BS antenna height	12 m
BS cable loss	2 dB
BS noise figure	3 dB
VUE number of antennas	1 TX - 2 RX
VUE antenna gain	2 dBi
VUE cable loss	0.2 dB/m (2 m cable)
VUE implementation loss	5 dB
VUE noise figure	7 dB
VUE TX power	23 dBm
Thermal noise	-174 dBm/Hz

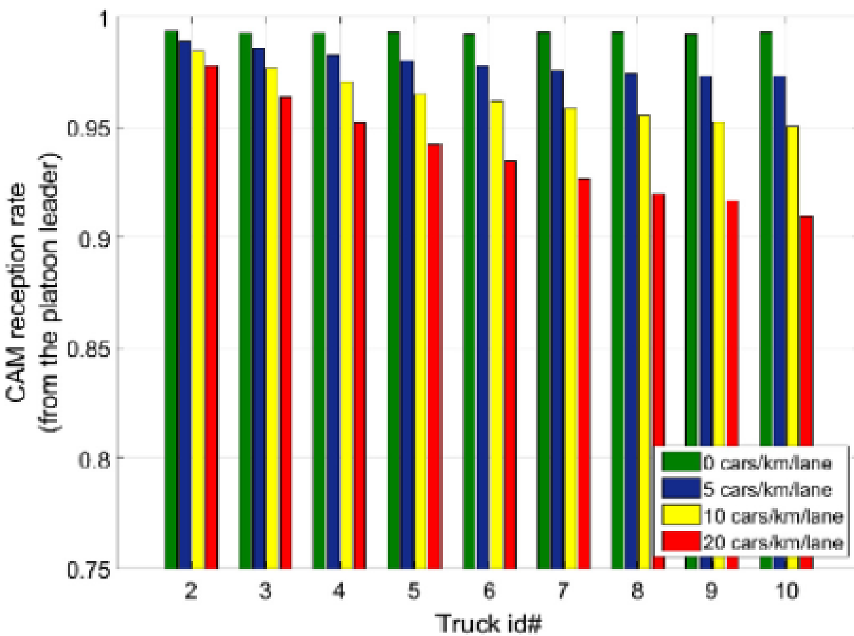
Performance in Highway Platooning



Highway traffic and truck model parameters.

Parameter	Assumption
Lanes per direction	2
Lane width	4 m
Trucks in the platoon	10
Truck length	16.5 m
Max. speed of trucks	100 km/h
Max. acceleration of trucks	Linear decay from 2 m/s^2 @ 0 km/h to 0 m/s^2 @ 100 km/h
Max. deceleration of trucks	0.3 g(= 2.94 m/s^2)
Actuation lag of trucks	20 ms
Density of non-platooned cars	0, 5, 10, 20 cars/km/lane
Speed of non-platooned cars	130 km/h (constant)
Radar measurement interval	60 ms
CAM message interval	100 ms
CAM message size	300 bytes

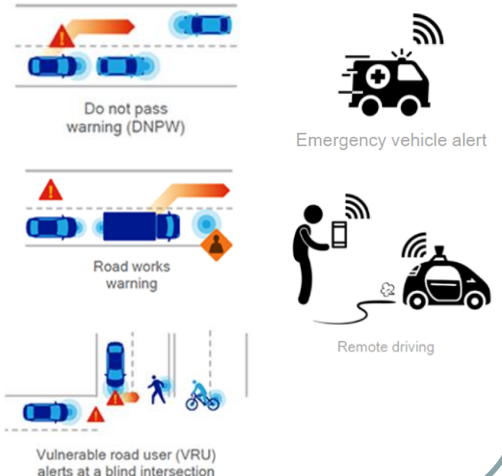
CAM reception rate in case of C-V2X Mode-4

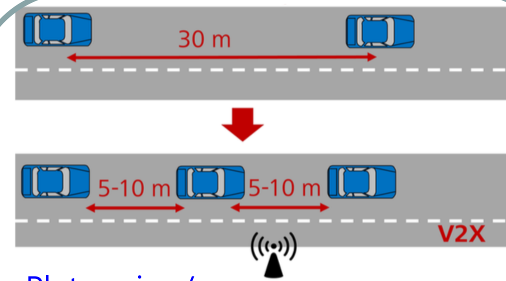


More Use Cases Through “Connected"

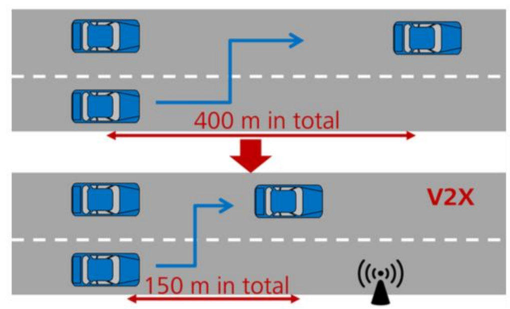
Better performance

New use cases

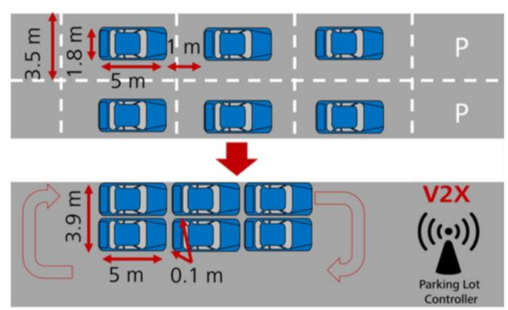




Platooning/
Cooperative Adaptive Cruise Control



Lane (or Road) Merging



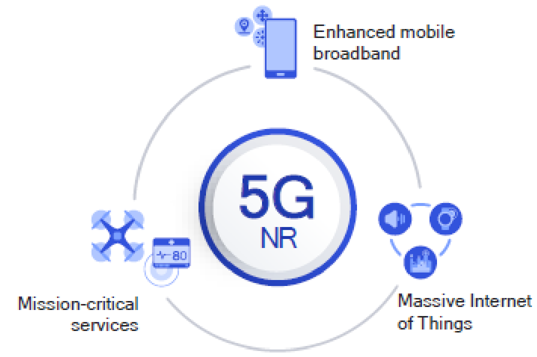
Connected Automated Parking

Advanced Cases w/ 5G

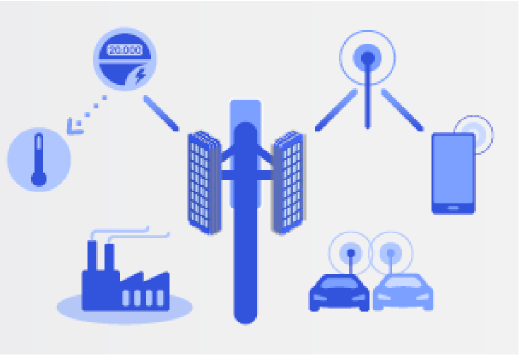
Qualcomm, LGE,
Use Cases, Requirements, and Design Considerations for 5G V2X, arXiv:1712.01754v

What is 5G?

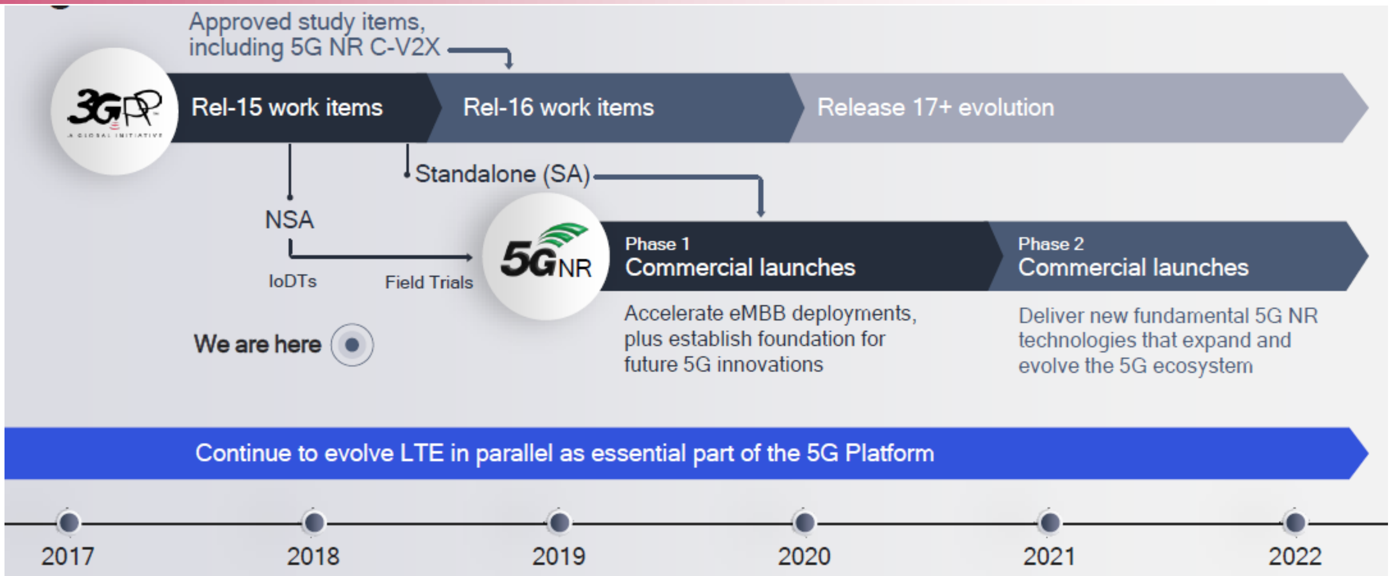
- Features
  - Fiber-like data speeds
  - Low latency for real-time interactivity
  - More consistent performance
  - Massive capacity for unlimited data

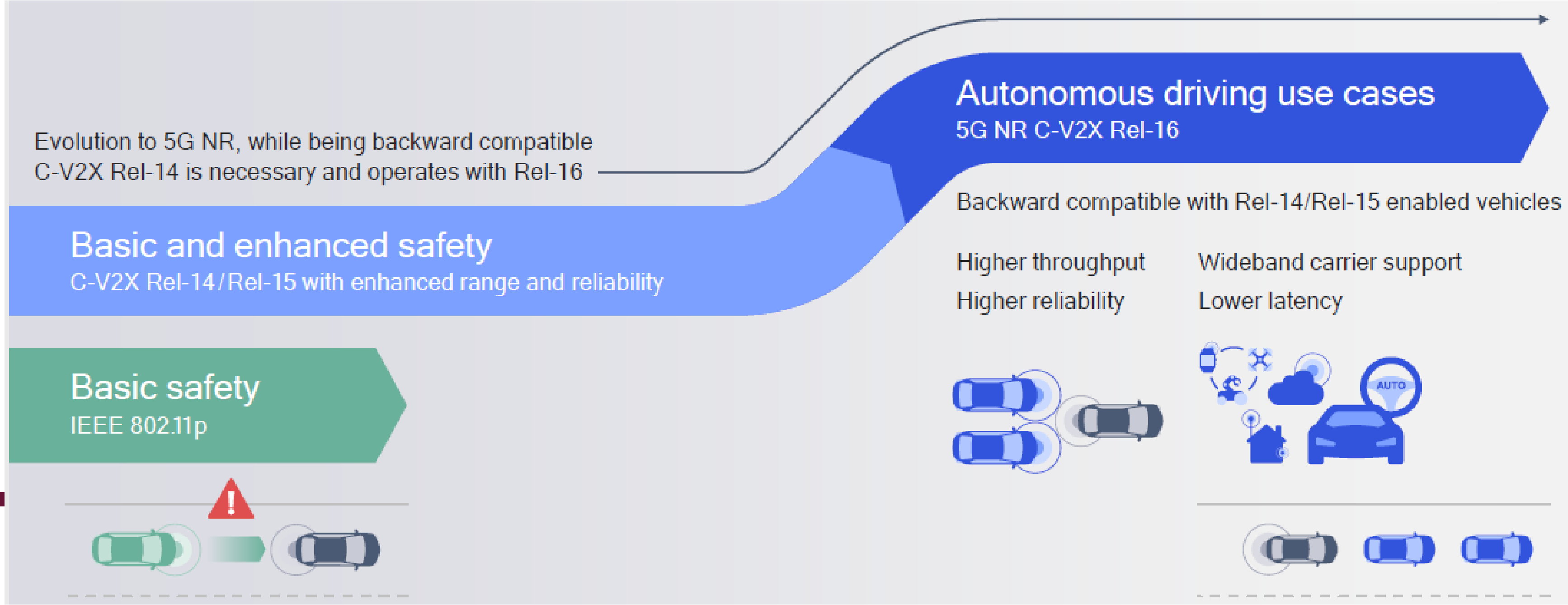


- Diverse services
  - Scalability to address an extreme variation of requirements
  - MC services, eMBB, mIoT
- Diverse spectrum
  - Low bands ~ 1GHz
  - Mid bands 1GHz ~ 6GHz
  - High bands (mmWave) 24GHz+
- Diverse deployments
  - From macro to indoor hotspots



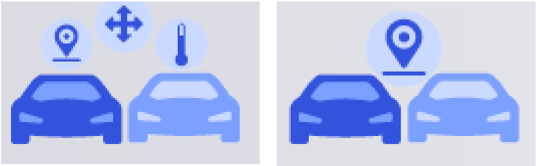
Evolution to 5G NR



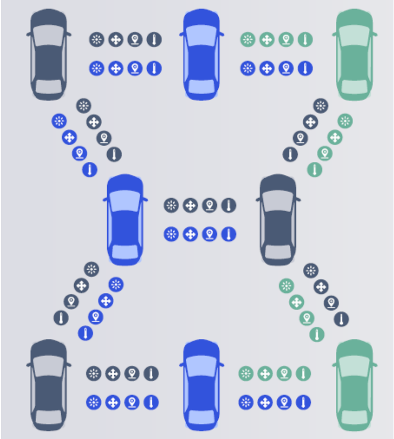


Why 5G in Autonomous Driving ?

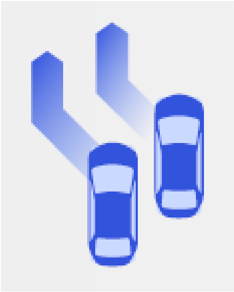
- Perception
  - Sharing of high throughput sensor data and real world model



- Path planning
  - Intention and trajectory sharing for faster, yet safe maneuvers

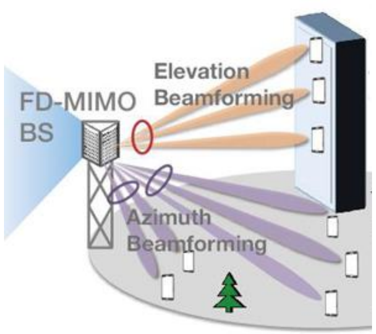


- Real-time local updates
  - Real-time sharing of local data with infrastructure and other vehicles (e.g., 3D HD maps)
- Coordinated driving
  - Exchanging intention and sensor data for more predictable, coordinated autonomous driving

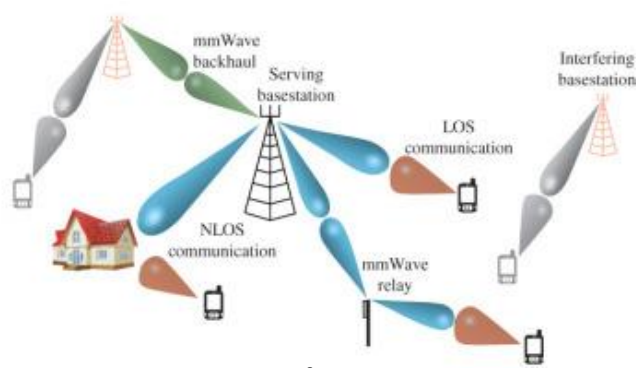


5G Enablers (1)

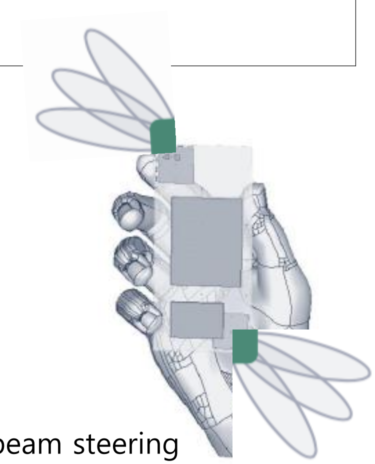
	NR(New Radio)	Evolution of LTE-Advanced Pro
eMBB	- 광대역 스펙트럼 사용(>6GHz, ~1GHz 대역폭 지원) - Multi-connectivity - Massive MIMO: Reciprocity-based MU-MIMO - mmWave beamforming and beam-tracking - Advanced channel coding: ME-LDPC, CA-Polar	- FD-MIMO 성능개선 - CoMP 성능개선 - LAA(Licensed Assisted Access) 성능 개선



FD-MIMO



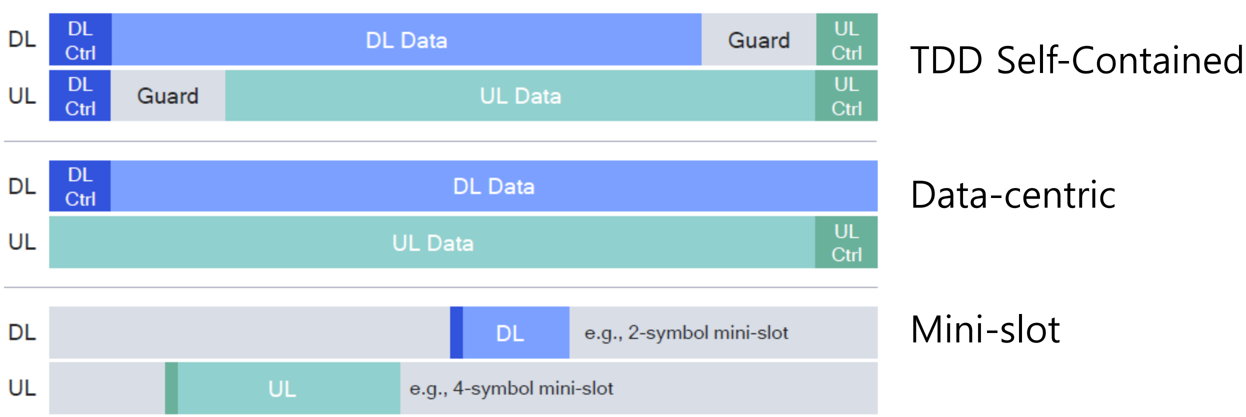
mmWAVE MIMO



Adaptive beam steering to overcome blockage from hand, head, body

5G Enablers (2)

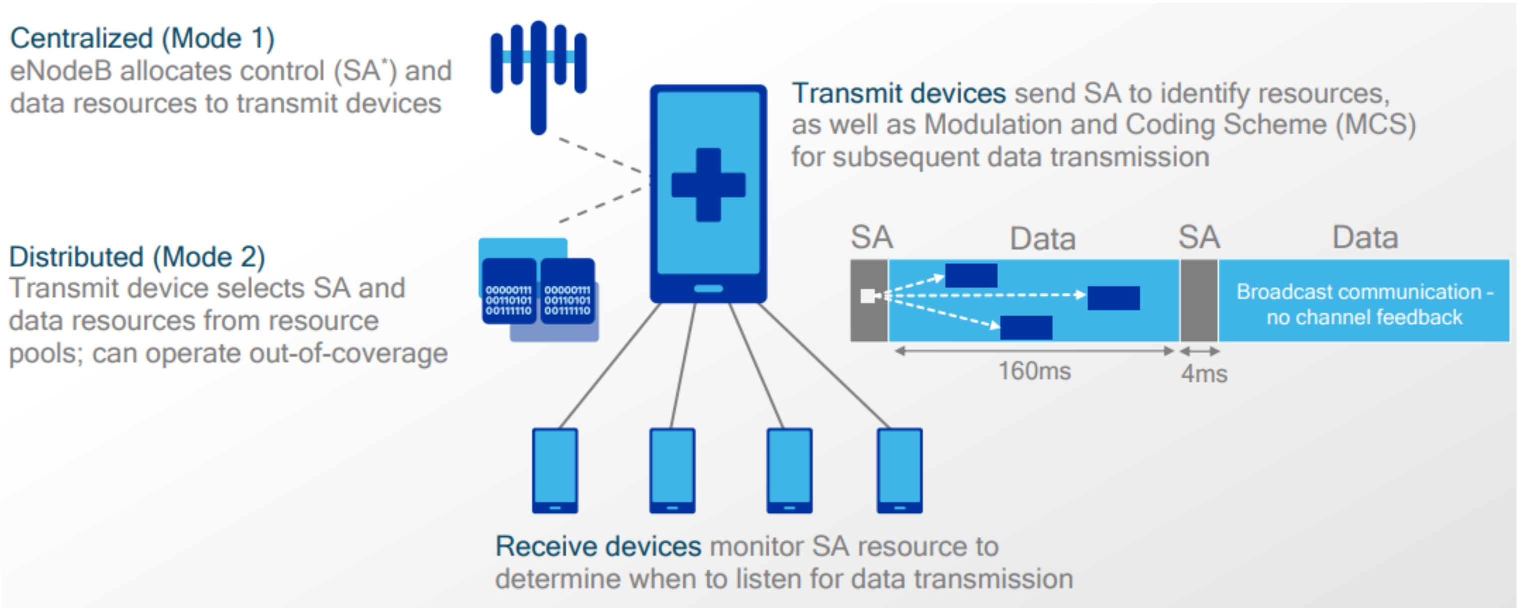
	NR(New Radio)	Evolution of LTE-Advanced Pro
mMTC	- Autonomous/grant-free/contention 기반 상향 비직교 다중화 방식	- 비면허 대역 NB-IOT - 스펙트럼 및 전력 효율 향상
URLLC	- 가변 TTI(슬롯 및 미니슬롯) - Self-contained 서브프레임 구조 - Grant-free, SR (Scheduling Request) -less 상향링크 전송 - 채널 코딩 및 HARQ - 송신 다이버시티 기술	- TTI 및 송수신 처리시간 단축 기술 - TDD 서브프레임 타입 개선



(Modes 1&2 in D2D) → Modes 3&4 in V2X

Modes 1 & 2 in D2D

- Mainly to prolong the battery lifetime at the cost of increasing the latency
- Not suitable for vehicular applications: High reliable, Low-latent, High-speed

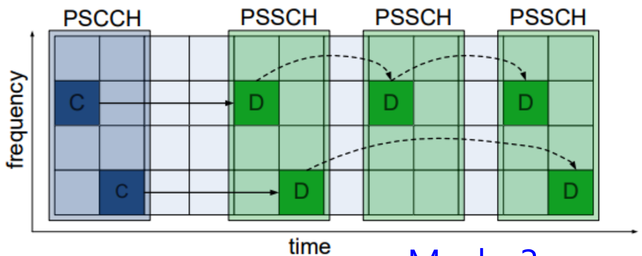


SA: Scheduling Assignment

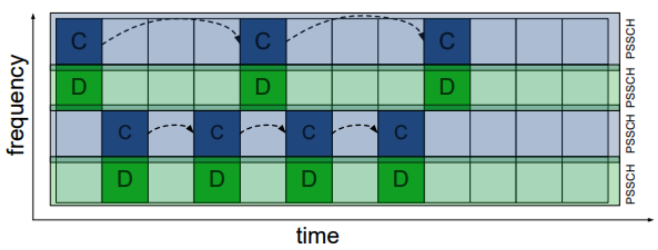
Wireless Communication Research Laboratory

(Modes 1&2 in D2D) ➔ Modes 3&4 in V2X

- **LTE V2X mode 3 (eNB)**
  - multiple SPS configurations
  - different period/MCS for flexibility
- **LTE V2X mode 4 (Ad-Hoc)**
  - resource location and MCS selected autonomously
  - resources are reserved in advance (“SPS”)
  - control-data in the same subframe (Reduced latency)

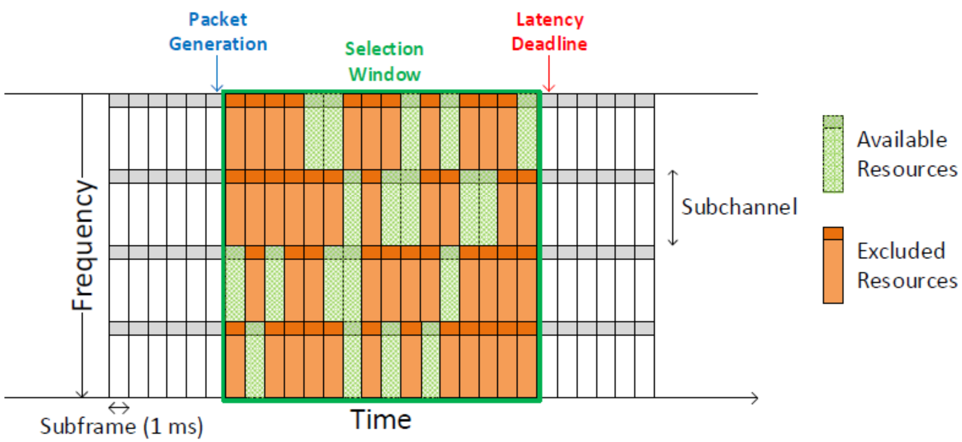


Mode 3

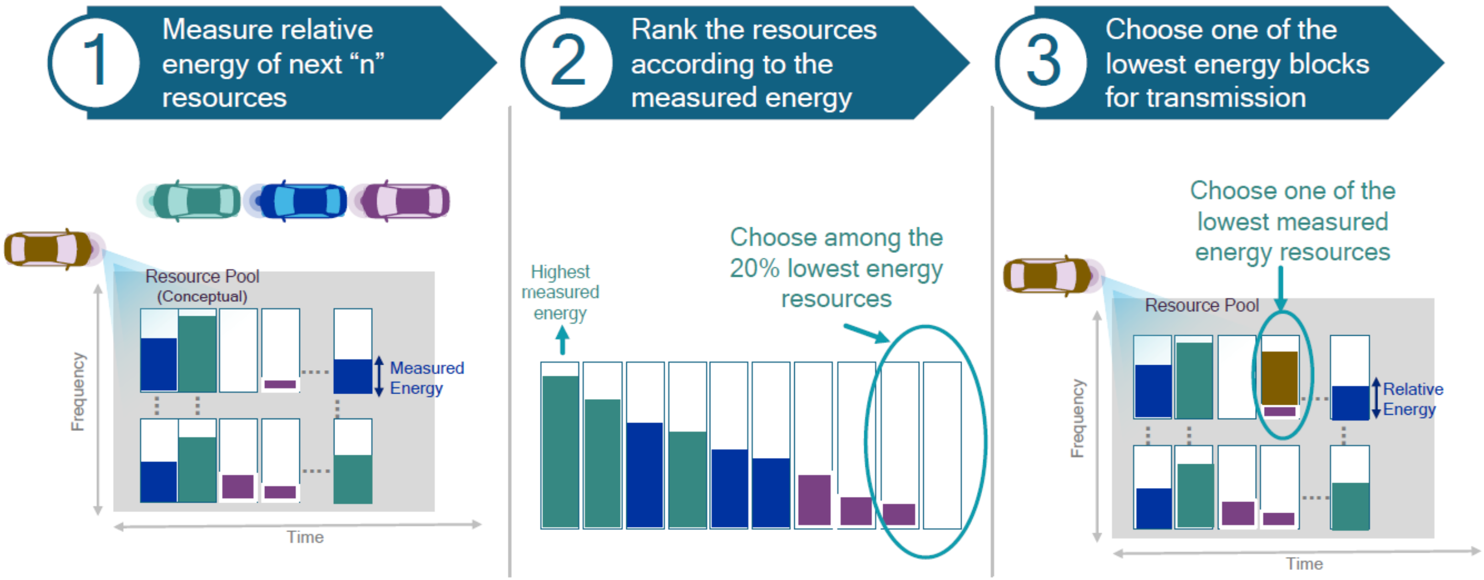


Mode 4

Sensing-based SPS in Mode 4



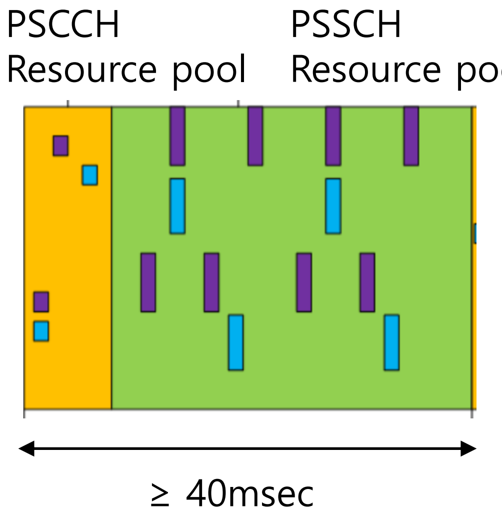
- After sending randomly selected number of packets in SPS configuration, resource needs to be re-selected and reserved.
- Measure average RSRP and select resource with low RSRP



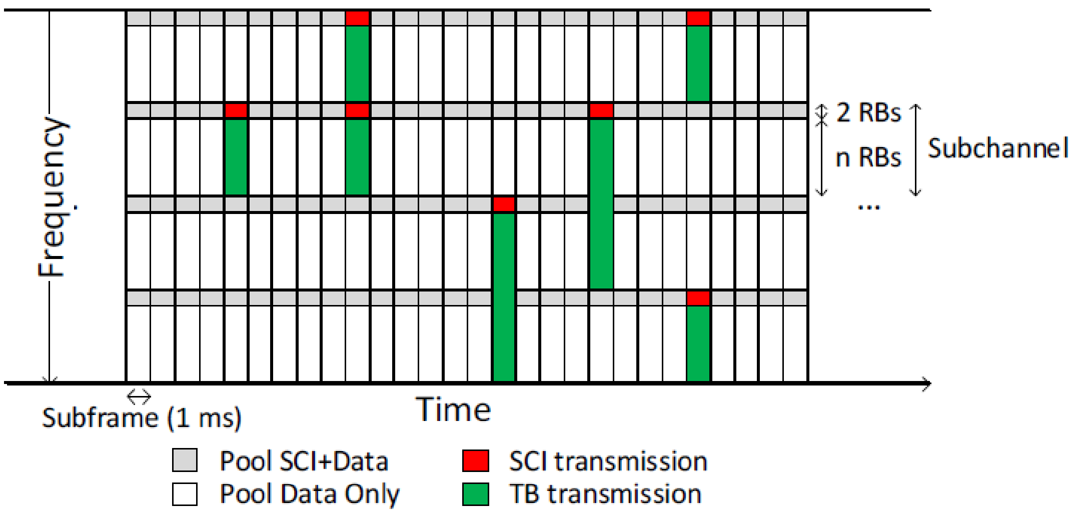
<Qualcomm>

Resource Pool Enhancement

- SA (PSCCH) pool and it associated data (PSSCH) pool can be FDMed
  - To reduce latency
  - To mitigate half duplex problem



TDMed Pools



Congestion control in Mode 4

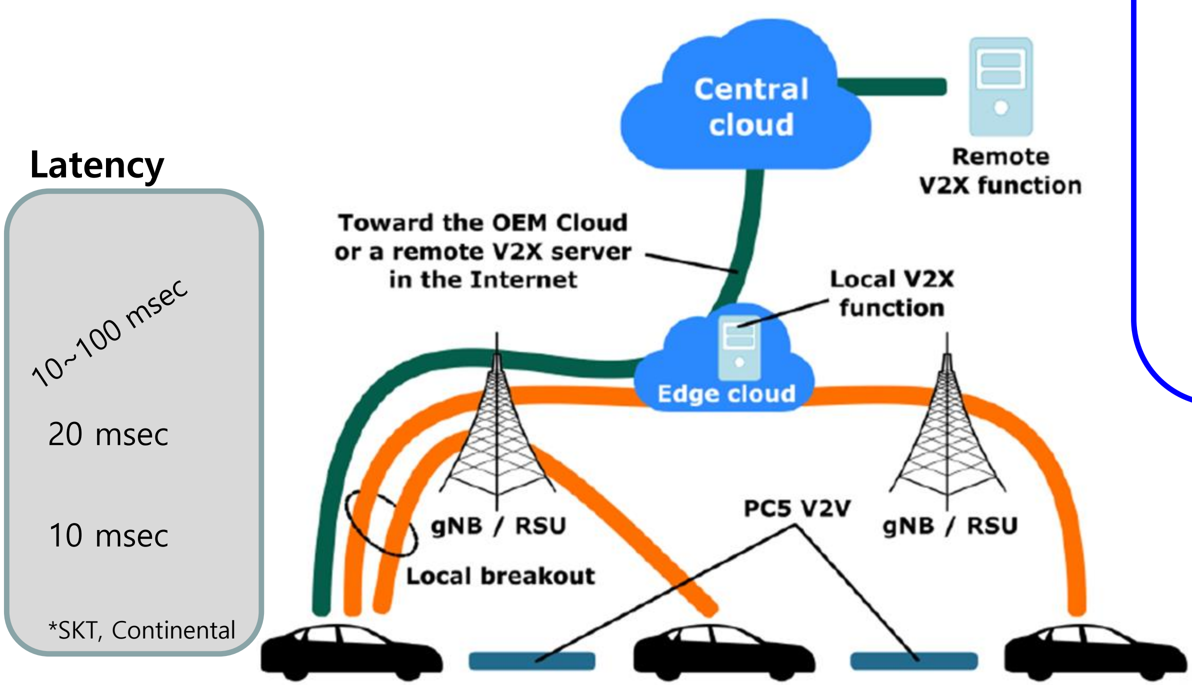
- Not specific algorithm specified
- Two metrics
  - **Channel busy ratio (CBR)**
    - Indication of the level of channel congestion
    - Amount of subchannels in the previous 100 subframes that experience an average RSSI higher than a preconfigured threshold (ususally -107 dBm/RB)
  - **Channel occupancy ratio (CR)**
    - Channel occupancy generated by the transmitting vehicle
    - Amount of subchannels that the transmitting vehicle utilizes during a period of 1,000 subframes
- Operation
  - If CR > CR_{Limit} for the measured CBR,
    - reduce CR below CR_{Limit} by packet dropping, MCS increasing, etc.

CBR Measured	CR_{Limit}
CBR ≤ 0.65	No limit
0.65 < CBR ≤ 0.675	1.6e-3
0.675 < CBR ≤ 0.7	1.5e-3
0.7 < CBR ≤ 0.725	1.4e-3
0.725 < CBR ≤ 0.75	1.3e-3
0.75 < CBR ≤ 0.775	1.2e-3
0.8 < CBR ≤ 0.825	1.1e-3
0.825 < CBR ≤ 0.85	1.1e-3
0.85 < CBR ≤ 0.875	1.0e-3
0.875 < CBR	0.8e-3

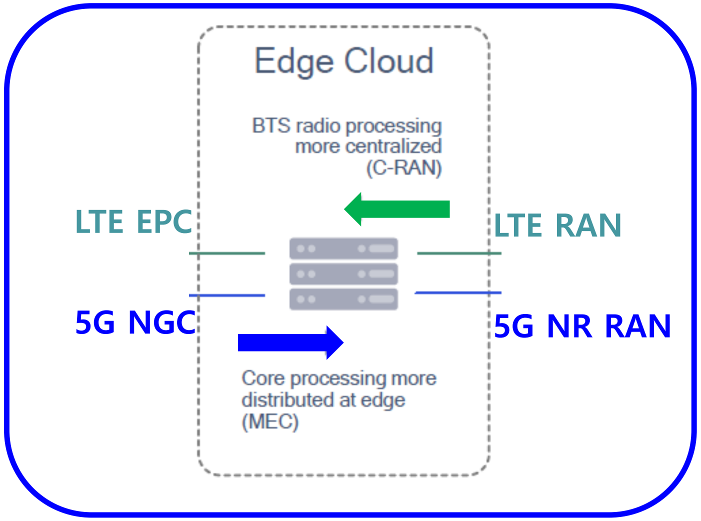
<LTE-V for sidelink 5G V2X vehicular communications, IEEE VT Mag. Dec. 2017>

MEC-based V2X Solution

- e2e latency reduction
- Local data processing, Backhaul bandwidth saving
- Use case: See-through (High-rate video sharing)

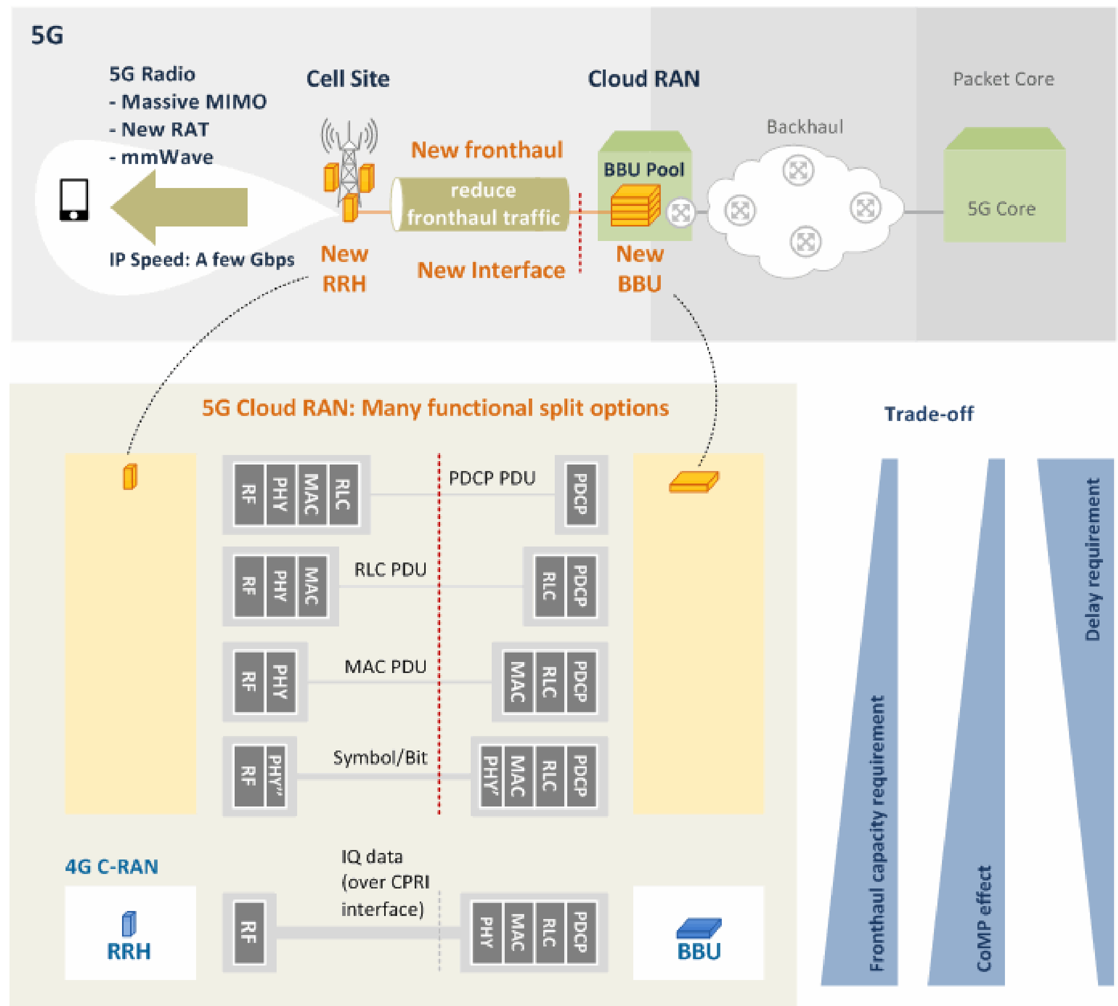


<Communication paths and end-2-end definitions in 5GCAR>



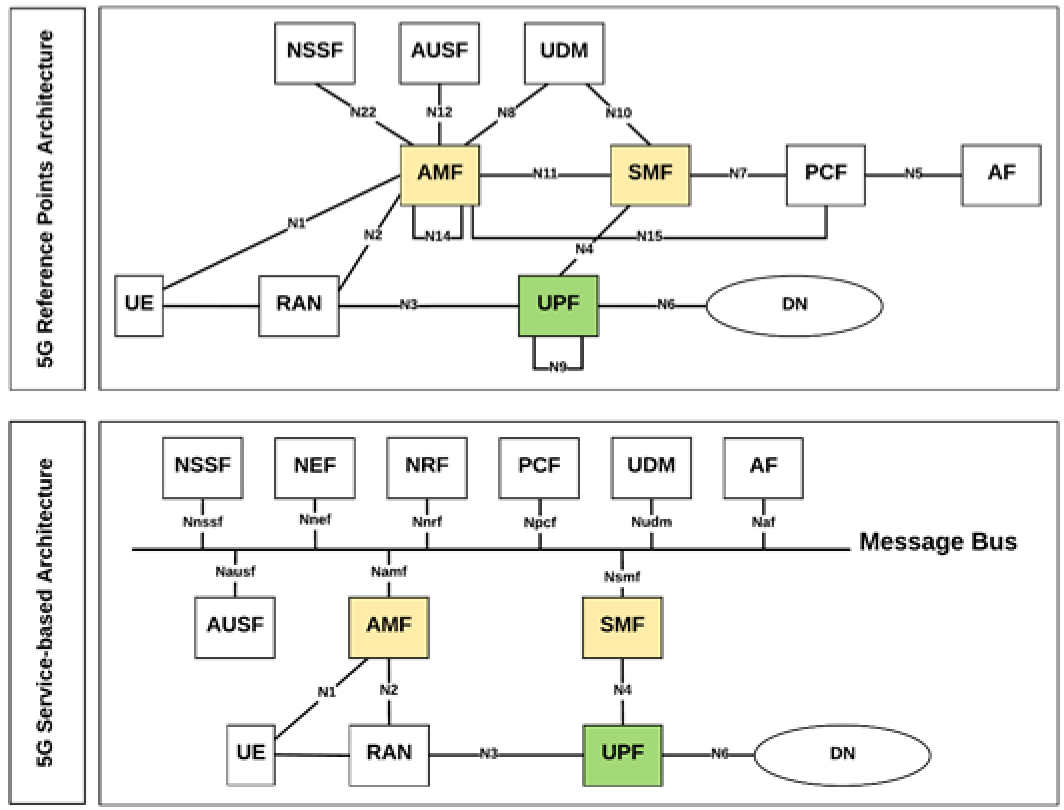
Cloud RAN

- Due to CPRI FH explosion
  - 2.45Gbps/RRH in 4G
    - 2-antenna
    - 20MHz BW
  - 10/100 Gbps/RRH in 5G
    - More antenna
      - Massive MIMO
    - Wider bandwidth
      - New RAT
      - mmWAVE
  - Max. CPRI capacity
    - ~10Gbps
- Split options Impact on
  - FH capacity
  - COMP effect
  - RAN virtualization gain



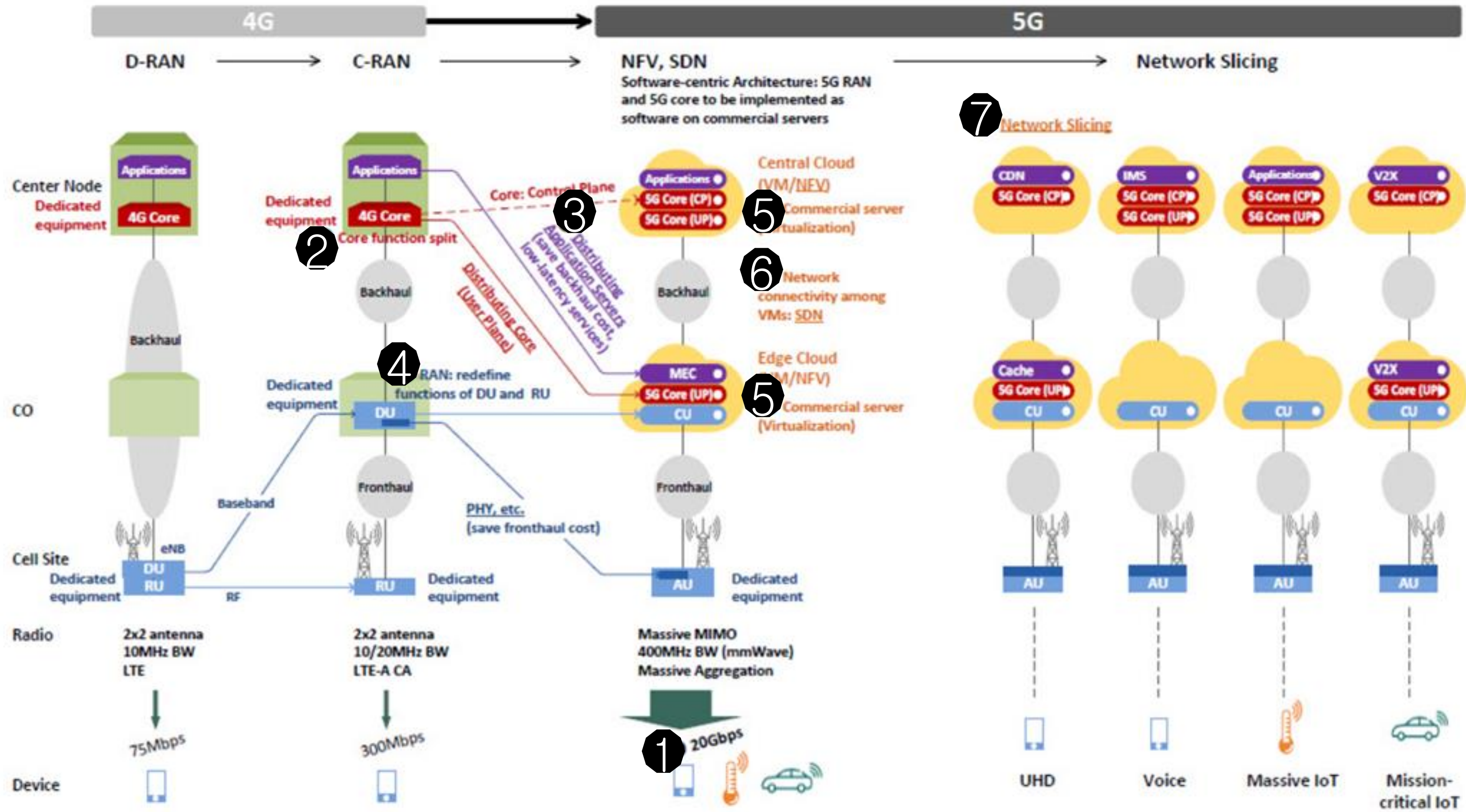
Service-Driven 5G Architecture

- 5G = "Service-based Architecture"
  - Architecture element : Network entity (LTE) ➔ Network functions (5G)
  - 5G의 network functions (NFs) 들은 virtualization 기술을 통해 범용 하드웨어에 설치
  - Software Defined Network (SDN) 기술과 더불어 "Network Slicing" 이 구현



SMF : Session Management Function
UPF : User Plane Function
NEF : Network Exposure Function
NRF : Network functions Repository Function
NSSF : Network Slice Selection Function
UDM : Unified Data Management
AUSF : Authentication Server Function
PCF : Policy Control Function (similar to PCRF)
AMF : core Access and Mobility management Function (similar to MME)

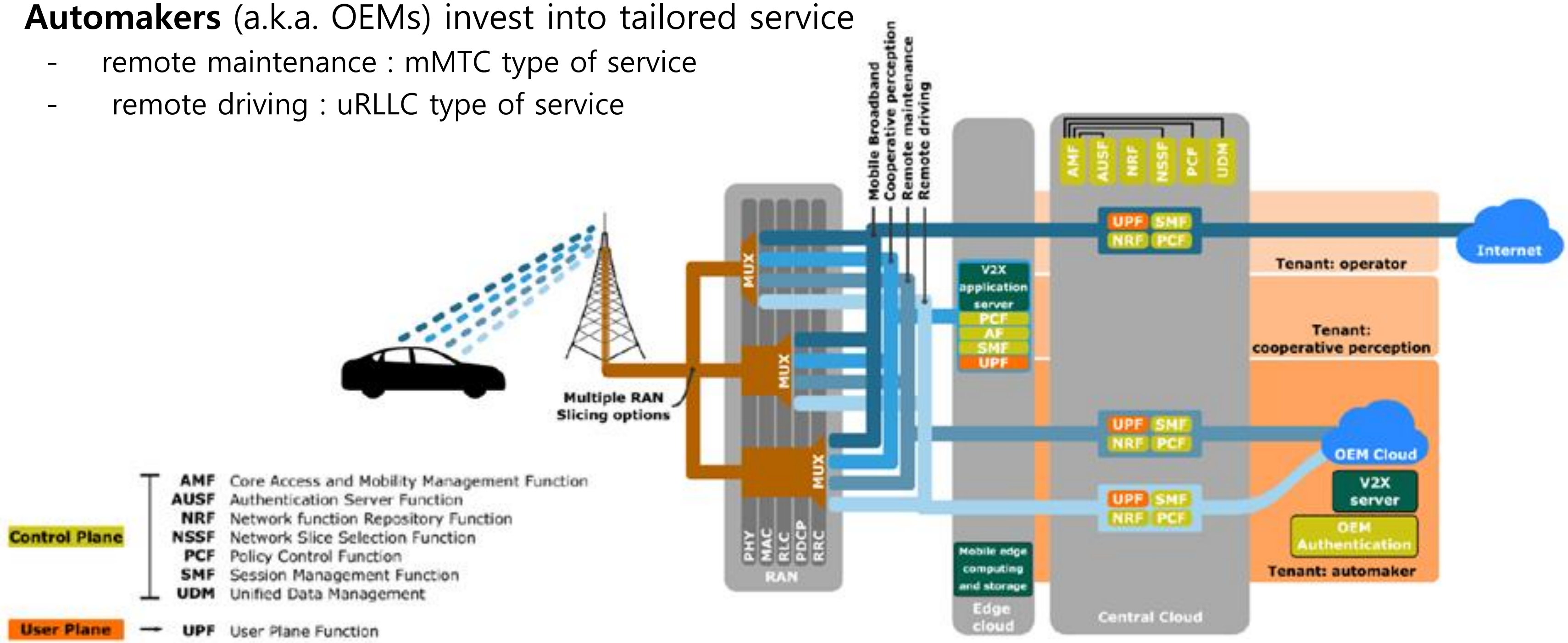
Network Architecture Evolution



DU : Digital Unit (BBU), CU : Central/Cloud Unit, UP : User Plane, MEC : Mobile Edge Computing, SDN : Software Defined Networking, IoT : Internet of Things, RU : Radio Unit (RRH), AU : Access Unit, CP : Control Plane, NFV : Network Function Virtualization, V2X : Vehicle-to-X, IMS : IP Multimedia Subsystem

Example of 5G V2X Sliced Network Scenario

- **Operator** controls the evolved Mobile Broadband slice
  - On board infotainment
  - Best effort wideband connectivity to the Internet
  - Central cloud
- **Cooperative perception** is local validity of the traffic generated by road users
  - Status messages are distributed to other road users in proximity in the shorted possible delay
  - RAN and edge cloud
- **Automakers** (a.k.a. OEMs) invest into tailored service
  - remote maintenance : mMTC type of service
  - remote driving : uRLLC type of service



Q & A