

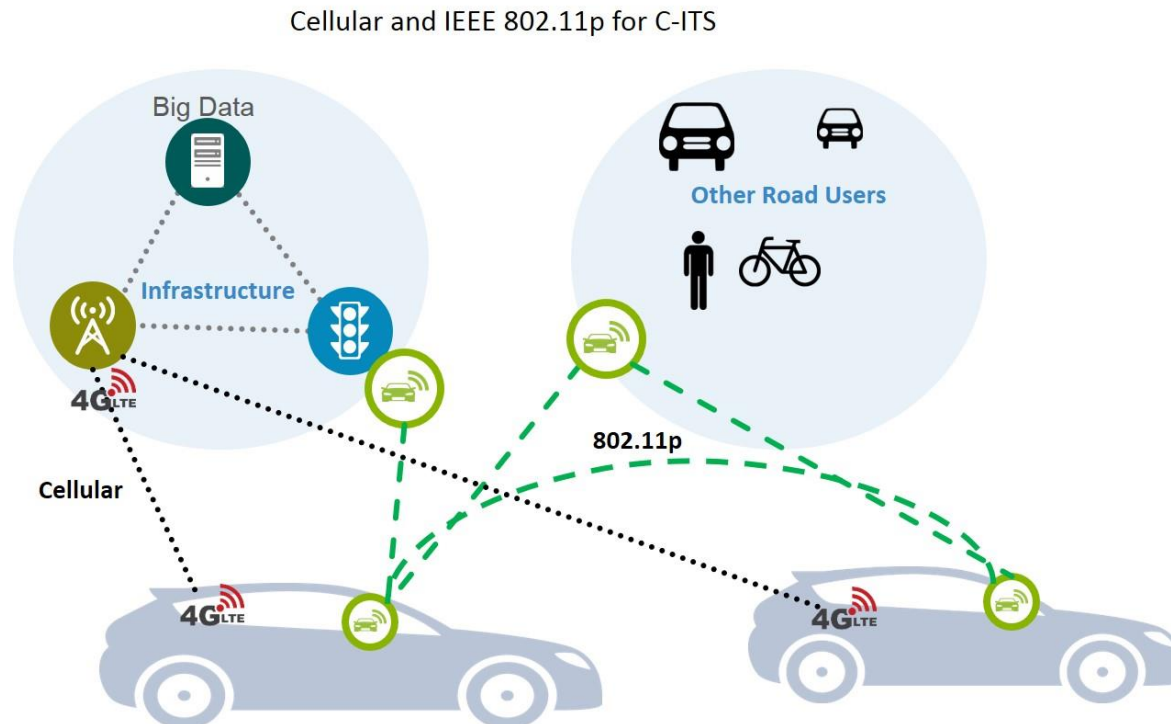


Intelligent Transportation Systems

Rolland Vida, BME TMIT

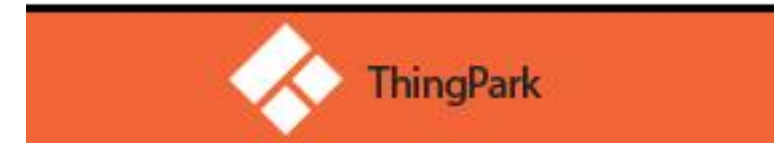
802.11p or LTE

- Requirements for Cooperative ITS systems
 - High relative speeds between transmitters and receivers
 - Extremely low latency in safety-related applications (<50 ms)
 - Tolerate high load generated by periodic transmission of multiple messages, and high vehicle density
 - V2x messages are mostly local in nature, are important for nearby receivers



802.11p or LTE

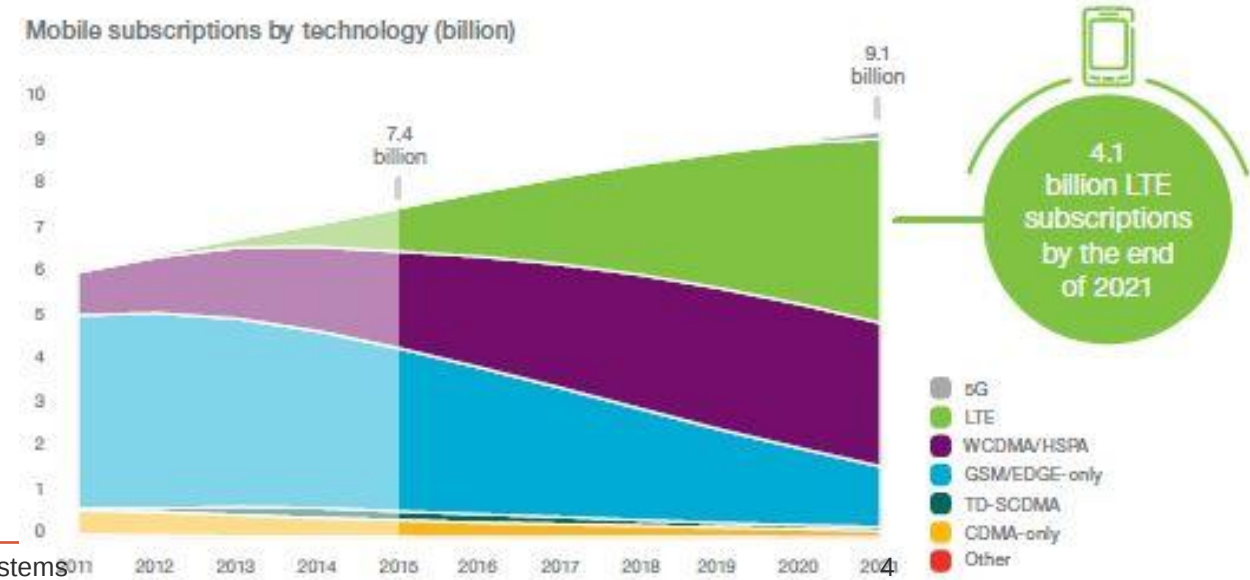
- **802.11p is here today**
 - Standard approved in 2009
 - Several ETSI ITS plug-test events
 - Extensive field trials
 - Safety Pilot, Drive C2X, Score@F, simTD, etc.
- Significant efforts in the last 10 years to validate 802.11p
 - This should be re-done for any other alternative technology



802.11p or LTE

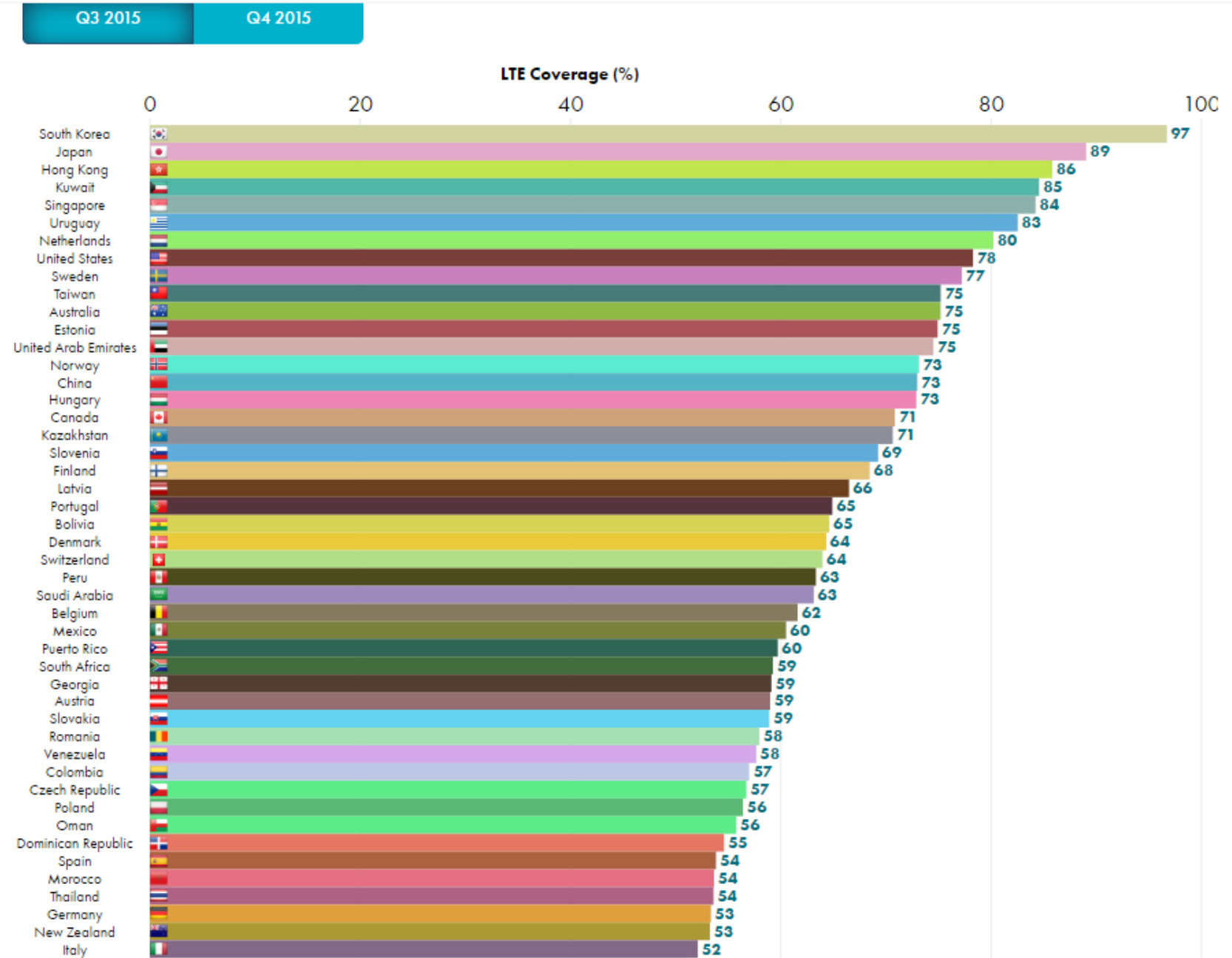
- (Some argue that) Cellular for V2V is still far out
- Cellular technology is by far the most successful wireless standard
 - 4.1 billion LTE subscriptions expected for 2021
- LTE (Rel. 8) dates back to 2009, 5G expected for 2020
 - Extensive cellular infrastructure, it takes time to upgrade
- Current versions of LTE can only address basic ITS use cases
 - No support for low latency and high mobility use cases
 - 3GPP V2x study group established in 2015

*Mobile subscriptions worldwide.
Source: Ericsson Mobility Report, Nov 2015*



State of LTE in 2016

- LTE coverage still far from 100%
- Around 50% is Germany, France, Italy
- Extensive 3G infrastructure



LTE support for V2x applications

- LTE Release 8 can cover most of the V2I – I2V non-safety use cases
- Unclear how it will perform in very congested scenarios
 - evolved Multimedia Broadcast/Multicast Service (eMBMS) in LTE-A (Rel. 9)
 - Designed to support static scenarios – crowds in football stadiums
 - Not efficient when a large number of incoming and outgoing vehicles
- Unclear how handovers between MNOs (mobile network operators) and cooperation between application service providers will be managed
- Is there an I2V business case to justify the large investments?
 - Vehicles traditionally a lower priority for cellular industry
 - 8 billion cellular subscribers, but only 100 million cars per year worldwide

LTE support for V2x applications

- Safety-related use cases represent the real challenge
 - In theory could work, if there is complete coverage along the roads (which is not yet the case)
 - In practice it would need to handle high bandwidth with very low latency, not ready for this
- Some V2V use-cases require **continuous information exchange** (1 – 20 Hz)
 - **Think about cooperative awareness, autonomous cars**
 - Too much data for LTE networks to handle
 - A single car generates 0.5 Gbyte per month (256 bytes/message, 5 Hz, 4 hours of driving/day)
 - At the receiver side, assuming 30 cars in the area of interest, roughly 15 Gbytes per month
 - 1 autonomous car in 2020 – **4 Tbyte per day**
- MNOs typically bill based on resources used (\$ / bit / s), but V2V traffic should be free
 - Alternative business model to be developed to justify investments
- eMBMS might help, but not widely deployed

THE COMING FLOOD OF DATA IN AUTONOMOUS VEHICLES

RADAR
~10-100 KB
PER SECOND

SONAR
~10-100 KB
PER SECOND

GPS
~50KB
PER SECOND

CAMERAS
~20-40 MB
PER SECOND

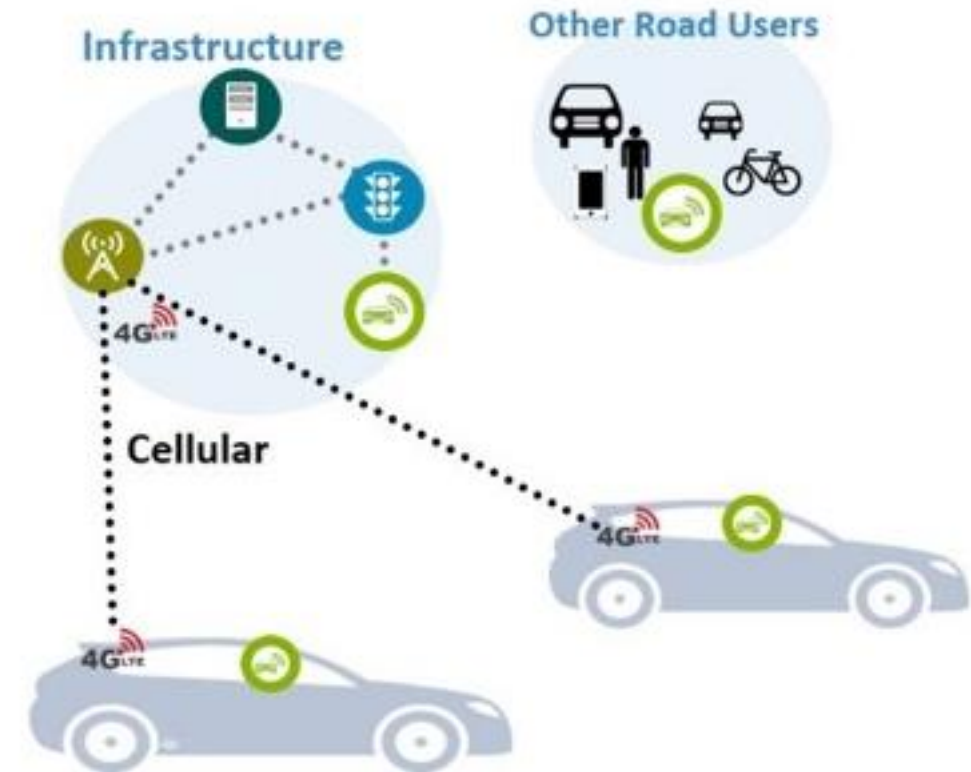
LIDAR
~10-70 MB
PER SECOND

AUTONOMOUS VEHICLES
4,000 GB
PER DAY... EACH DAY



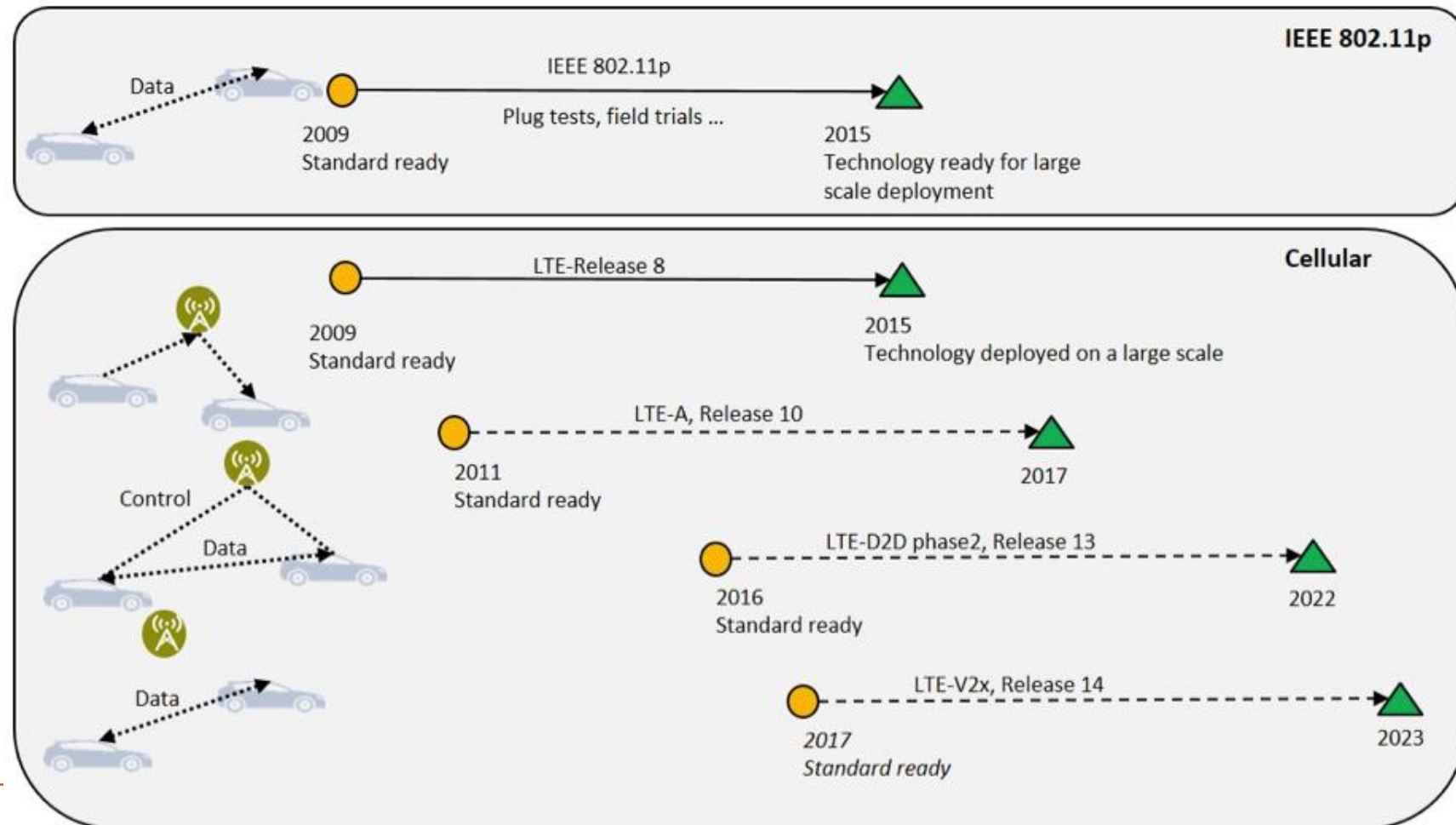
LTE support for V2x applications

- Some V2V use cases do not require high bandwidth, but **very low latency**
 - event-based broadcasting of Decentralized Environmental Notification messages (DENM)
- Could work in the cellular network, but not always
 - Across multiple MNOs, across borders, across cells
- **Another solution: develop direct communication technology, as part of the cellular system**
 - **Device-to-Device** communication, part of Release 12, but not suitable for V2V
 - If two devices want to communicate directly, the network allocates the time / frequency resources
 - The network manages the interference generated by the D2D communication
 - Signalling/control via the eNodeB
 - Direct data sending between the UEs
 - D2D will not work if no continuous network coverage



Timeline for cellular V2x

- 3GPP will surely find the technical solution, the question is **"when?"**
 - LTE-V2x probably in release 14, 15, by the end of 2017
 - Much time ahead until large scale deployment



V2x in 5G

- V2x probably part of 5G
 - Fundamentally redesigned hardware to support the architectural changes
 - Not before 2020

5G roadmap
Source: 5G Infrastructure
Public Private Partnership
(5G-PPP), 2015

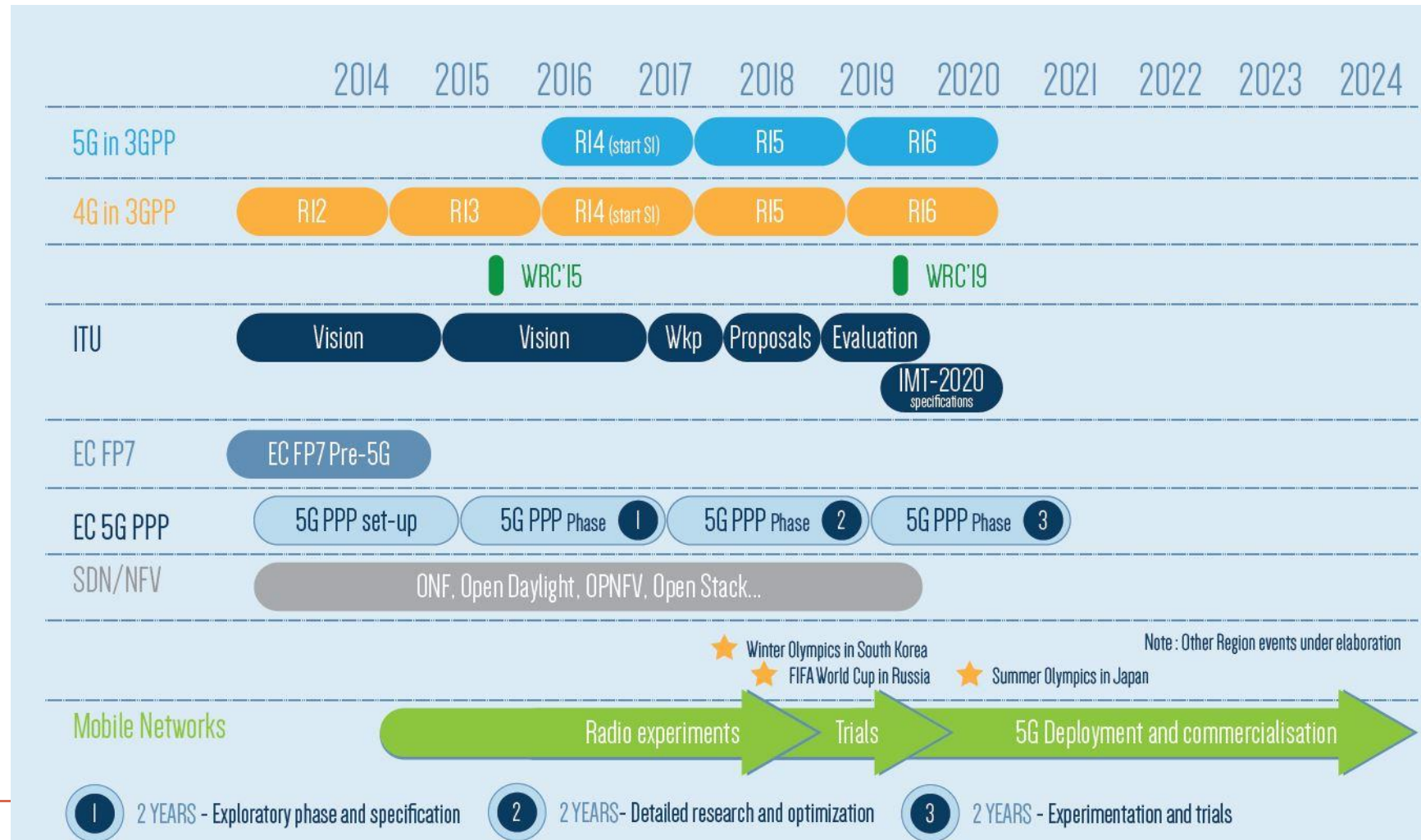


FIGURE 4. 5G ROADMAP

Taxonomy of ITS Use Cases

Vehicle-to-X

Non-Safety

Safety

Comfort

Traffic Information
Systems

Situation
Awareness

Warning
Messages

Contextual
Information

Entertainment

Optimal
Speed
Advisory

Congestion,
Accident
Information

Adaptive
Cruise Control

Blind Spot
Warning

Traffic Light
Violation

Electronic
Brake Light



Taxonomy of Use Cases

Vehicle-to-X

Non-Safety

Many messages

High data rate

Low latency demands

Low reliability demands

Safety

Few messages

Small packet size

High latency demands

High reliability demands

Diversity of requirements

Application	Latency	Reliability	# Vehicles	Area	Persistence
Information Query	★	★	★★★★	★★★★	
Hazard Warning	★★★★	★★	★★	★★★★	
ACC, el. Brake Light	★★★★	★★	★	★	
Cooperative Awareness	★★	★★★★	★	★	★
Intersection Assistance	★★	★★★★	★★	★★	★
Platooning	★★★★	★★★★	★★	★	★

[1] T. L. Willke, P. Tientrakool, and N. F. Maxemchuk, "A Survey of Inter-Vehicle Communication Protocols and Their Applications," IEEE Communications Surveys and Tutorials, vol. 11 (2), pp. 3-20, 2009

Freeway $\Leftrightarrow$ Urban

- 1D mobility
 - Bimodal connectivity
 - Stable connection
(vehicles on same lane)
 - AND
 - unstable connection
(vehicles on opposite lane)
 - High speed
 - ...
- 2D mobility
 - Bipolar connectivity
 - Many neighbors
(when standing)
 - OR
 - Few neighbors
(when driving)
 - Obstacles
 - ...

Convergence towards heterogeneous approaches

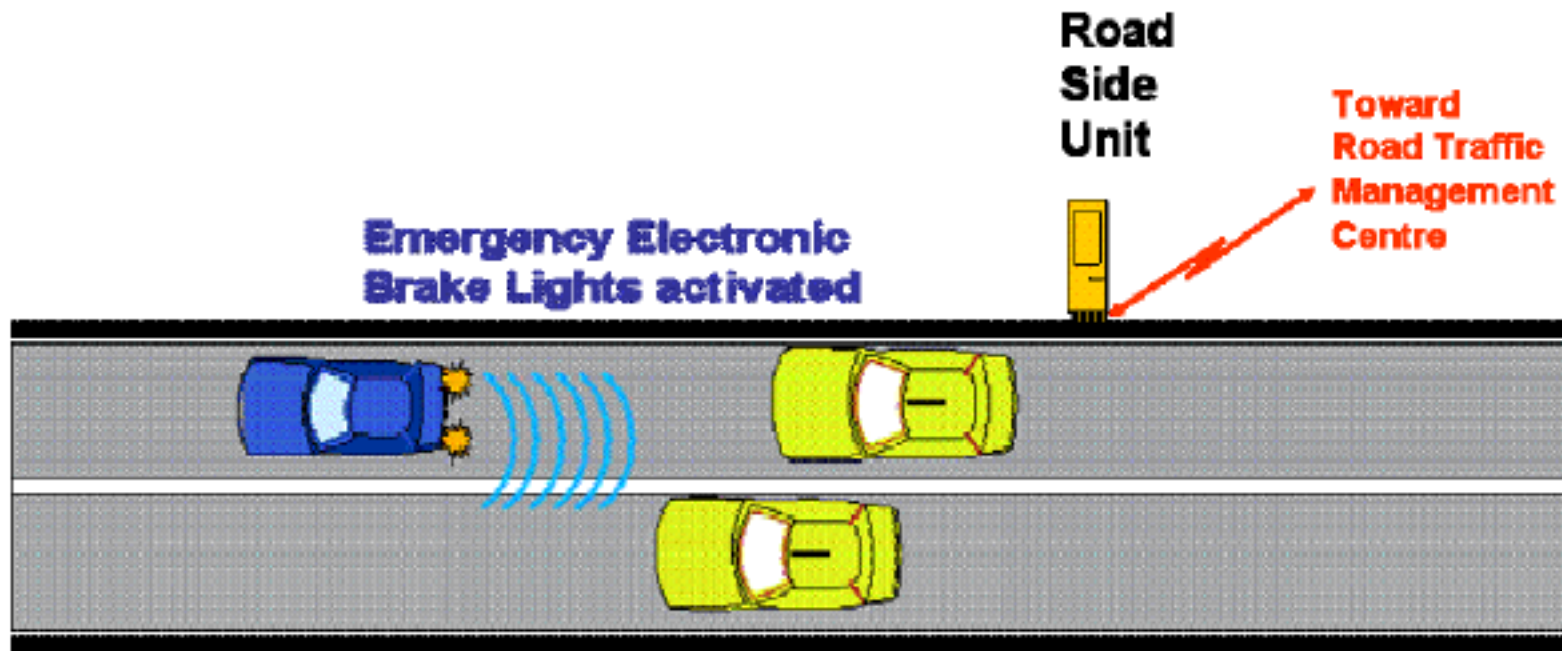
- Same system needs to work in multiple environments
 - Vehicle starts to drive in city with infrastructure support
 - Continues driving on freeway (still with infrastructure support)
 - Loses infrastructure support when turning onto local highway
 - Finishes driving in city without infrastructure support

ITS use cases

- Basic Set of Applications
 - Defined by ETSI (ETSI TR 102 638)

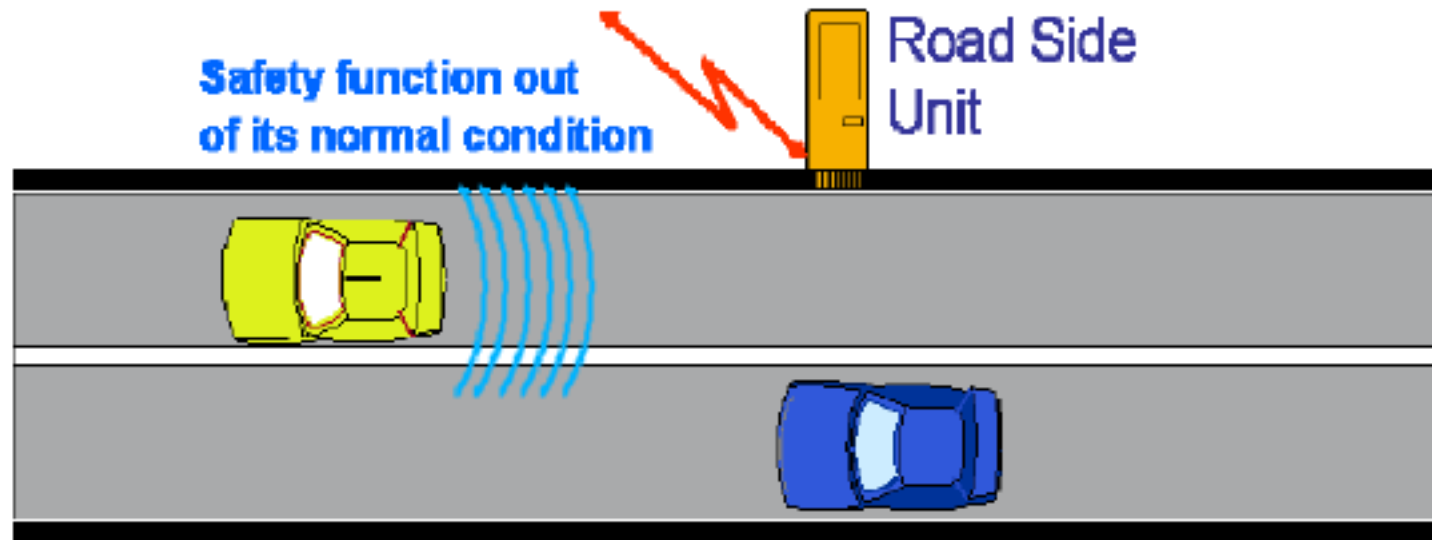
Vehicle Status Warnings

- **Emergency Electronic Brake Lights**
 - **Application name:** Road hazard warning.
 - A vehicle signals its hard braking to its local followers
 - Minimum frequency of periodic message 10 Hz



Vehicle Status Warnings

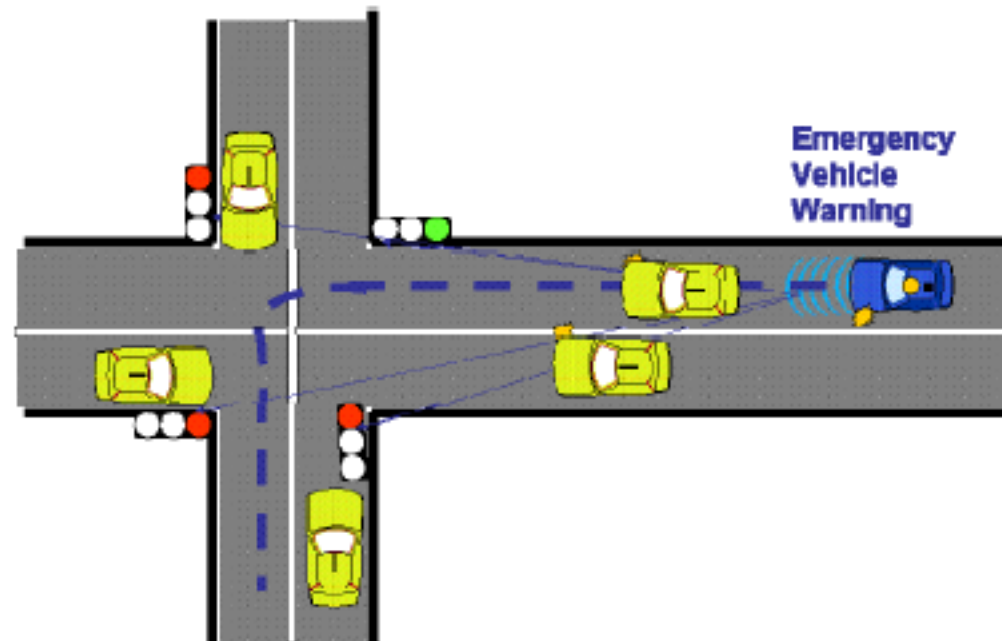
- **Safety function out of normal condition warning**
 - **Application name:** Road hazard warning.
 - a vehicle detecting a safety function (steering, braking, etc.) being out of its normal condition and presenting dangers to others to signal to them this abnormal vehicle state
 - Minimum frequency of periodic message 1 Hz



Vehicle type warnings

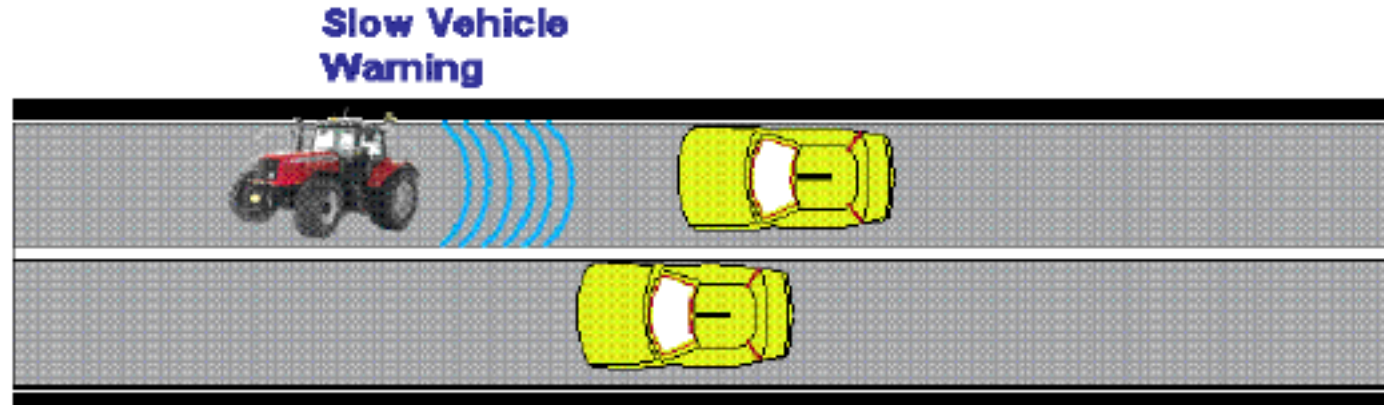
- **Emergency vehicle warning**

- **Application name:** Co-operative awareness
- Allows an active emergency vehicle to indicate its presence
- Minimum frequency of V2X co-operative awareness messages issued by the emergency vehicle: 10 Hz
- Specific use case security requirement: protection and authentication of the CAM message



Vehicle type warnings

- **Slow vehicle warning**
 - **Application name:** Co-operative awareness
 - any slow vehicle to signal its presence (vehicle type) to other vehicles
 - Minimum frequency of the periodic message: 2 Hz.



Vehicle type warnings

- **Motorcycle warning**

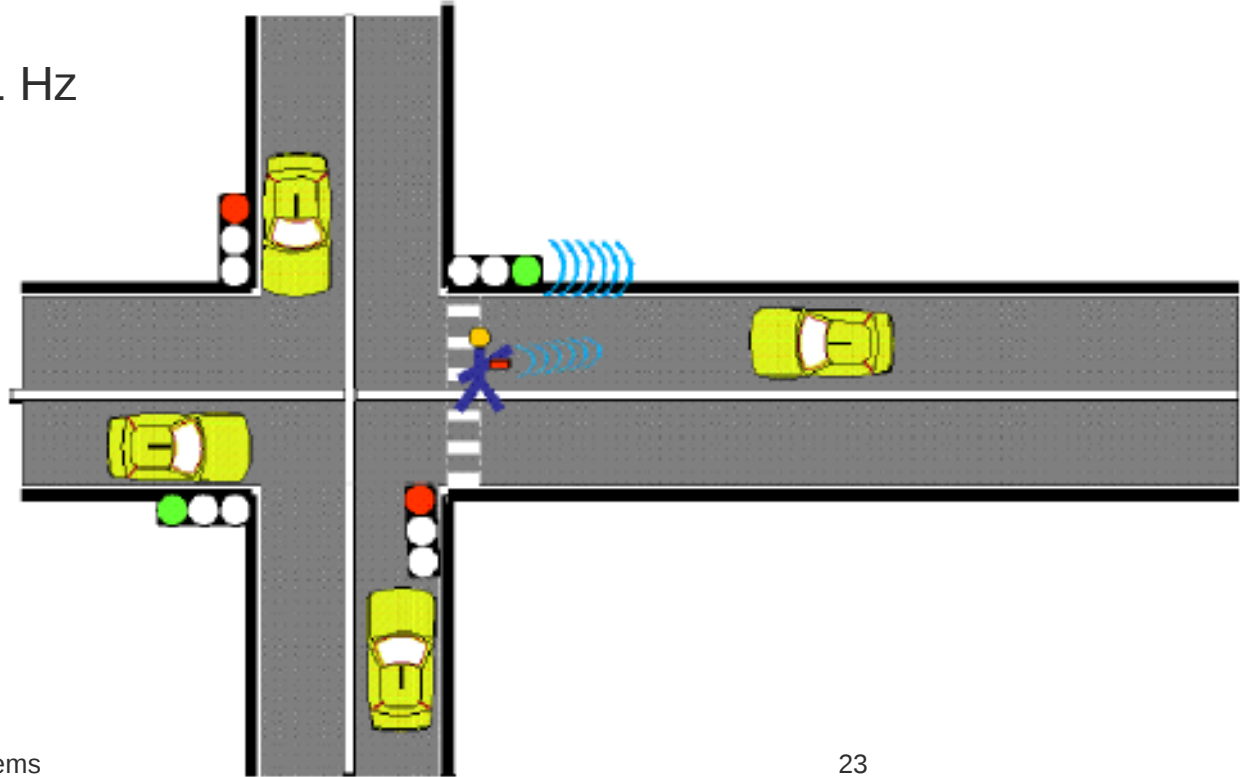
- **Application name:** Co-operative awareness
- Warn driver for arriving motorcycle. This is especially useful in case of reduced visibility
- Road side unit to be installed if line of sight between vehicles is obstructed. RSU must be capable to relay signal or to detect and signal a collision risk.
- Minimum frequency of V2V co-operation awareness messages: 2 Hz.



Vehicle type warnings

- **Vulnerable road user Warning**

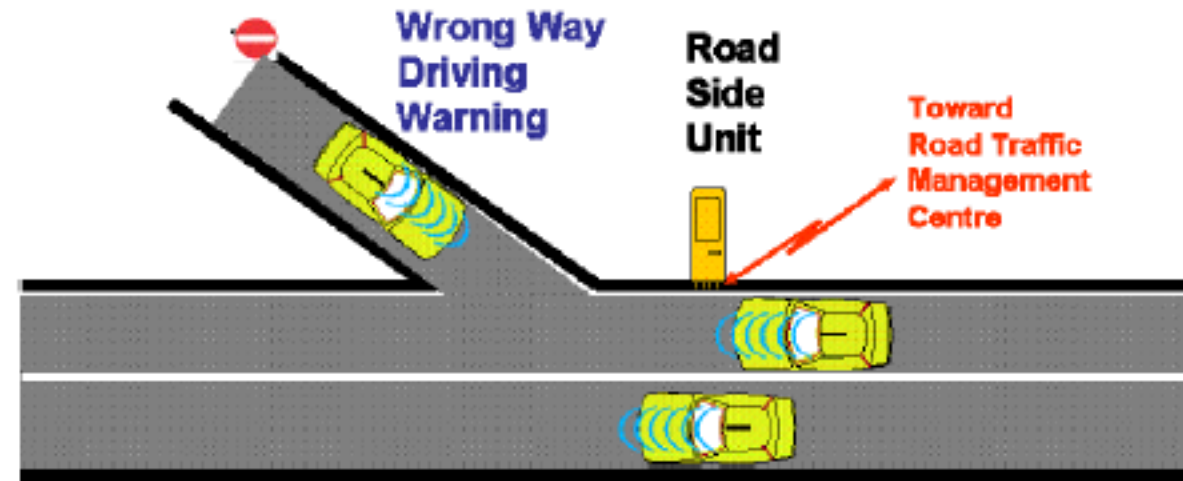
- **Application name:** Co-operative collision avoidance or mitigation.
- Provides warning to vehicles of the presence of vulnerable road users, e.g. pedestrian or cyclist, in case of dangerous situation
- Capability for a human equipped with relevant device or for a road side unit equipped with relevant system to broadcast I2V co-operative awareness messages providing information on the presence, trajectory and speed of a vulnerable road user.
- Minimum CAMs frequency of the vulnerable user: 1 Hz



Traffic hazard warnings

▪ Wrong way driving warning

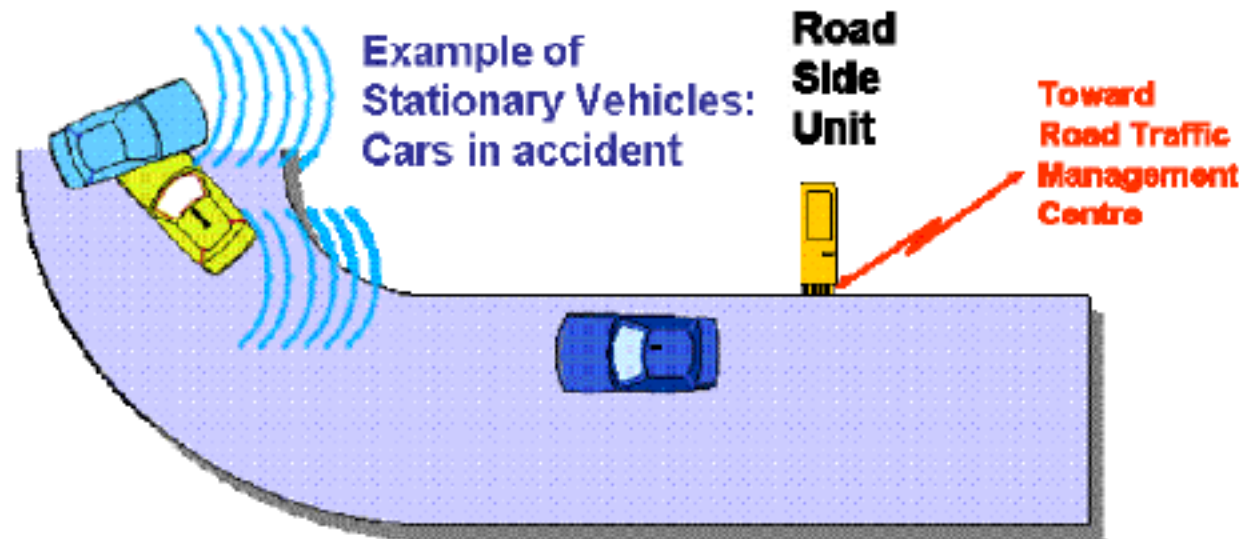
- indicates to vehicles in the affected area that a vehicle is driving against the planned direction of traffic
 - This form of driver behaviour may be a violation of local laws and require identification of the vehicle and driver by the appropriate authority
- Limit as much as possible frontal collisions due to wrong way driving.
- Capability for a vehicle, to detect that it is driven in a wrong way and to broadcast in V2X decentralized environmental notification messages its current "wrong way heading" status
- Minimum frequency of the periodic message: 10 Hz.



Traffic hazard warnings

▪ Stationary vehicle warning

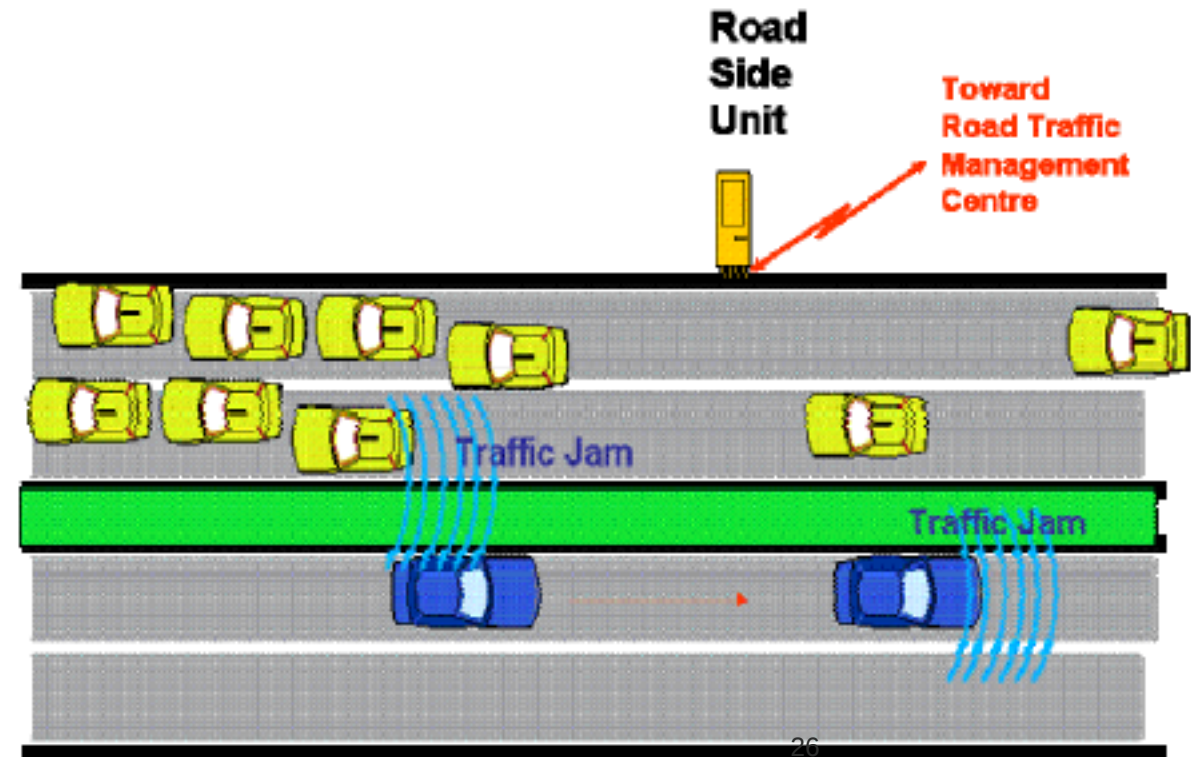
- Any vehicle being dangerously immobilized on the road (consecutive to an accident, a breakdown or any other reason) to alert other approaching vehicles of the risk for them associated to this dangerous situation
- Minimum frequency of the periodic message: 10 Hz.



Traffic hazard warnings

▪ Traffic condition warning

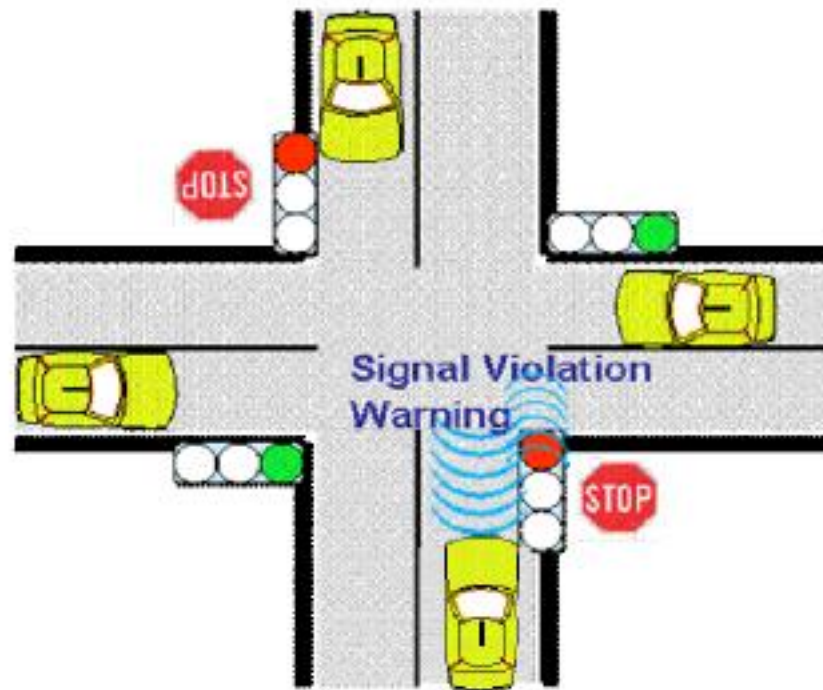
- Any vehicle or roadside station to signal to other vehicles the current traffic condition (e.g., traffic jam)
- Such data may be propagated by the ITS network as authoritative traffic management messages in order to mitigate the impact of the traffic condition on traffic flow
- Capabilities for all vehicles crossing the car signalling a traffic jam to store and forward received V2X decentralized environmental notification messages according to their geocasting parameters
- Minimum frequency of the periodic message: 1 Hz.



Traffic hazard warnings

- **Signal violation warning**

- allows a detecting ITS station (most likely a road side unit) to signal to affected users that a vehicle has violated a road signal and increased the risk of an accident
 - This form of driver behaviour may be a violation of local laws and require identification of the vehicle and driver by the appropriate authority.
- Minimum frequency of C2X decentralized environmental notification messages: 10 Hz.



Traffic hazard warnings

- **Roadwork warning**

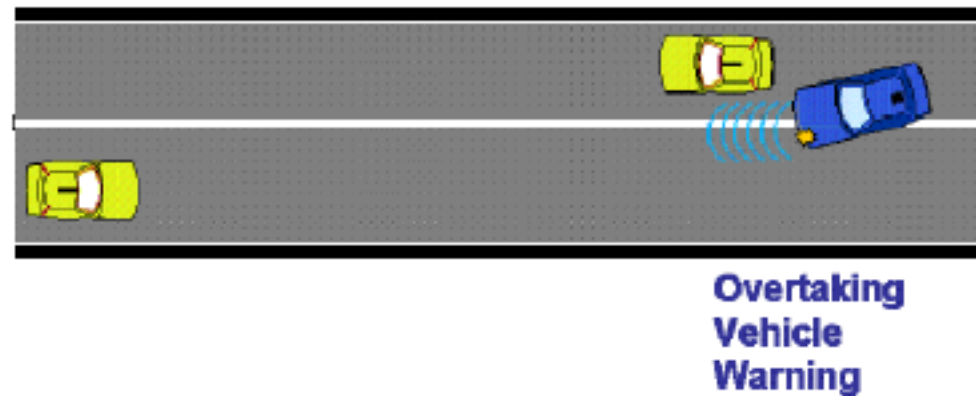
- Via road infrastructure to vehicle communication, provides information on current valid roadwork and associated constraints
- Capabilities for concerned vehicles to store and forward according to geocasting messages cancel rules, I2V decentralized environmental notification messages
- Minimum frequency of the periodic message: 2 Hz.



Dynamic vehicle warnings

- **Overtaking vehicle warning**

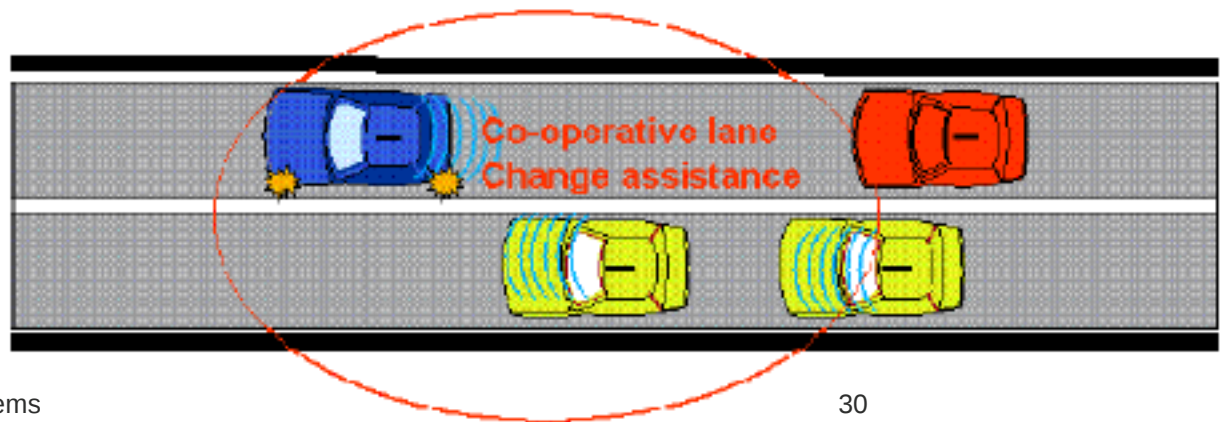
- **Application name:** Co-operative awareness.
- An overtaking (passing) vehicle signals its action to other local vehicles to secure the overtaking situation
- Requires accurate positioning of vehicles on digital map
- Minimum frequency of the periodic message: 10 Hz.



Dynamic vehicle warnings

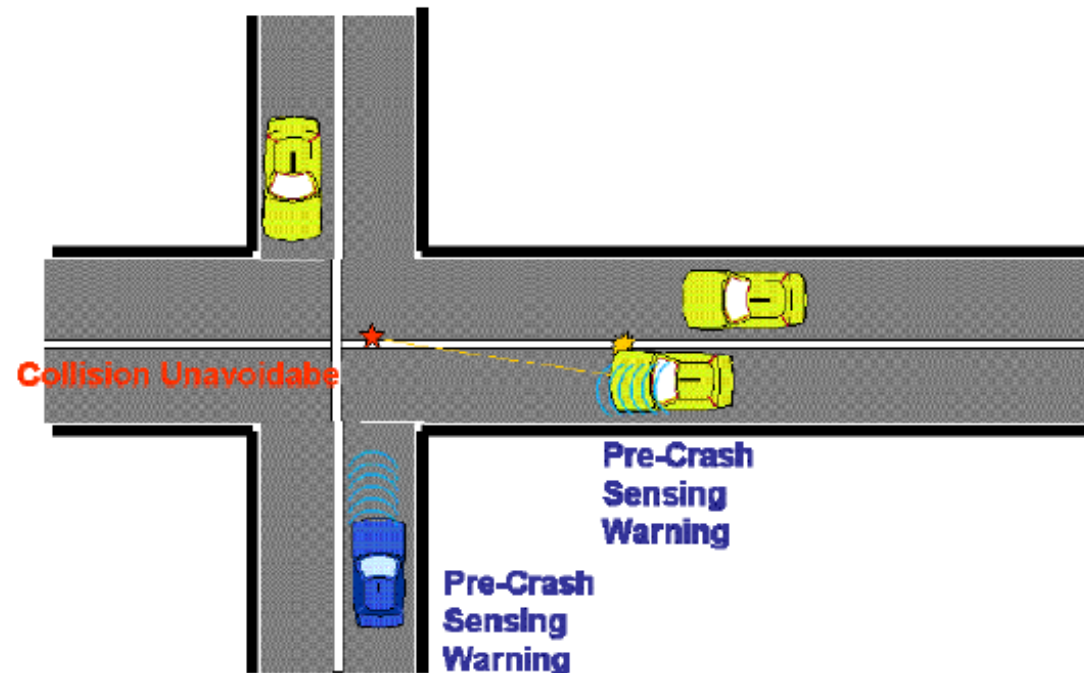
▪ Lane change assistance

- Provides the driver assistance by giving information about cars on the neighbouring lane and facilitating this change through V2V co-operation
- Capability for a vehicle to broadcast V2X co-operative awareness messages indicating a lane change.
- Capability for this vehicle to co-operate in some manner with other vehicles involved in a lane change situation.
- Minimum duration of the total exchange: according to the respective vehicles speeds and transmission ranges.
- Minimum frequency of V2V co-operation awareness messages: 10 Hz.
- Vehicles relative positioning accuracy: at least equal to 2 m.



Dynamic vehicle warnings

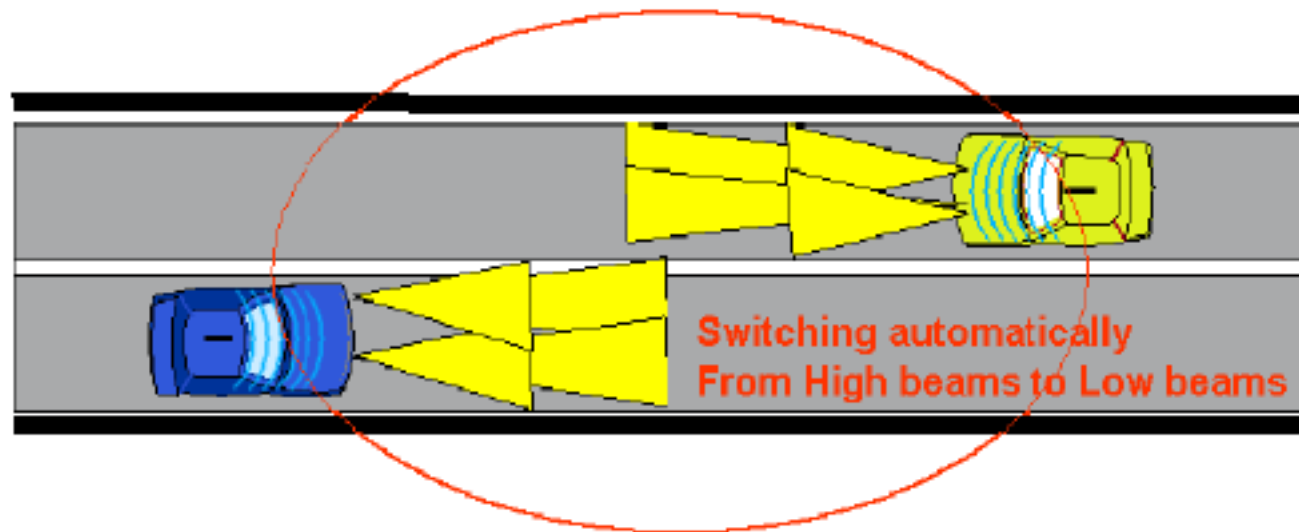
- Pre-crash sensing warning
 - **Application name:** Co-operative collision avoidance or mitigation.
 - Prepare for imminent and unavoidable collision by exchanging vehicles attributes after unavoidable crash is detected
 - Minimum frequency of CAMs: 10 Hz.
 - Maximum latency time: 50 ms. (for the other applications is usually 100 ms)



Dynamic vehicle warnings

- **Co-operative glare reduction**

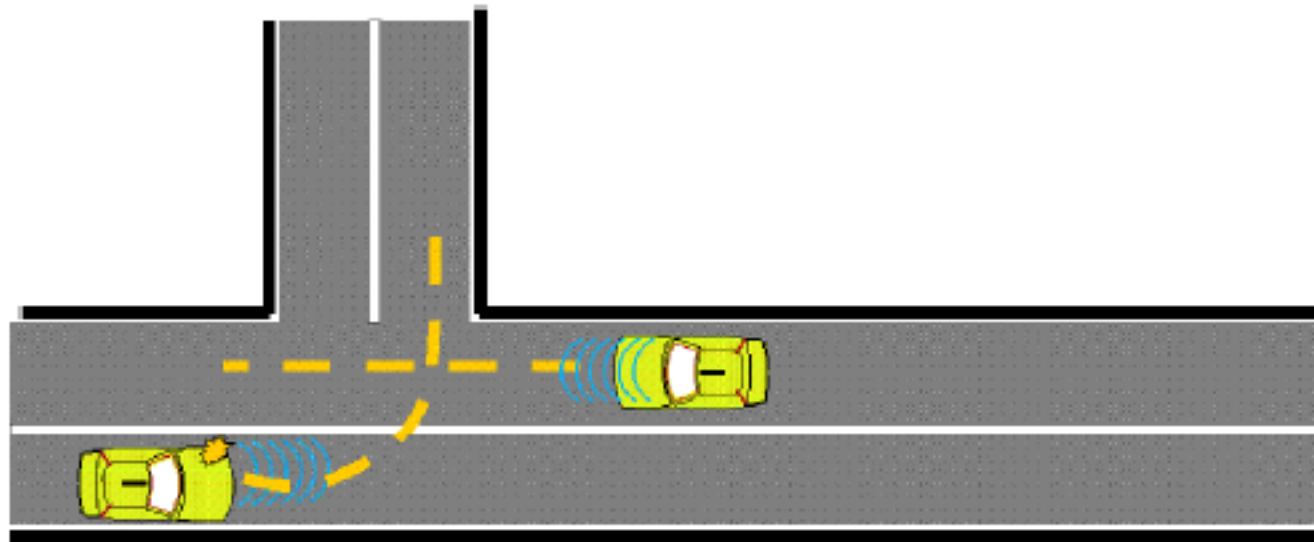
- **Application name:** Co-operative awareness.
- Enable a capable vehicle from automatically switching from high-beams to low-beams when detecting a vehicle arriving in the opposite direction
- Minimum frequency of V2V co-operation awareness messages: 2 Hz
- Vehicles relative positioning accuracy: at least equal to 20 m



Collision Risk Warning

- **Across traffic turn collision risk warning**

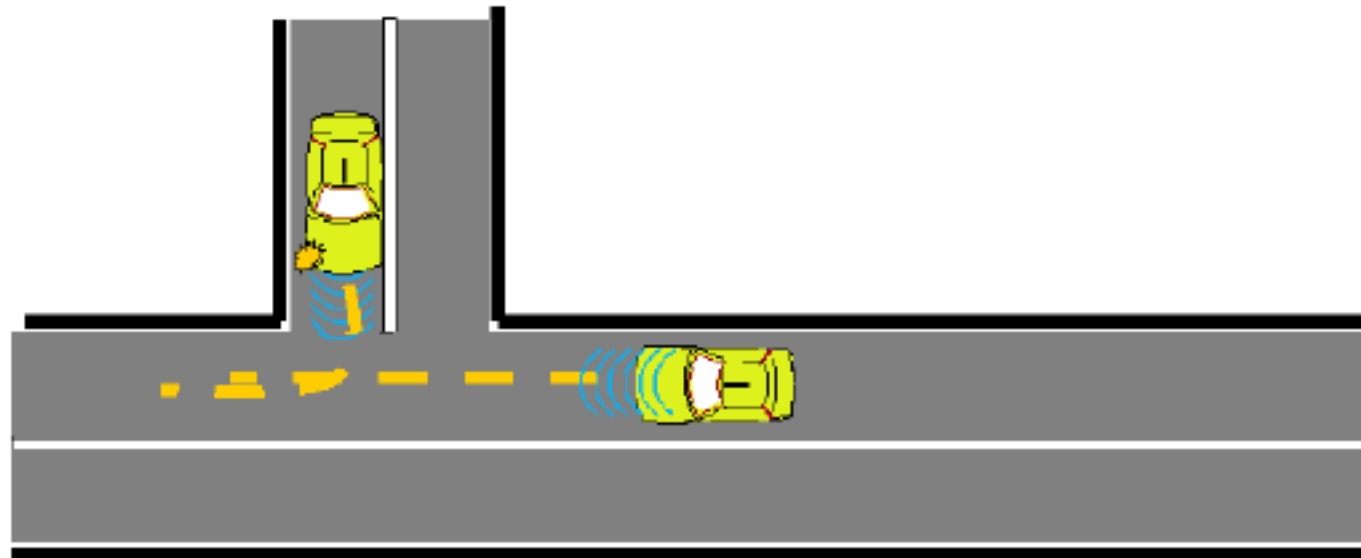
- **Application name:** Co-operative collision avoidance or mitigation.
- inform approaching vehicles that a vehicle (the transmitting vehicle) is intending to turn across traffic
- An indication of turning does not authorize the turning vehicle to turn and national laws will apply.
- Minimum frequency of the CAMs: 10 Hz.



Collision Risk Warning

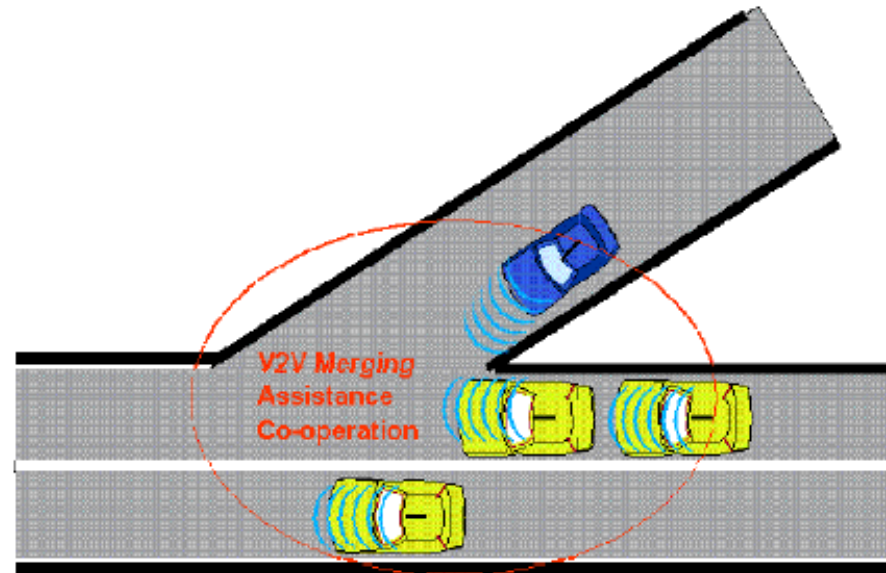
▪ Merging Traffic Turn Collision Risk Warning

- **Application name:** Co-operative collision avoidance or mitigation.
- Provide information of presence, position and movement of incoming vehicles from left side, turning right.
- Road side unit to be installed if line of sight between vehicles is obstructed. RSU needs to be capable to relay signal or to detect and signal a collision risk
- Minimum frequency of the CAMs: 10 Hz.



Collision Risk Warning

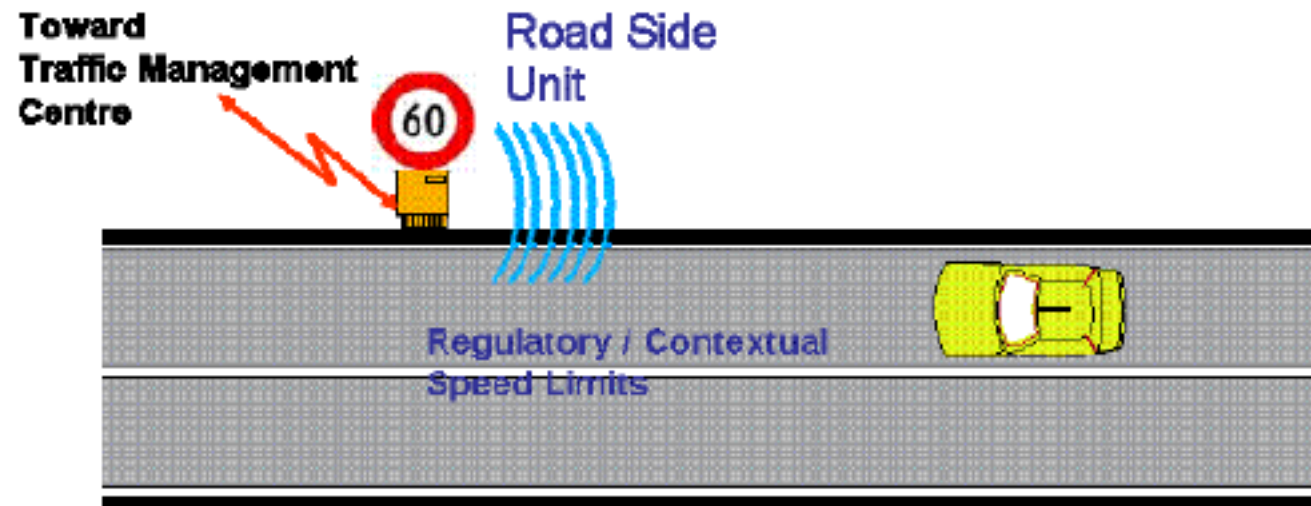
- Co-operative merging assistance
- **Application name:** Co-operative awareness.
- Vehicles involved in a merging negotiate together the merging process to avoid collision
- Road side unit to be installed if line of sight between vehicles is obstructed. RSU needs to be capable to relay signal or to detect and signal a collision risk.
- Minimum frequency of V2V Co-operation Awareness messages: 10 Hz
- Vehicles relative positioning accuracy: at least equal to 2 m



Traffic Efficiency

- **Regulatory/contextual speed limits**

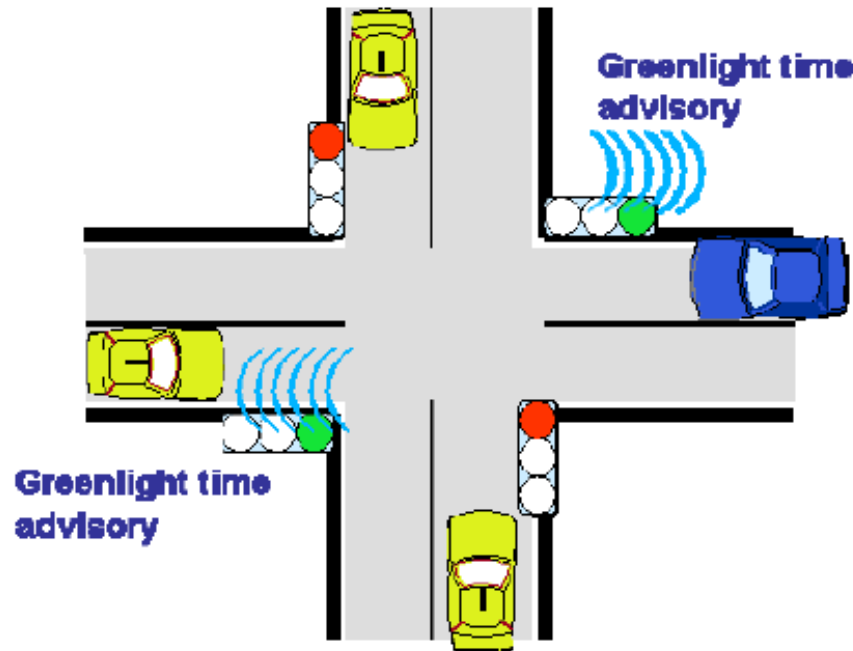
- **Application name:** Co-operative traffic management.
- A capable Road Side Unit to broadcast at a given frequency the current local speed limits (regulatory and contextual)



Traffic Efficiency

- **Traffic light optimal speed advisory**

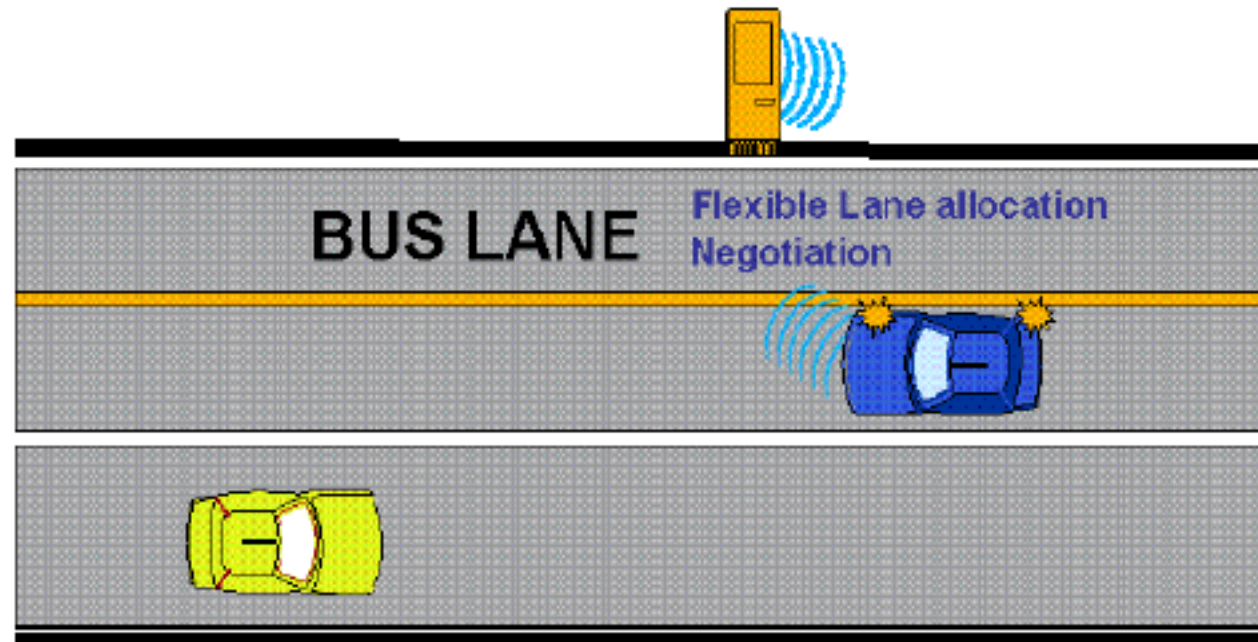
- **Application name:** Co-operative traffic management.
- a traffic light to broadcast timing data associated to its current state (e.g. time remaining before switching between green, amber, red).
- Minimum frequency of the periodic message: 2 Hz.
- Minimum duration of the Reception: according to the vehicle speed and transmission range
- Minimum positioning accuracy: better than 5 m.



Traffic Efficiency

▪ Co-operative flexible lane change

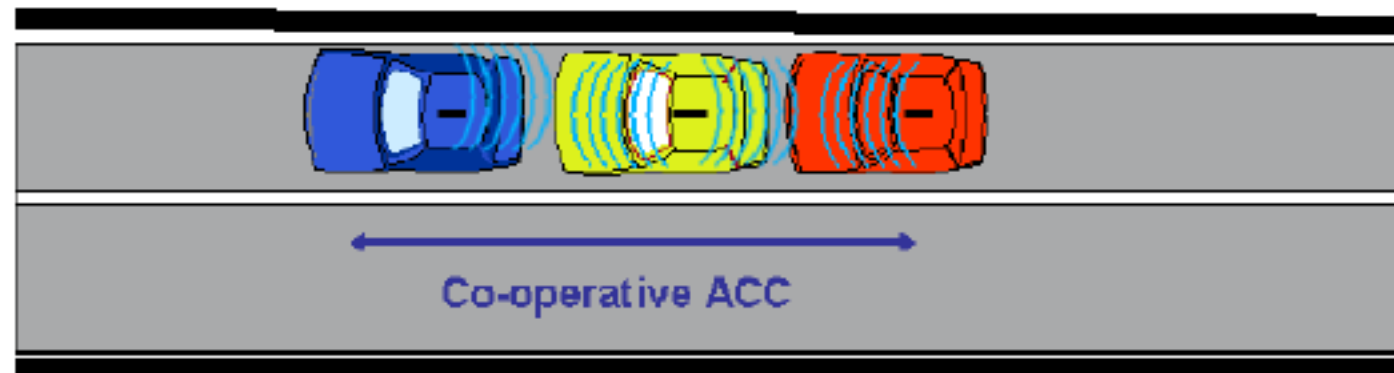
- considers the flexible allocation of a dedicated lane (e.g. reserved to public transport) to some vehicles which get a permanent or temporary access right under specific conditions (e.g. if no bus is present).
- Capability for vehicles to receive and process messages and signal to its driver if can use or not the local specific lane (e.g. according to its vehicle type, its propulsion energy, its number of occupants, its mission, etc.).
- Maximum latency time: 500 ms.
- Minimum frequency of V2V co-operation awareness messages: 1 Hz



Traffic Efficiency

- **Co-operative adaptative cruise control**

- the use of V2X co-operative awareness messages and unicast exchanges to obtain lead vehicle dynamics and general traffic ahead in order to enhance the performances of current ACC
- Maximum latency time: 100 ms.
- Minimum frequency of V2V co-operation awareness messages: 2 Hz.



Traffic Efficiency

- **Co-operative vehicle-highway automation system (Platoon)**

- the use of V2X co-operative awareness messages and unicast exchanges for vehicles to operate safely as a platoon on a highway or specific lane.
- Movement of a platoon of vehicles without drivers (only the leading one). A good example is the transfer of electrical shared vehicles from one place to another at low speed.
- Minimum frequency of V2V co-operation awareness messages: 2 Hz.
- Vehicles relative positioning accuracy better than 2 m.

