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Qualcomm

5G NR based C-V2X

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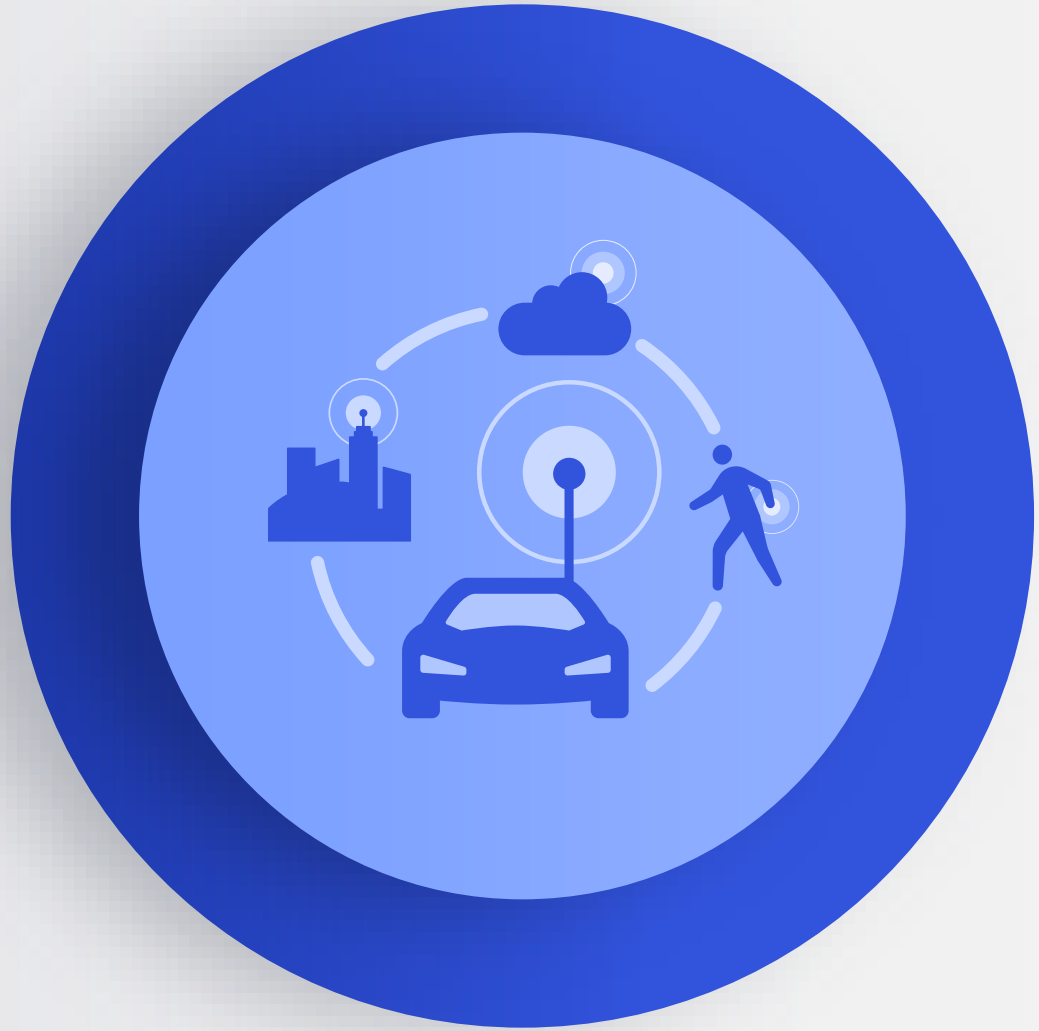
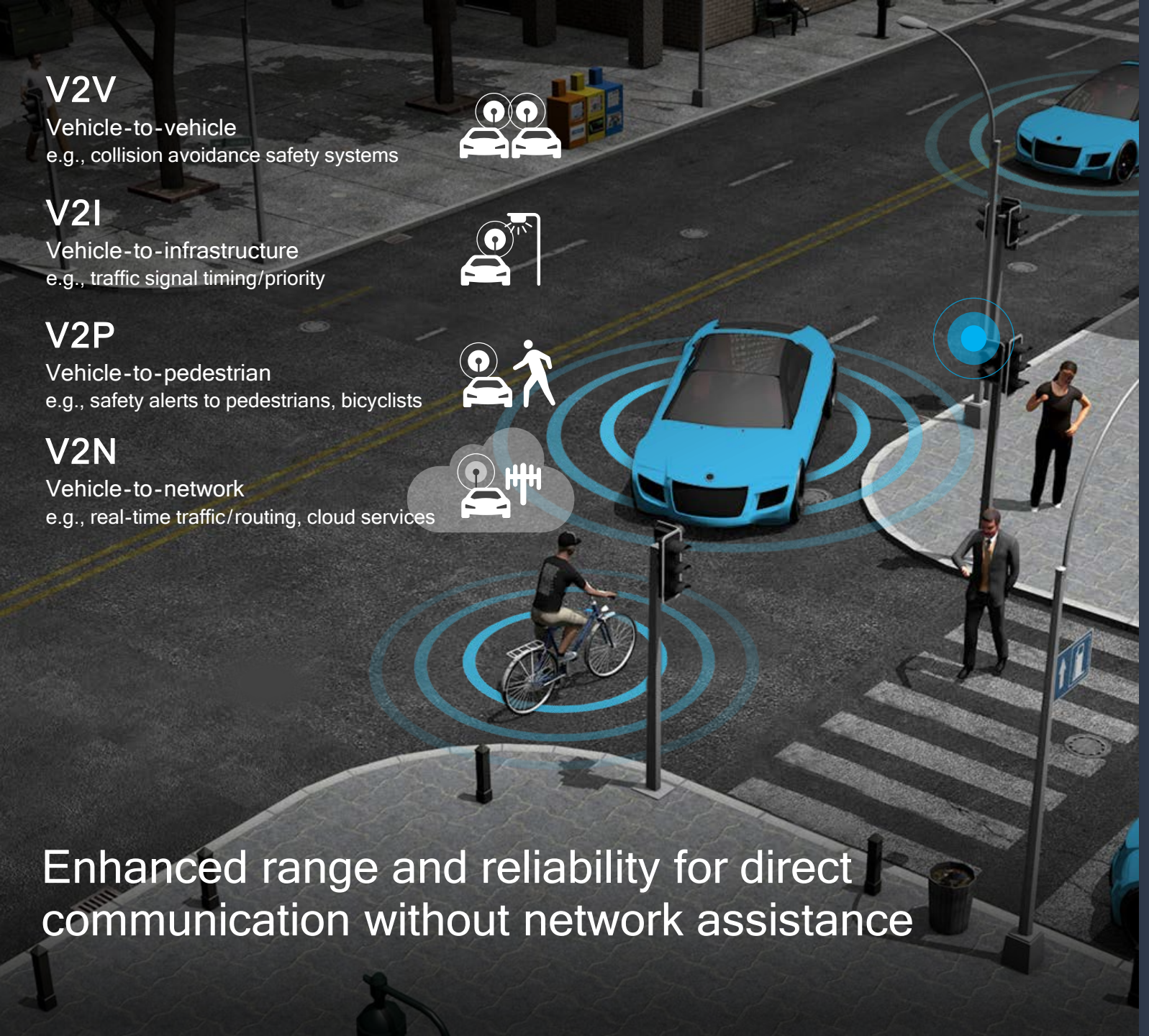
5G NR based C-V2X for autonomous driving

- Rel-14 C-V2X for automotive safety is gaining momentum and broad ecosystem support
- 5G NR provides a unified connectivity fabric to expand into new industries
- C-V2X has a clear and forward compatible evolution path to 5G NR
- 5G NR C-V2X provides URLLC and high data rate to support higher level of predictability for autonomous driving

Rel-14 C-V2X

Gaining momentum for automotive safety





C-V2X

Establishes the foundation for safety use cases and a continued 5G NR C-V2X evolution for future autonomous vehicles

- Release 14 C-V2X completed in 2017
- Broad industry support – 5GAA
- Global trials started in 2017
- Our 1st announced C-V2X product in September, 2017

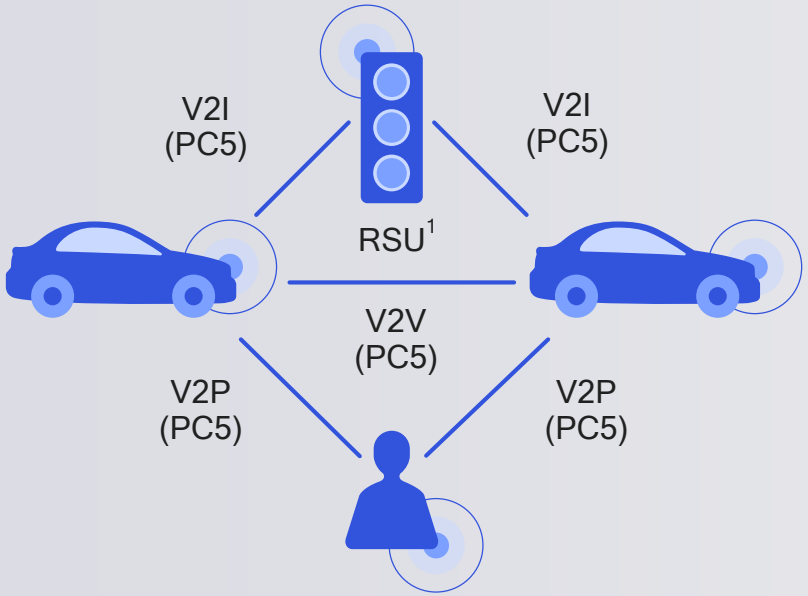
C-V2X enables network independent communication

Direct safety communication independent of cellular network

Low latency Vehicle to Vehicle (V2V), Vehicle to Infrastructure (V2I), and Vehicle to Person (V2P) operating in ITS bands (e.g. 5.9 GHz)

Direct PC5 interface

e.g. location, speed, local hazards

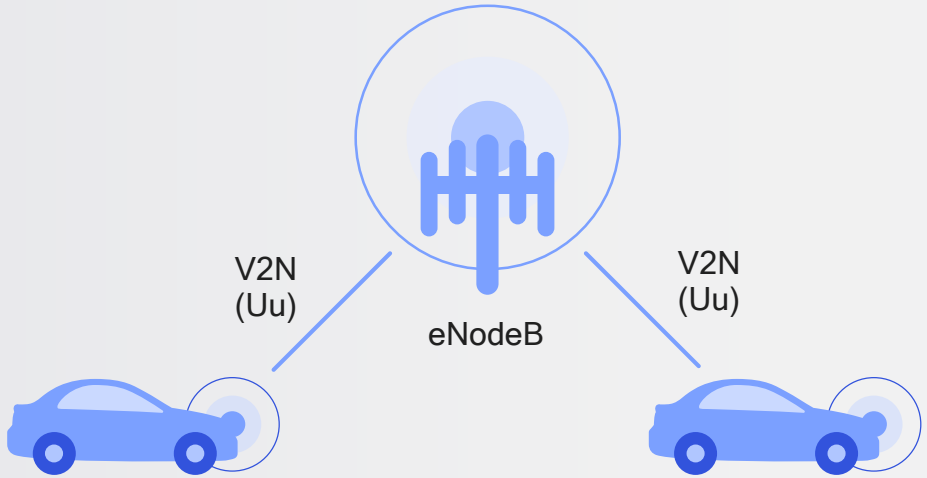


Network communications for complementary services

Vehicle to Network (V2N) operates in a mobile operator's licensed spectrum

Network Uu interface

e.g. accident 2 kilometer ahead



1. RSU stands for roadside unit

C-V2X complements other ADAS[1] sensor technologies

Provides 360° NLOS[2] sensing for higher levels of predictability and autonomy

ADAS

Radar

Camera

Lidar

Ultrasonic

C-V2X

3D HD maps

Precise positioning

Brain of the car to help automate the driving process by using:

Sensor fusion | Machine learning

1 Advanced Driver Assistance Systems; 2 Non-line of Sight

C-V2X offers key advantages in multiple dimensions

Enhanced range and reliability

Up to 500km/h relative speed support

More cost efficient than other technologies

5G NR

Forward compatible evolution path to 5G

Enhanced range and reliability for direct communication without network assistance

Self managed for reduced cost and complexity

Synergistic with cellular modem

Leverage of cellular ecosystem

Reuse of SAE / ETSI upper layers

Qualcomm® 9150 C-V2X Chipset

The Qualcomm 9150 C-V2X chipset with integrated GNSS will be featured as a part of the Qualcomm® C-V2X Reference Design to deliver a complete solution for trials and commercial development

Driving C-V2X towards commercialization

Qualcomm Technologies, Inc.'s (QTI) first-announced C-V2X solution supports C-V2X Direct Communications (V2V, V2I and V2P) based on 3GPP Release-14

C-V2X is gaining momentum

Trials started in 2017 using the Qualcomm 9150 C-V2X solution

C-V2X specifications completed in 2017

Global trials

ConVeX trial in Germany
Qualcomm, Audi, Ericsson, SWARCO, U. of Kaiserslautern

Towards 5G trial in France
Qualcomm, PSA Group, Orange, Ericsson

Ford trials in US
Qualcomm, AT&T, Ford, Nokia and McCain with SANDAG, Caltrans and the City of Chula Vista

Nissan trials in Japan
Qualcomm, Continental, Ericsson, Nissan, NTT DOCOMO, INC., OKI

More trials to follow in 2018

C-V2X gaining support from automotive and telecom leaders

5GAA is a cross-industry consortia to help define C-V2X and its evolution to 5G

5GAA Automotive Association

Automotive industry

Vehicle platform, hardware, and software solutions

Telecommunications

Connectivity and networking systems, devices, and technologies

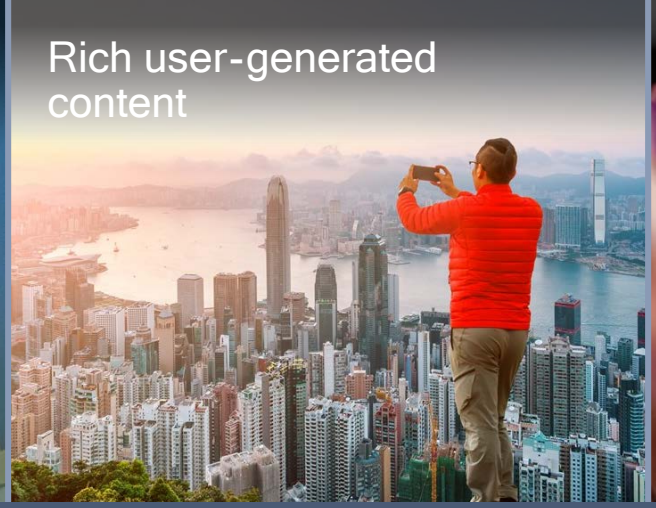
End-to-end solutions for intelligent transportation mobility systems and smart cities

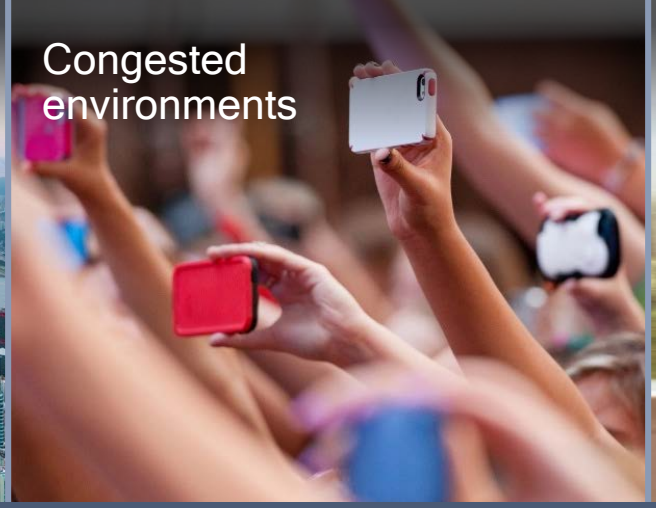
Airgain Alpine Electronics Analog Devices Anritsu EMEA Ltd AT&T Audi BAIC Beijing University Bell Mobility BMW Bosch CATT Cetecom China Transinfo China Unicom CMCC Continental Daimler Danlaw DEKRA Denso Deutsche Telekom Ericsson FEV Ficosa Ford Fraunhofer Gemalto Hirschman Car Hitachi Automotive US Honda Huawei Infineon Intel Interdigital Jaguar Land Rover Juniper KDDI Keysight KT Laird Tech LG Murata Nissan Nokia NTT DoCoMo OKI Orange P3 Group Panasonic Proximus PSA Qualcomm Rohde & Schwarz Rohm SAIC Samsung Savari SIAC SK Telecom Skyworks Softbank Sumitomo Telefonica Telekom Austria Telstra TÜV Valeo Veniam Verizon Viavi Vodafone Volkswagen (VW) ZF ZTE

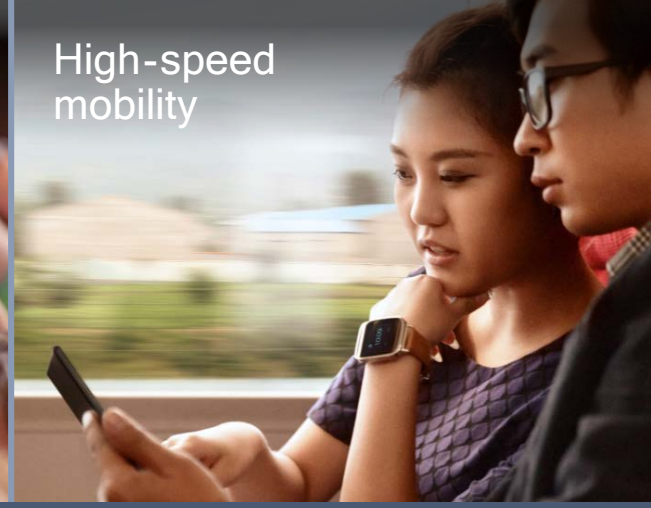
Source: http://5gaa.org/; accurate as of January, 2018

5G NR

A unified connectivity fabric to expand into new industries



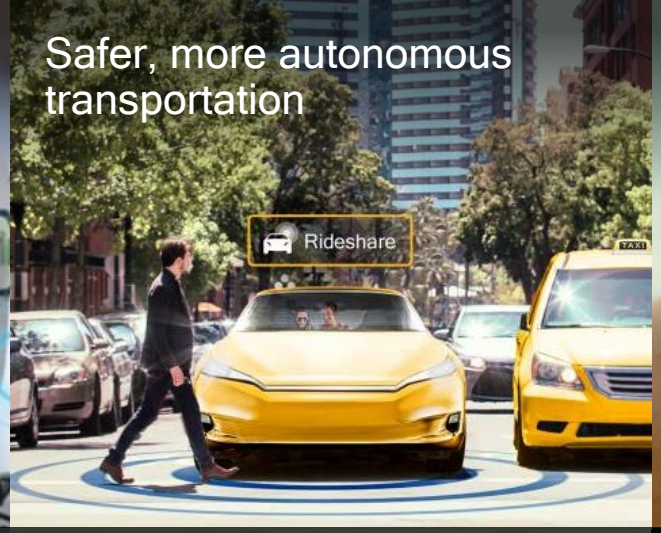


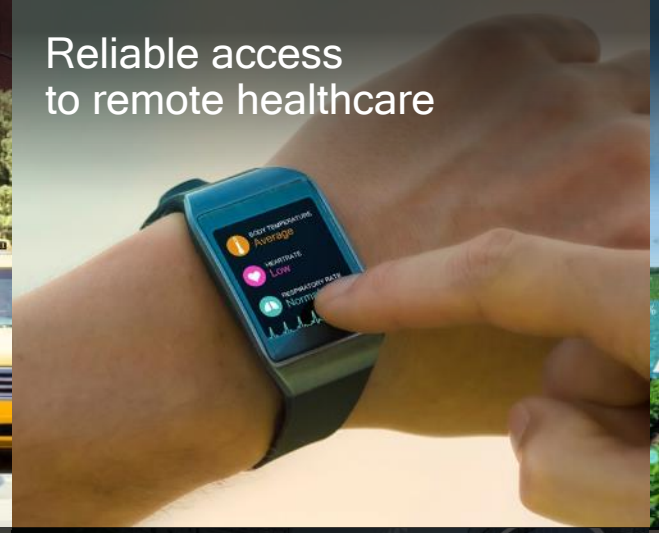


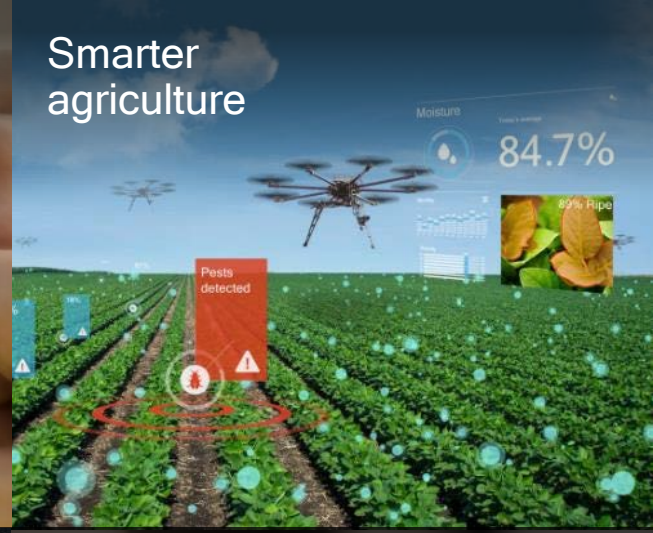
5G

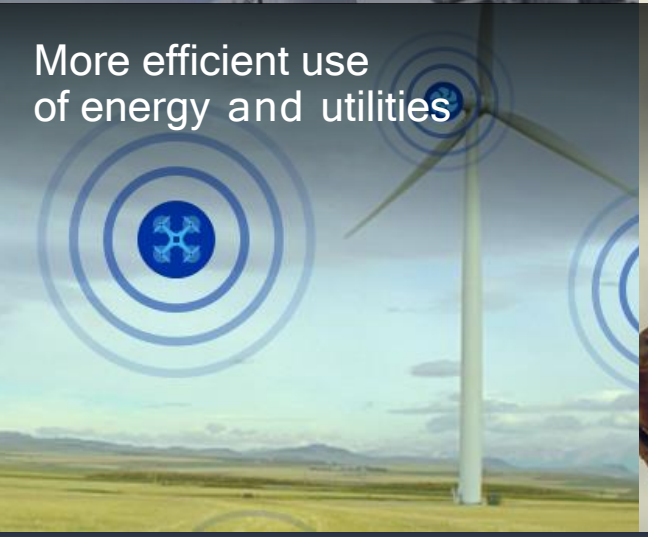
5G is essential for next generation mobile experiences

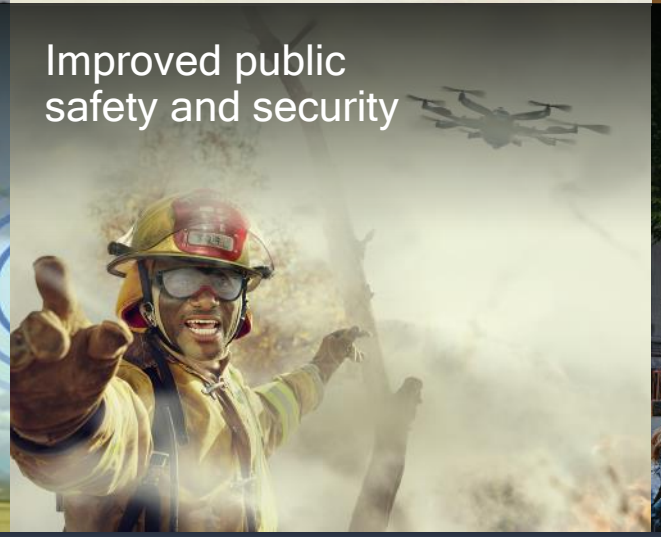
- Fiber-like data speeds
- Low latency for real-time interactivity
- More consistent performance
- Massive capacity for unlimited data











5G

5G will expand the mobile ecosystem to new industries

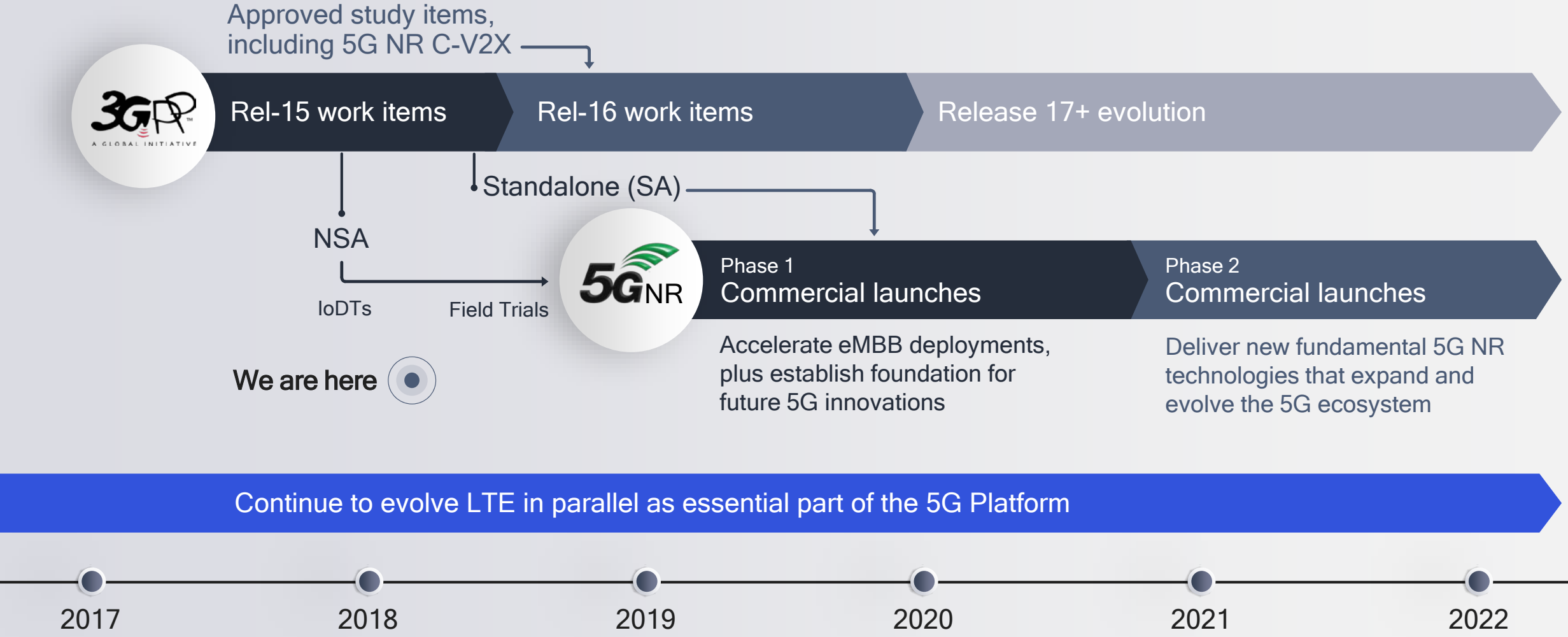
*The 5G Economy, an independent study from IHS Markit, Penn Schoen Berland and Berkeley Research Group, commissioned by Qualcomm

Powering the digital economy

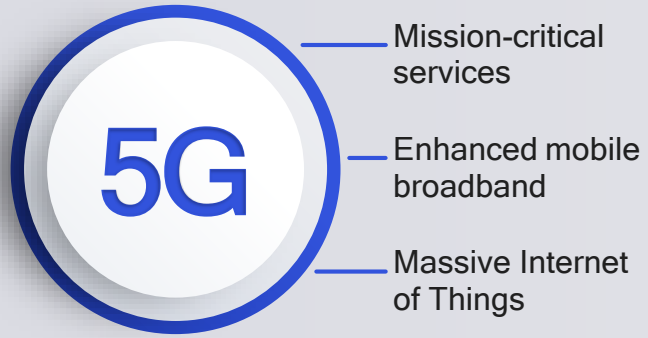
>$12 Trillion

In goods and services by 2035*

Accelerating 5G NR to meet the ever-increasing global demand for mobile broadband

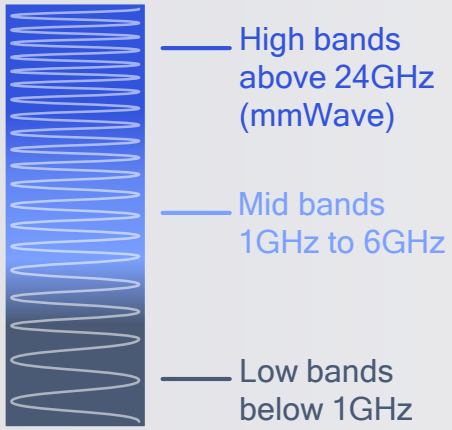


5G NR Designing a unified, more capable 5G air interface



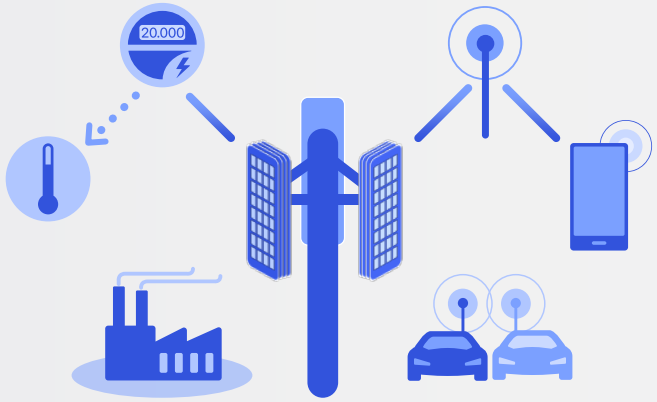
Diverse services

Scalability to address an extreme variation of requirements



Diverse spectrum

Getting the most out of a wide array of spectrum bands / types



Diverse deployments

From macro to indoor hotspots, with support for diverse topologies

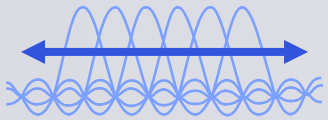
A unifying connectivity fabric for future innovation

A platform for existing, emerging, and unforeseen connected services

3GPP Rel-15 establishes a solid foundation for 5G NR

For enhanced mobile broadband and beyond

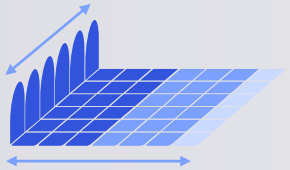
Scalable OFDM-based air interface



Scalable OFDM numerology

Efficiently address diverse spectrum, deployments and services

Flexible slot-based framework



Self-contained slot structure

Key enabler to low latency, URLLC and forward compatibility

Advanced channel coding

ME-LDPC and CA-Polar[1]

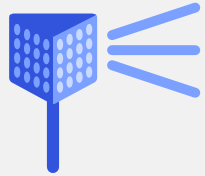
Efficiently support large data blocks and a reliable control channel

Massive MIMO

Reciprocity-based MU-MIMO

Efficiently utilize a large number of antennas to increase coverage / capacity

Mobile mmWave



Beamforming and beam-tracking

Enables wide mmWave bandwidths for extreme capacity and throughput

Qualcomm

Our technology inventions are driving Rel-15 specifications

Early R&D investments | Best-in-class prototypes | Fundamental contributions to 3GPP

Learn more at: https://www.qualcomm.com/5gnr

1. Multi-Edge Low-Density Parity-Check and CRC-Aided Polar

5G NR C-V2X

Brings new capabilities to
C-V2X for autonomous driving

5G NR C-V2X

Communication augments 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

Advanced use cases for autonomous driving

High throughput sensor sharing

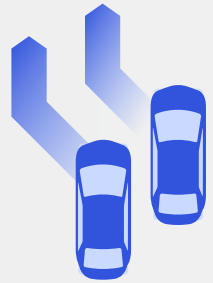
High throughput and reliability to enable the exchange of raw or processed data gathered

Intent / Trajectory sharing

High throughput and URLLC to enable planned trajectory sharing

Real-time local updates

High throughput to build local, dynamic maps based on camera and sensor data; and distribute them at street intersections



Coordinated driving

URLLC and high date rate to exchange path planning information in timely fashion

Wideband carrier support

High throughput

Ultra-low latency

Ultra-high reliability

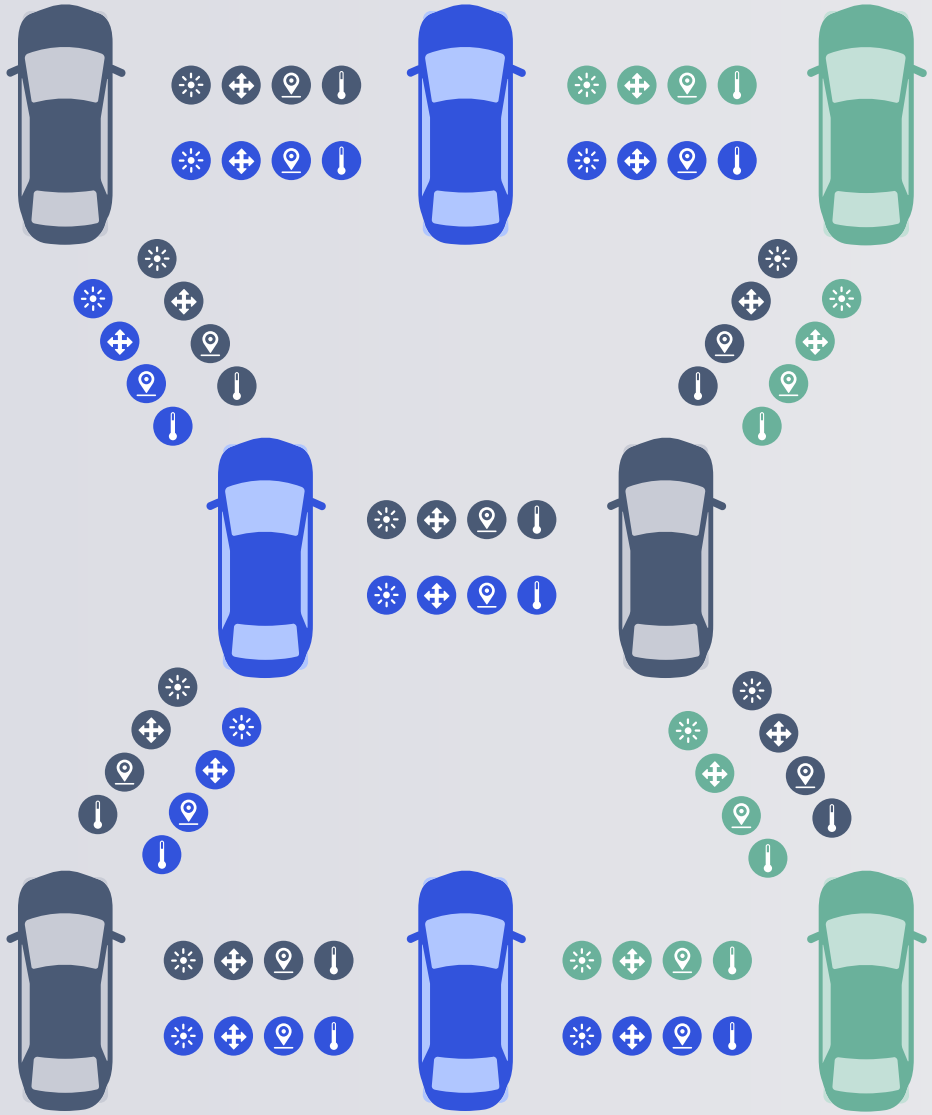
Ultra-reliable

Low latency
(a few milliseconds)

At high speeds
(up to 500km/h relative speeds)

Advanced use cases for autonomy requires high data rates and URLLC

Each individual vehicle can transmit significant amounts of data reliably and in timely fashion



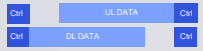
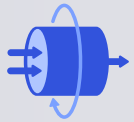
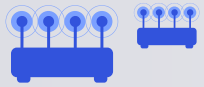
More reliable

Lower latency
(a few milliseconds)

At high speeds
(up to 500km/h relative speeds

Advanced use cases for autonomy requires high data rates and URLLC

This will lead to huge amount of data to be shared between many vehicles, as well as, vehicles and infrastructure, especially for high vehicle density deployments

NR Design		5G NR C-V2X capabilities for autonomous driving
Scalable OFDM-based air interface		5G C-V2X is expected to efficiently addresses diverse spectrum bands for different use cases Leveraging wideband carrier support and OFDMA to deliver higher data rates
Self-contained slot structure		Smaller slot structure with immediate feedback to enable ultra reliable low latency communications
Advanced channel coding		State of the art LDPC/polar coding to deliver higher reliability with low complexity
Wideband carrier support		Wideband carrier based higher data rates and system capacity
Larger number of antenna		Efficiently utilize larger number of antennas than Rel-14 to deliver higher data rate and long range

Leveraging 5G NR capabilities for C-V2X Direct Communications

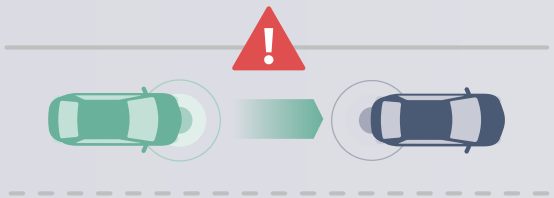
Providing high throughput and URLLC capabilities for autonomous driving

Evolving C-V2X Direct Communications towards 5G NR

While maintaining backward capabilities

Evolution to 5G NR, while being backward compatible
C-V2X Rel-14 is necessary and operates with Rel-16

Basic safety
IEEE 802.11p

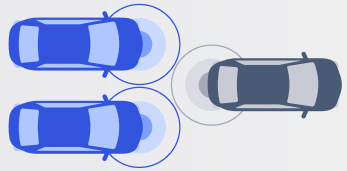


Basic and enhanced safety
C-V2X Rel-14/Rel-15 with enhanced range and reliability

Autonomous driving use cases
5G NR C-V2X Rel-16

Backward compatible with Rel-14/Rel-15 enabled vehicles

- Higher throughput
- Higher reliability
- Wideband carrier support
- Lower latency



Evolving C-V2X Direct Communications towards 5G NR

5G NR C-V2X complements Rel-14 with new capabilities

Targeting new use cases for autonomous driving

Rel-14 C-V2X

Automotive safety

Do not pass warning (DNPW)

Intersection movement assist (IMA) at a blind intersection

Blind curve / Local hazard warning

Rel-16 5G NR C-V2X

Autonomous driving

Real-time local updates

Intention / Trajectory sharing

High throughput sensor sharing

Coordinated driving

Resulting in a 5G NR C-V2X design that addresses autonomous vehicle use case requirements

5G NR C-V2X

Higher throughput

High spectral efficiency to achieve higher data rate

High vehicle speeds

Support higher data rates at relative speeds up to 500km/h

Lower latency

Access latency below 1ms for time critical use cases

Harmonious coexistence

Can coexist with Rel-14 in the same channel/band

Higher reliability

Unicast multicast support using efficient feedback

Backward compatibility

Vehicles with Rel-16 will also support Rel-14 for safety

Intention Sharing

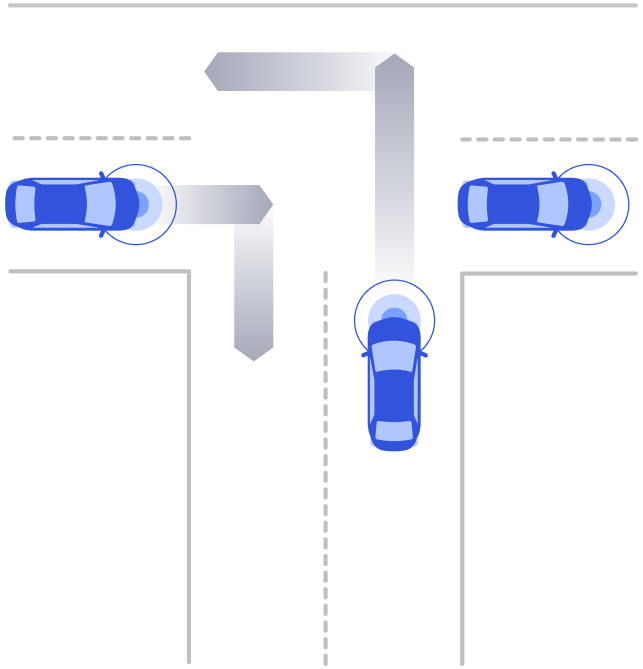
Supporting high level of predictability for advanced path planning

Intention/trajectory sharing for autonomous driving

Providing higher level of predictability and traffic efficiency for advanced path planning

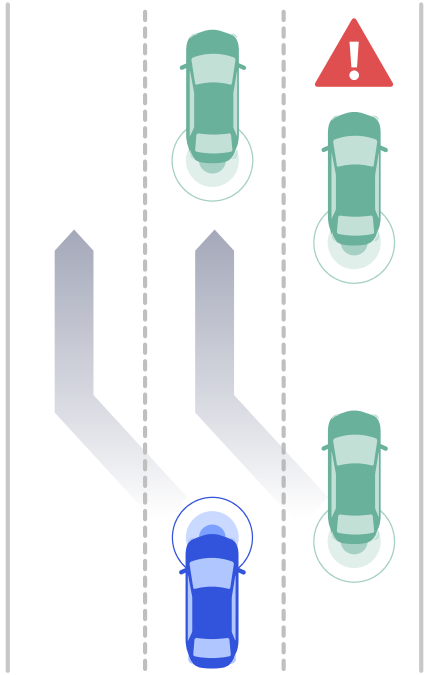
Efficient maneuvers

Autonomous vehicles are able to make quicker, yet safe maneuvers by knowing the planned movements of surrounding vehicles



Advanced path planning

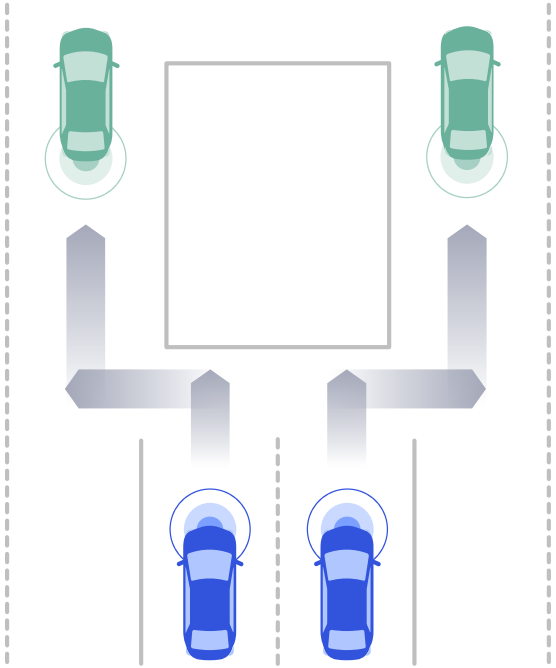
Supporting the level of predictability needed for advanced path planning for autonomous driving



Sudden braking and lane change on a freeway

Coordinated driving

Autonomous vehicles are able to choose time-efficient paths toward their given destinations as they know the planned movements of other vehicles



Leveraging 5G NR capabilities for intent sharing

High throughput

Requires high data rate (e.g. more than 100Mbps within 1km stretch

Low latency

Trajectory information has to be shared within a few milliseconds

High reliability

To accurately share trajectory information in a timely fashion

Intent/trajectory sharing for faster yet safe maneuvers

A vehicle trying to change lanes is demonstrated for three scenarios

Scenario1

Human-driven vehicle without C-V2X

May suffer from collision due to lack of blind spot detection

Scenario 2

Autonomous vehicle without C-V2X

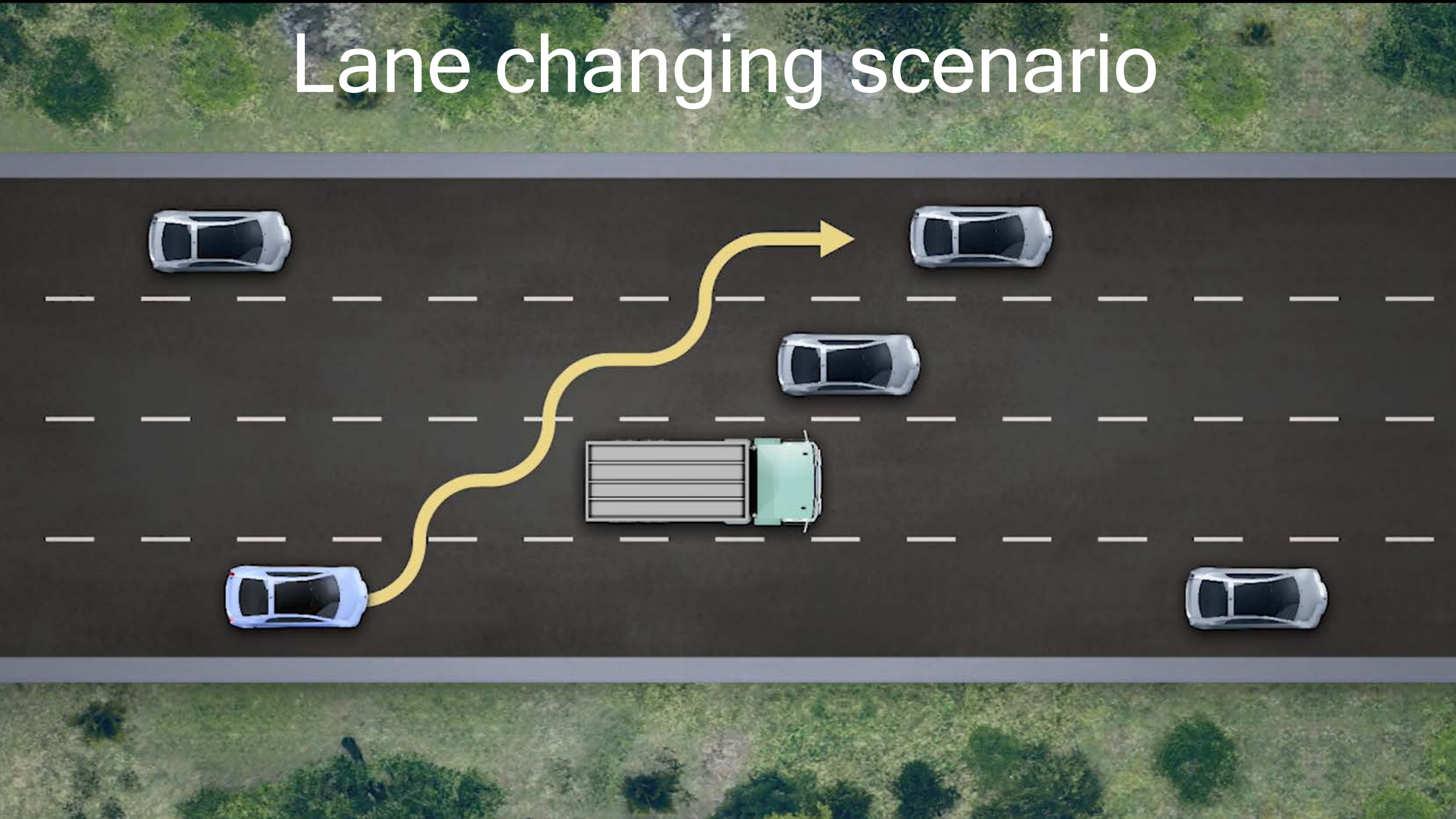
Safe, but may require significantly longer maneuver time

Scenario 3

Autonomous vehicle with 5G NR based C-V2X

Enables vehicles to select faster yet safe path

Lane changing scenario



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