V2X Communication Protocols:

Survey Presentation Slides

Motivation

The era of connected vehicles

Vehicle to vehicle

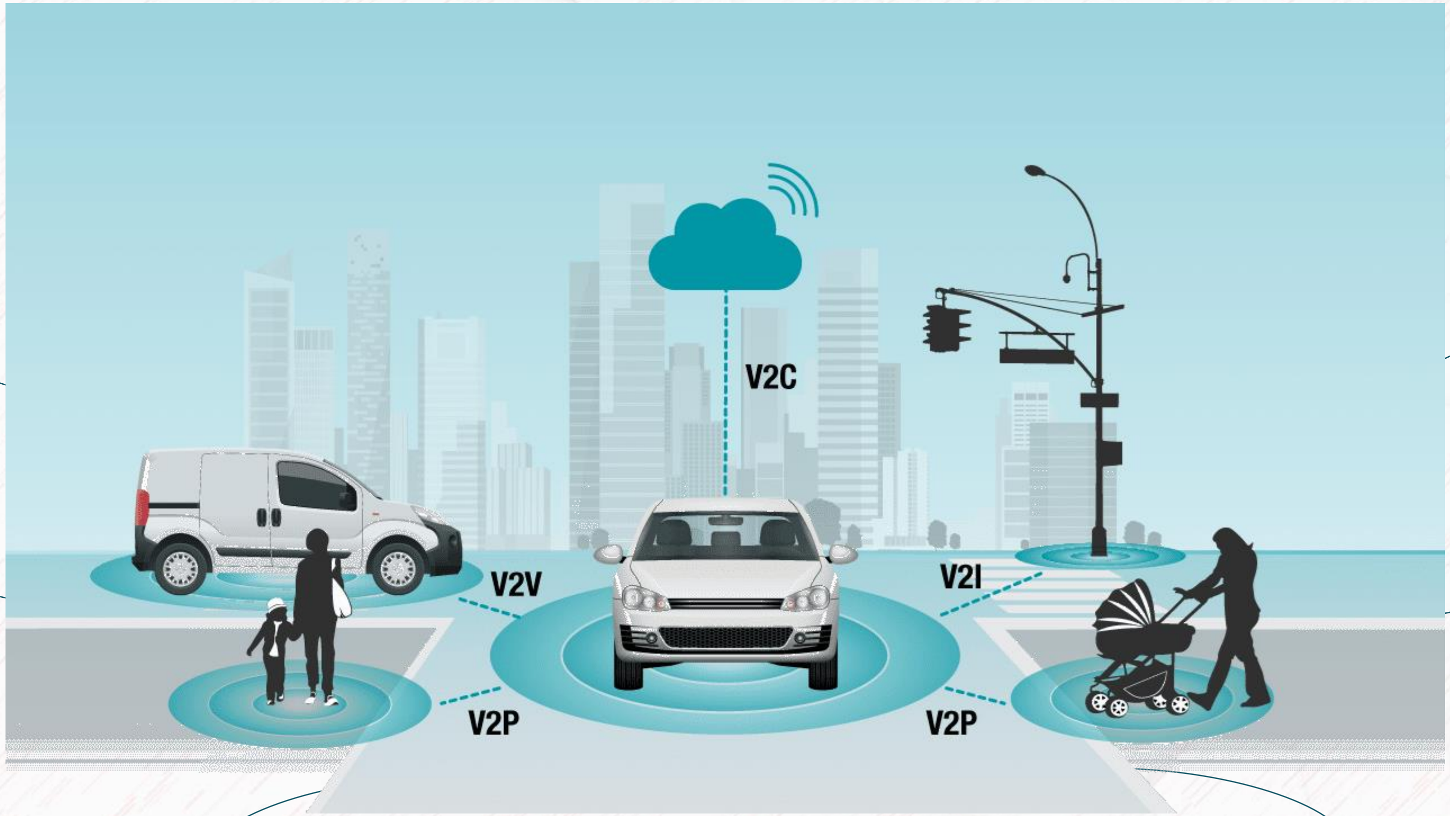
Vehicle to pedestrian

Vehicle to road

Vehicle to Infrastructure

Vehicle to cloud

Vehicle to grid



Why is the need for an always-connected vehicle?

Fewer driving fatalities/injuries

>1.2M

people die on the roads each year worldwide[1]

More predictable, productive travel

3.1B

gallons of fuel wasted due to traffic congestion in the US[2]

Less greenhouse gas emissions

14%

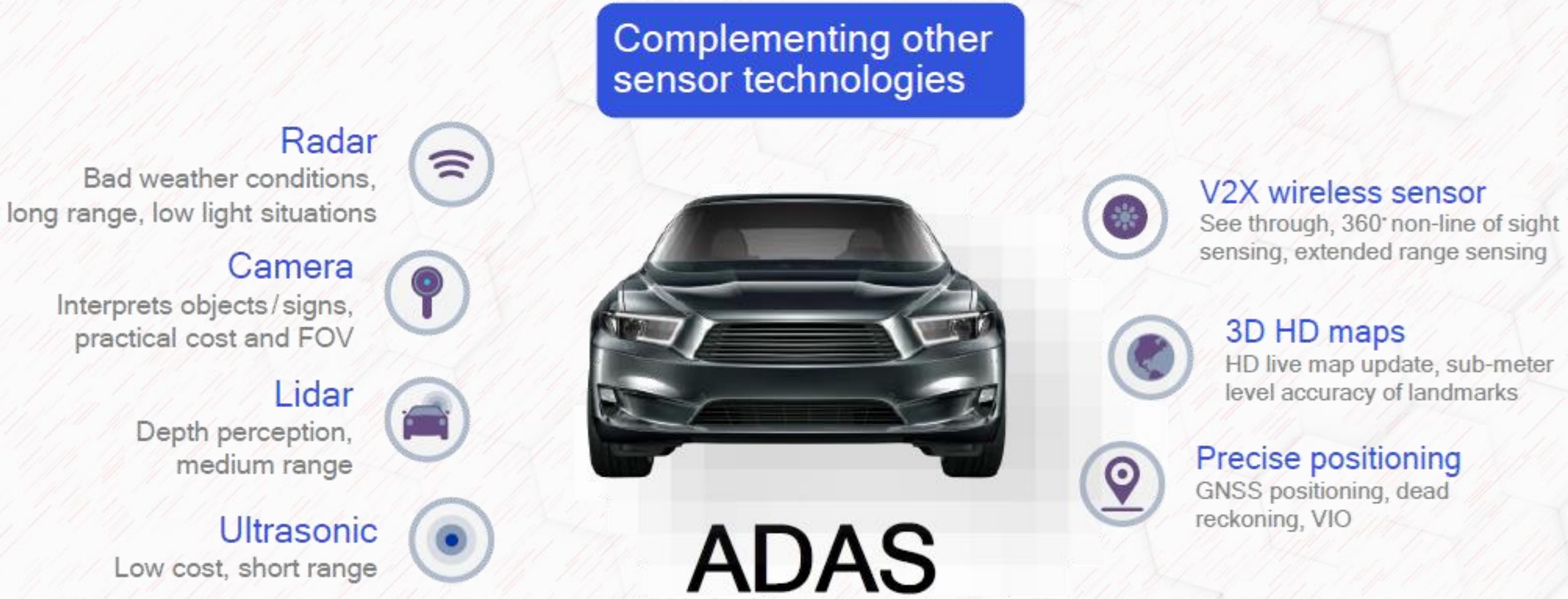
of all global warming emissions from transportation[3]

[1]Global Status Report on Road Safety, World Health Organization 2015;
[2]Texas Transportation Institute Urban Mobility Report, 2015; [3]U.S., Environmental Protection Agency (EPA) 2014

V2X communication is a critical component to the vision of achieving a smart city

Giving vehicles the ability to communicate with each other and beyond

V2X is a key technology enabler to enhanced ADAS



Bringing significant value to advanced driver assistance systems (ADAS)

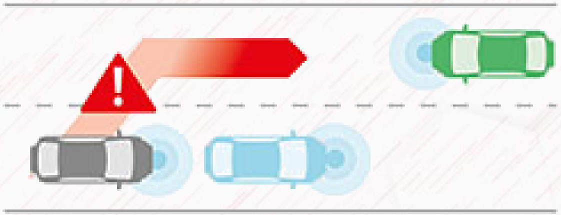
Improved active safety by providing 360° non-line-of-sight awareness

Better traffic efficiency allowing vehicles to safely drive closer to each other for optimized traffic flow

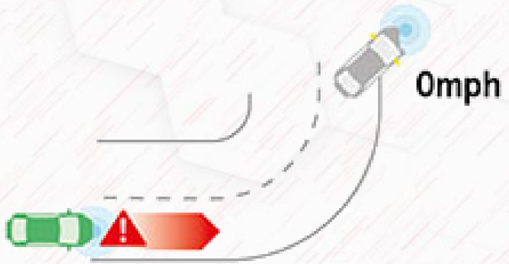
Increased situational awareness providing ability to gather data from further ahead for a predictable driving experience

V2X enables a broad and growing set of use cases

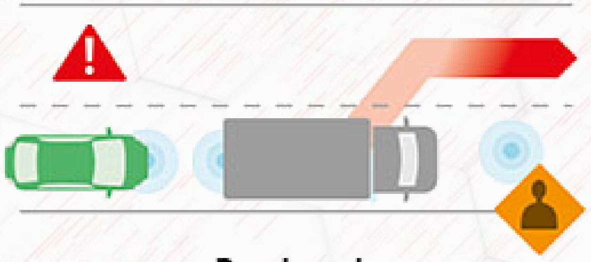
Much more than collision avoidance



Do not pass
warning (DNPW)



Blind curve/local
hazard warning



Road works
warning

Intersection movement assist
(IMA) at a blind intersection

Vulnerable road user (VRU)
alerts at a blind intersection

Left turn
assist (LTA)

DSRC & C-V2X

Unique characteristics of vehicular communications

High mobility of nodes

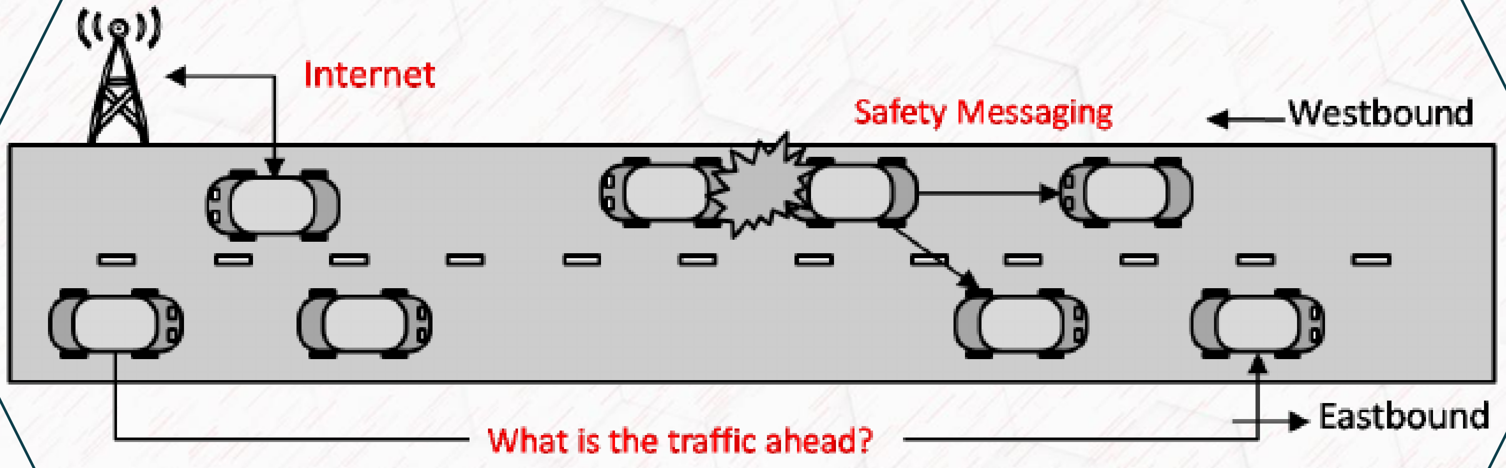
High node density

Dynamic network topology

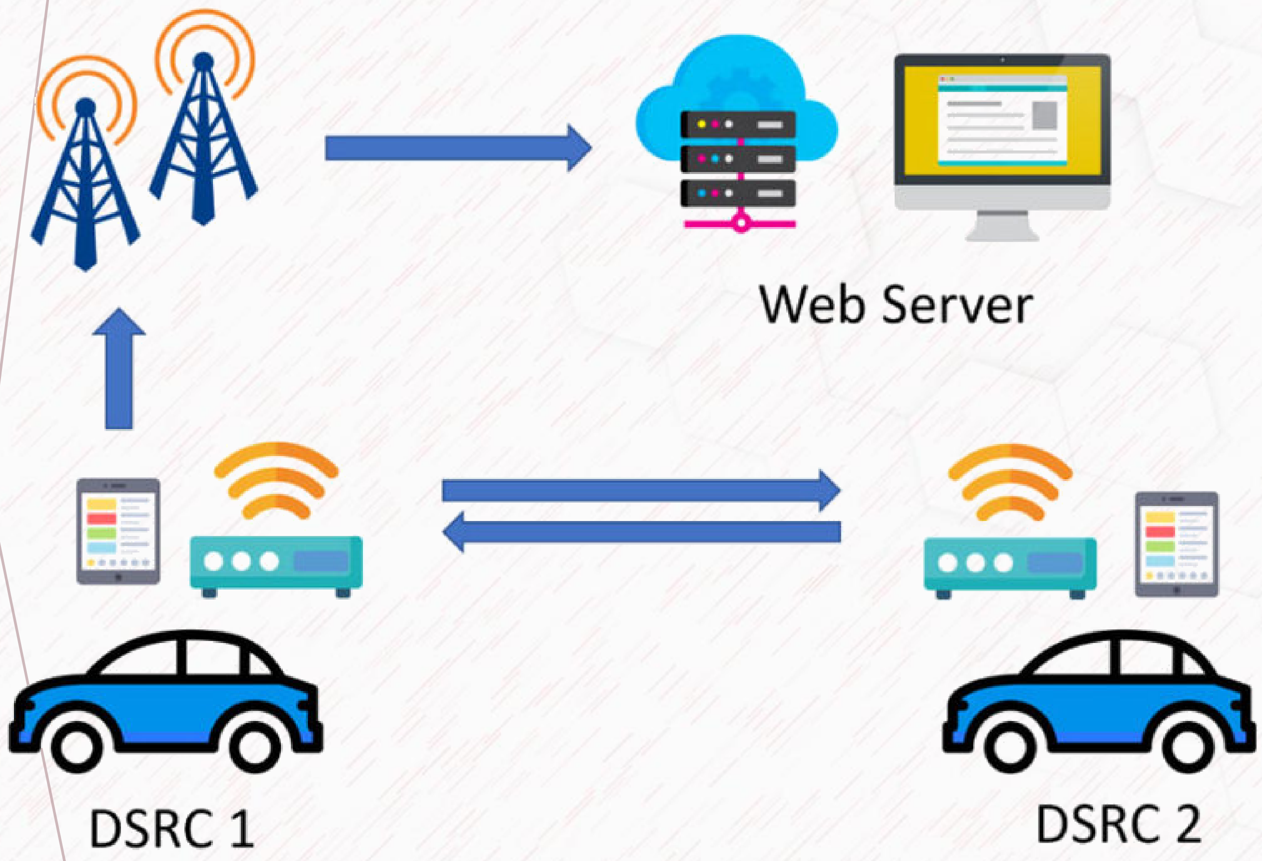
Time-sensitive and delay intolerant

Ultra low latency and high reliability requirement

Frequent non-LOS environments



DSRC: IEEE 802.11p has established the foundation for V2X



Wi-Fi based technology – 802.11p standard

Adapted for latency-critical V2X communications in the 5.9Ghz band with a dedicated bandwidth of 75Mhz

Established security and upper layer specifications

With service layer/performance requirements defined by SDOs e.g., SAE, ETSI-ITS[1]

Based on the 802.11 family of CSMA-CA protocol

In CSMA/CA, the device listens to the channel before sending a packet, and any packet is sent only if the channel is clear

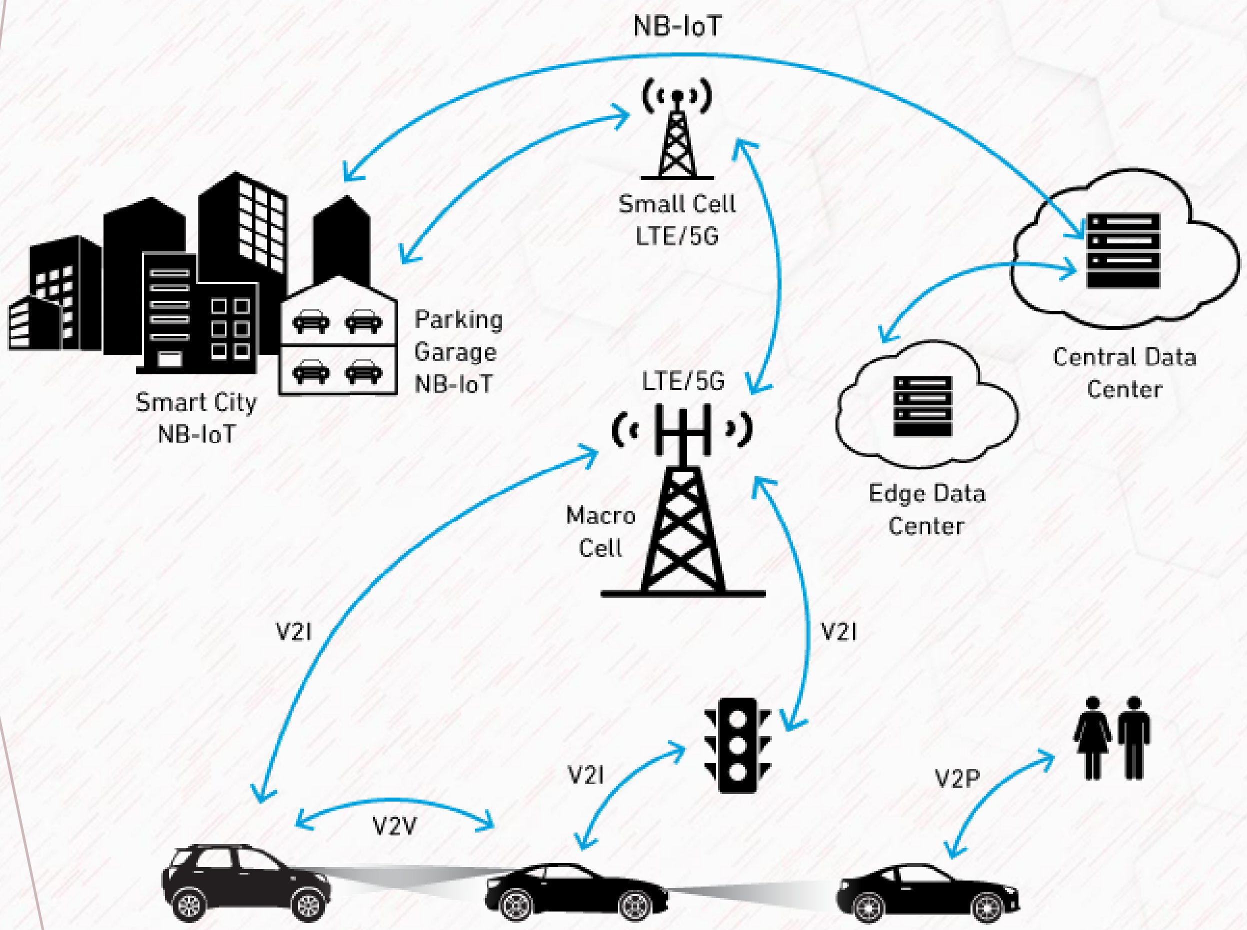
Short range for high-speed communications

DSRC can support high driving speeds of up to 500km/hr with limited range of about 300m. It therefore relies on fixed infrastructure called Road-Side Units (RSUs) for safety critical communication

[1]Standard Development Organizations, e.g., Society for Automotive Engineers, European Telecommunications Standards Institute-Intelligent Transport Systems

3GPP Cellular-V2X was introduced as an alternative solution

C-V2X Communications



Global 3GPP standard specifications

The C-V2X technology platform has evolved from Rel-14 to 5G NR-based C-V2X based on requirements defined by 3GPP

Builds upon existing cellular network platform

C-V2X leverage years of innovation in the cellular domain providing a compelling alternative to DSRC-based communications

Enhanced V2X direct communications

Improvements over 802.11p – up to a few additional seconds of alerts latency and up to 15km coverage range. C-V2X Direct Communications provides enhanced range and reliability without relying on cellular network assistance or coverage

Designed for high-speed vehicular use cases

3GPP C-V2X R-14 is enhanced to support vehicular use cases up to 500km/h relative speeds in varying road conditions

802.11p DSRC versus 3GPP C-V2X

	DSRC	C-V2X	Implication(s)
Synchronization	Asynchronous	Synchronous	Since synchronization allows time division multiplexing (TDM) and has a lower channel access overhead, V2X achieves a higher spectral efficiency than 802.11p.
Resource Multiplexing across Vehicles	TDM only	FDM and Time Division Multiplexing (TDM) possible	Because FDM allows for a larger link budget, an extended range or more reliable performance at the same range can be achieved.
Channel Coding	Convolutional	Turbo	The turbo codes and SC-FCM waveform used in V2X can also achieve a longer range or more reliable performance at the same range.
Waveform	OFDM	SC-FDM	
Retransmission Mechanism	No HARQ	Hybrid Automatic Repeat Request (HARQ)	By utilizing HARQ, useful for the purpose of recovering the original data from a corrupted message, V2X can achieve a higher link efficiency, longer transmission range or more reliable performance.
Resource Selection	Carrier Sense Multiple Access with Collision Avoidance (CSMA-CA)	Semipersistent transmission with relative energy-based selection	The V2X scheme optimizes resource selection by choosing the close to "best" resource, with no contention overhead. On the contrary, IEEE 802.11p with CSMA-CA protocol selects the first "good enough" resource, thus leading to contention overhead

802.11p DSRC versus 3GPP C-V2X

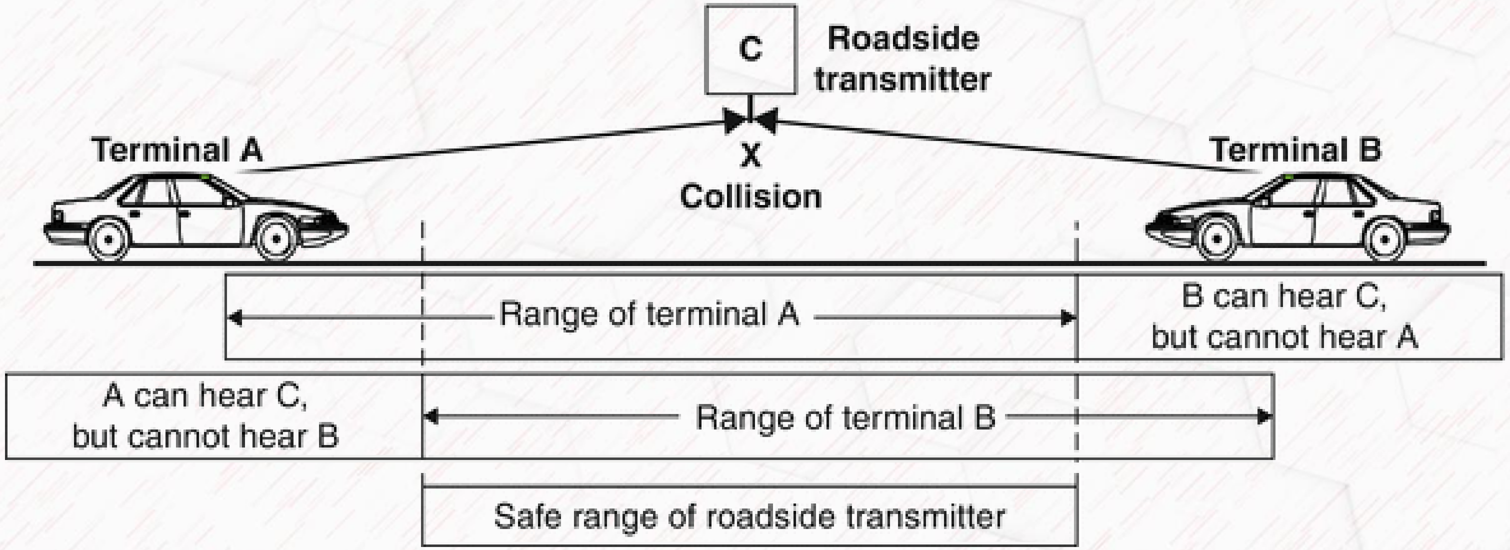
	DSRC	C-V2X	Implication(s)
Frequency Band	5.86-5.92 Ghz	450Mhz-4.99Ghz	C-V2X edges out DSRC across a broad range of important feature characteristics
Data rate	Up to 27Mb/s	Up to 1Gb/s	
Capacity	Medium	High	
Coverage	Intermittent	Ubiquitous	
Mobility Support	Up to 60km/hr	Up to 350km/hr	
Quality-of-Service Support	Enhanced Distributed Channel Access (EDCA)	QCI and bearer selection	
Broadcast/Multicast Support	Native broadcast	Through eMBMS	
CAPEX/OPEX	High	Relatively low	

Limitations of the two technologies

DSRC: Hidden node problem

1 In DSRC, the MAC layer consists of two parts, the IEEE 802.11p forms the lower layer while IEEE 1609.4 contains the upper MAC layer.

2 When packets are transmitted, the handshake and ACK mechanism does not exist



3 The clear-to-send mechanism is not set by default in CSMA/CA medium access, which results in the hidden node problem[1]

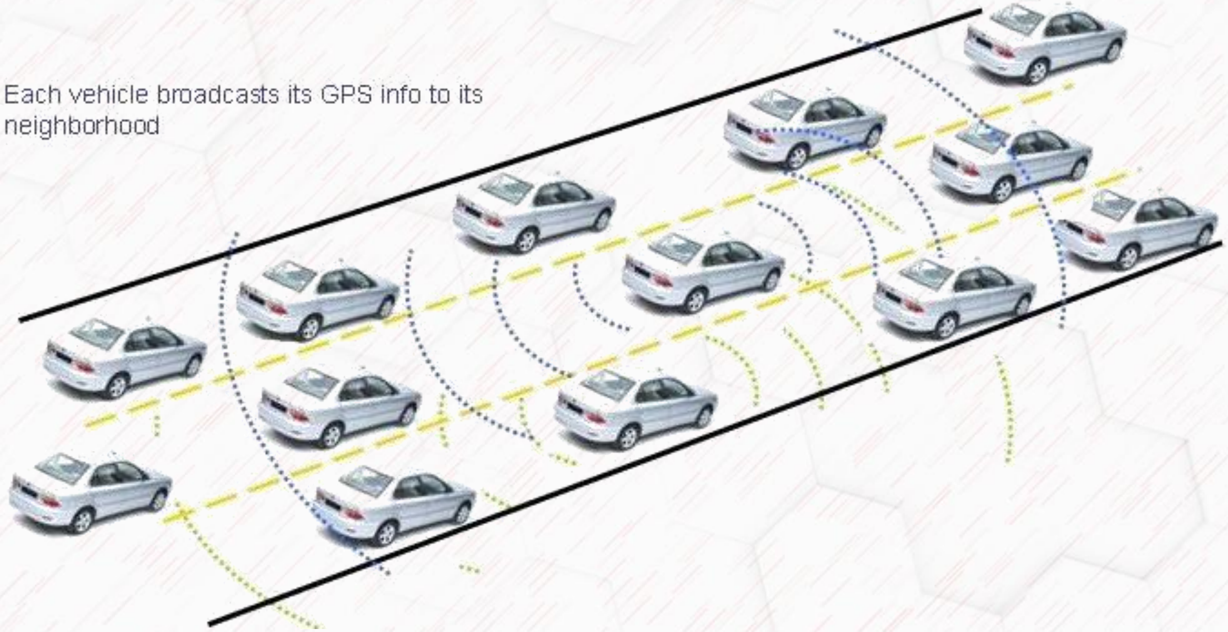
4 This problem results in packet collisions, poor link performance and unreliable broadcast service in high vehicle density scenarios

[1] A Survey of Autonomous Vehicles: Enabling Communication Technologies and Challenges, Nadeem M. et al. (2021)

DSRC: Congestion issues

1. As the number of vehicles increase, the communication load also increases, which cause congestion

2. This congestion leads to delay and packet loss that affects the performance of the network

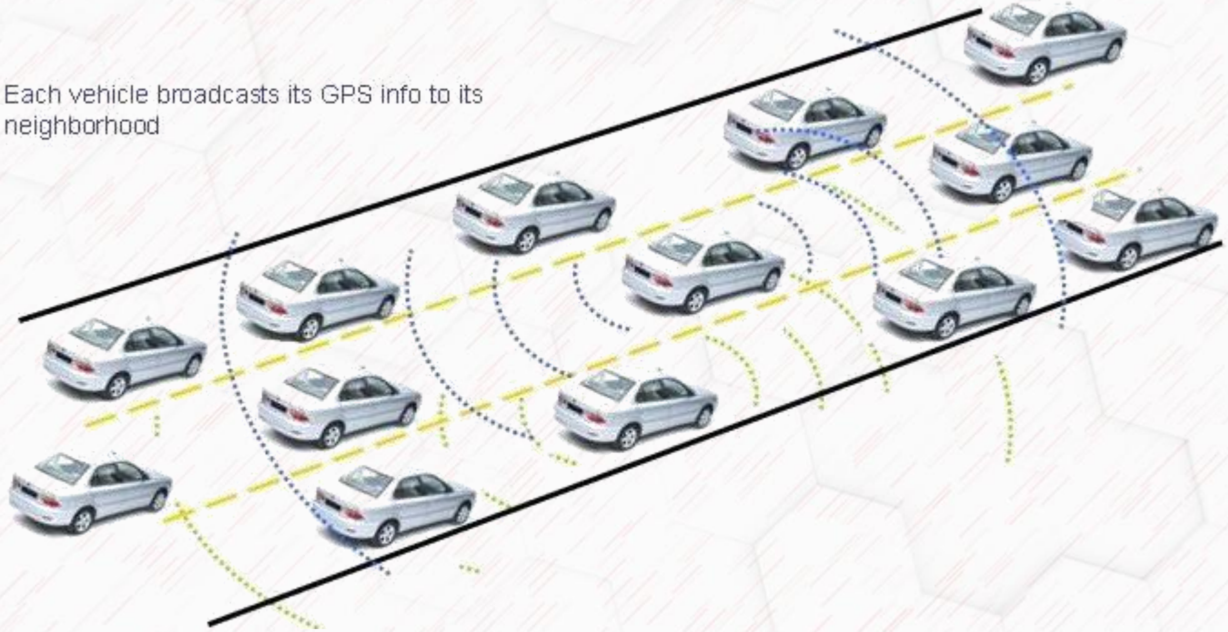


3. The increased number of vehicles also increases the intensity of the channel will result is severe degradation of performance

C-V2X: Congestion issues

1 Cellular base station coverage is much larger than a zone of the relevance of safety messages and as such, many vehicles can receive irrelevant messages

2 These irrelevant messages can be reduced with the help of multicast service by broadcasting messages to the multicast group only

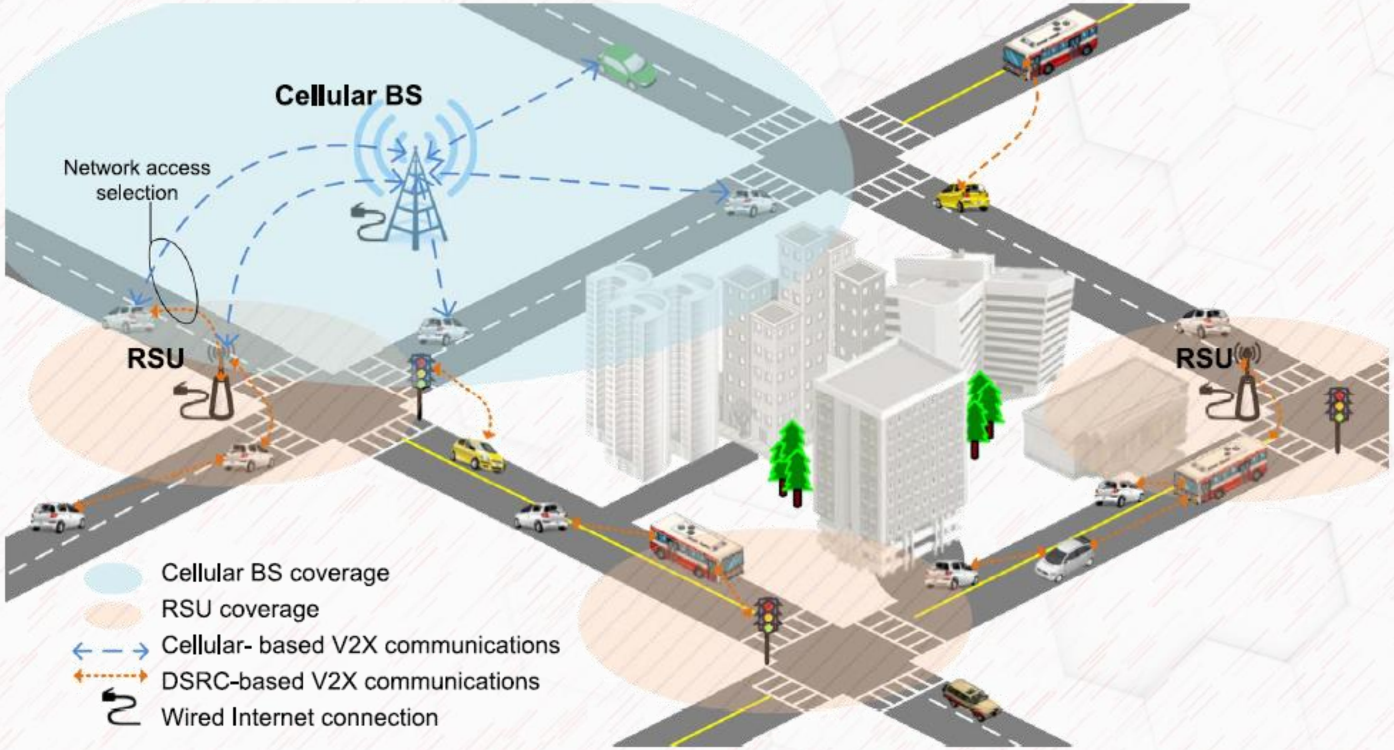


3 Control signaling overhead associated with the join and leave process multicast service of C-V2X can be high

DSRC: Handover issues

1. A vehicle that travels with high speed has to change several network topologies over time.

2. Horizontal handover is the handover of moving vehicles from one RSU to another, whereas vertical handover is handover of a vehicle between different cellular base stations.



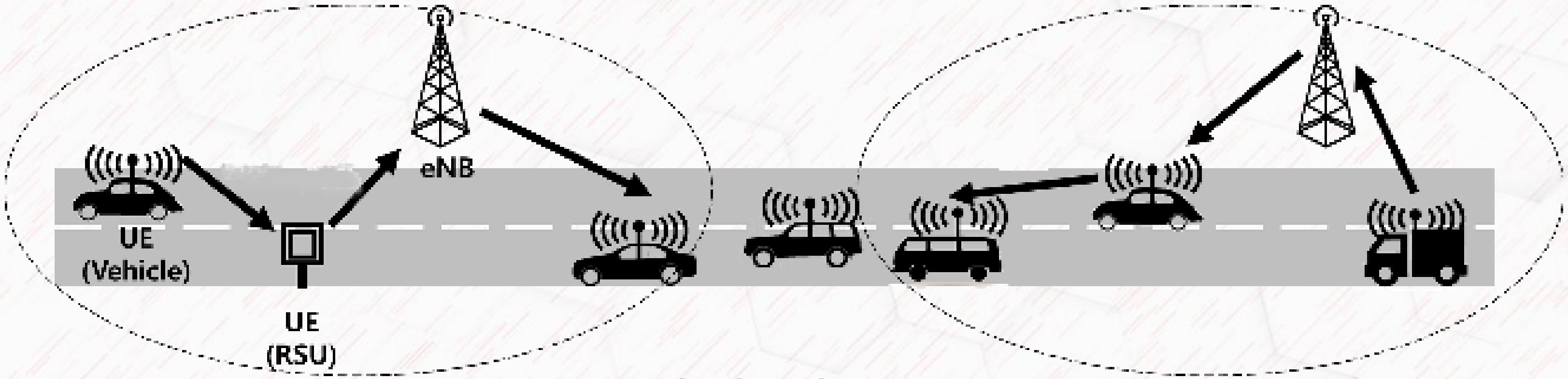
3. A vertical handover takes longer time compared to the horizontal handover. This will result into the hidden terminal problem[1].

[1] A Survey of Autonomous Vehicles: Enabling Communication Technologies and Challenges, Nadeem M. et al. (2021)

C-V2X: Latency issues

1. Due to the centralized control nature of cellular networks, every vehicular data needs to be passed through the BS which limits its applicability to V2V communications with very strict delay requirements

2. In a unicast mode, a vehicle sends its safety message to a cellular BS, which unicasts the message either to every vehicle in the cell or to the relevant vehicles only



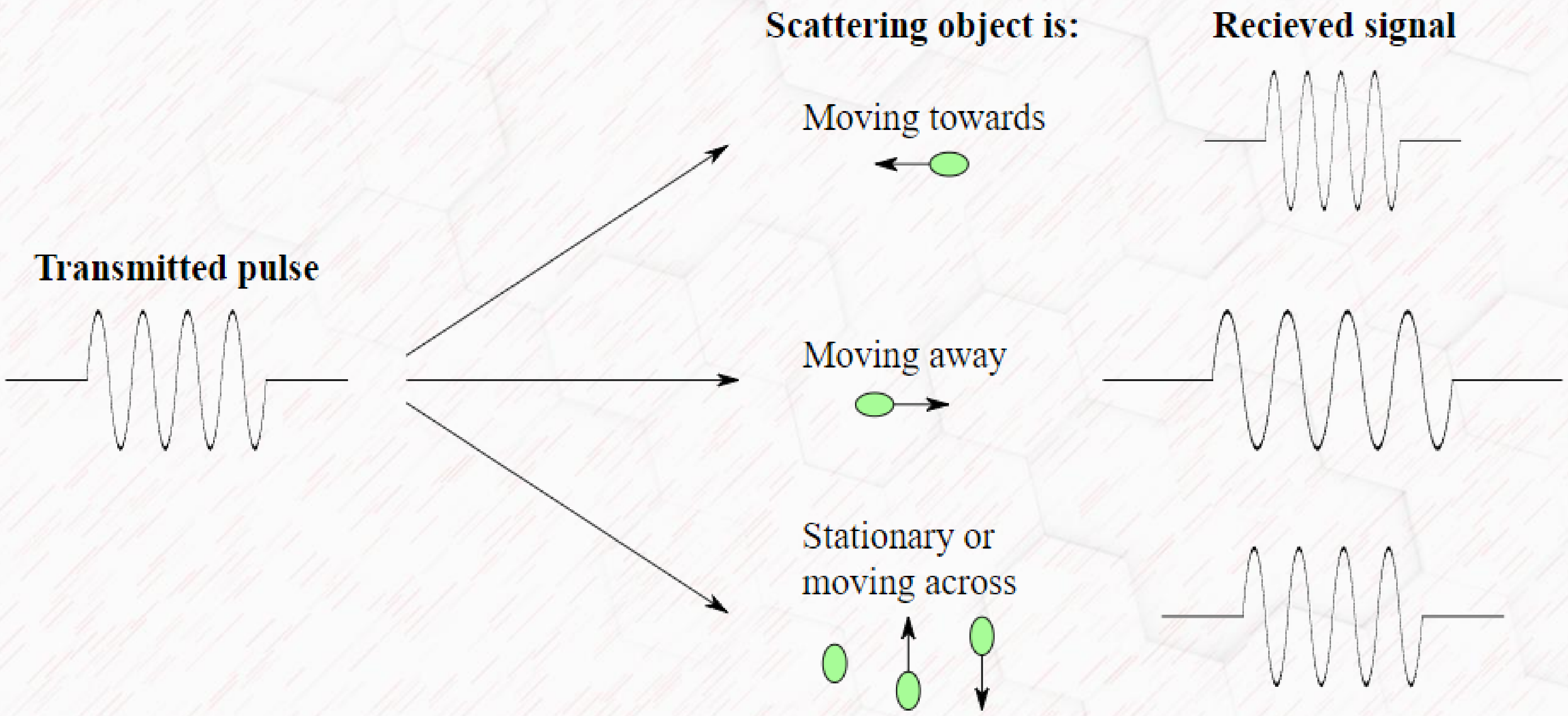
Relay-based V2X

3. Studies show that the downlink channel becomes a bottleneck even when there is a small number of vehicles in the cell leading to latency issues

DSRC: Doppler spread

1 Doppler spread occurs due to the relative motion of transceivers

2 The relative velocities shift the signal frequency and the signal at the receiver is at a different frequency compared to the broadcast signal

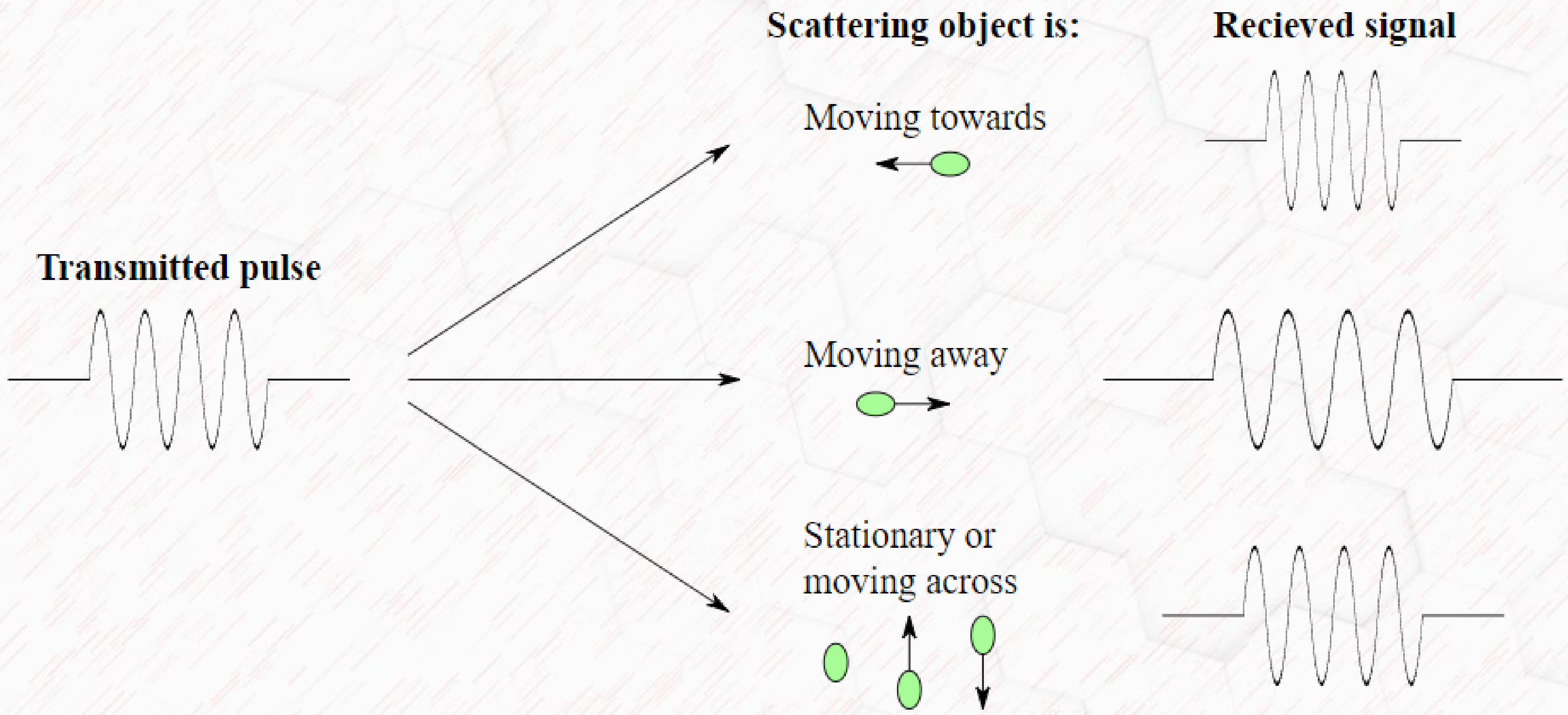


3 The transmitted signal in DSRC technology faces this Doppler shift phenomenon due to vehicle motion on road which will affect predicting the exact location and position of the vehicle

C-V2X: Doppler spread

1 LTE V2X system may be required to support very high carrier frequency up to 6 GHz, and vehicles may achieve high relative velocity when driving at high speed in the opposite direction causing Doppler effects.

2 The Doppler effects can introduce interference among carriers. In addition, short coherence time due to Doppler effects results in an inaccurate channel estimation

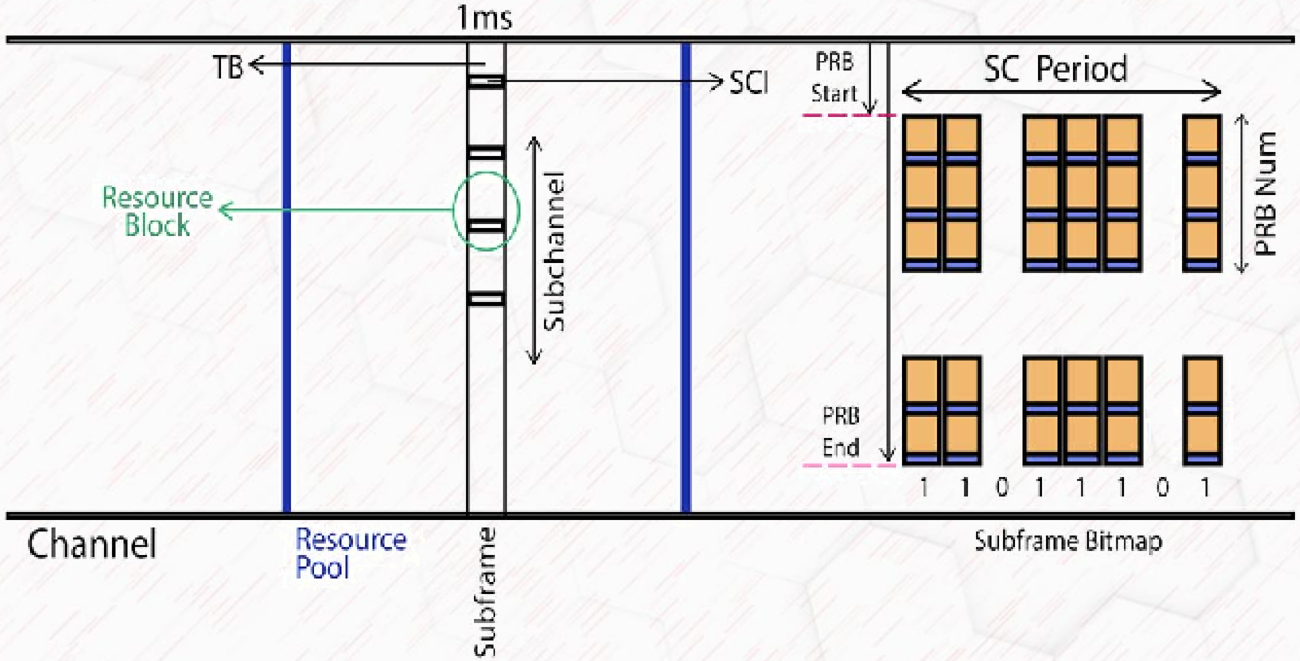


3 If the existing physical layer design of LTE is used for LTE V2X, then the time interval of reference signal will be higher than the coherence time, as a result, the performance for demodulation of data will strongly fall

C-V2X: Resource Allocation Issues

1. Due to a large number of concurrent transmission in dense vehicular traffic scenario, it is essential to efficiently utilize the available resources.

2. In LTE D2D, a number of concurrent transmissions are low compared to vehicular traffic scenarios so LTE D2D resource allocation may not be applicable for V2X traffic



3. Further, due to highly mobile and dense vehicular users in LTE V2X communications, D2D centralized resource allocation may result in extra signaling overhead as UE needs to frequently connect to eNB whereas random resource allocation may result in resource collision due to unilateral bad decisions of vehicular UE

DSRC and C-V2X: Security Vulnerabilities

1 The traffic-related and safety-critical information transferred in the V2X network may be reproduced, falsify or modified by an attacker causing a disastrous effect.

2 An attacker may mimic an authorized entity such as RSU or eNB and may distribute wrong information to nearby vehicles causing a traffic jam and accidents

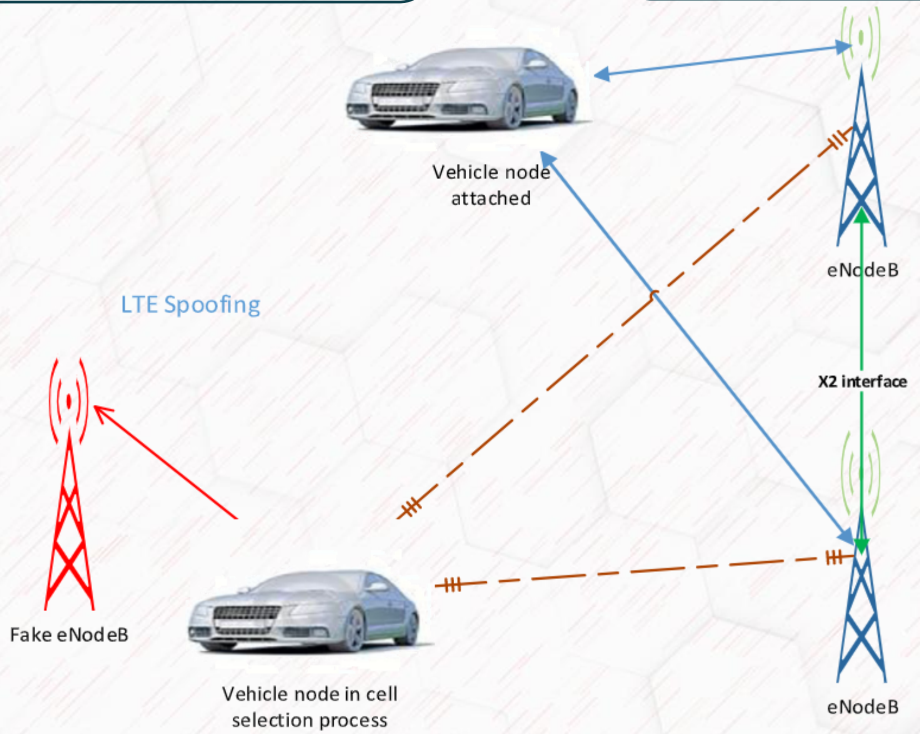


Fig. 9. LTE spoofing attack.

3 LTE V2X communications must satisfy the fundamental security requirements and requirements specific to LTE V2X in order to provide defence against various attacks

Proposed solutions in the literature

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