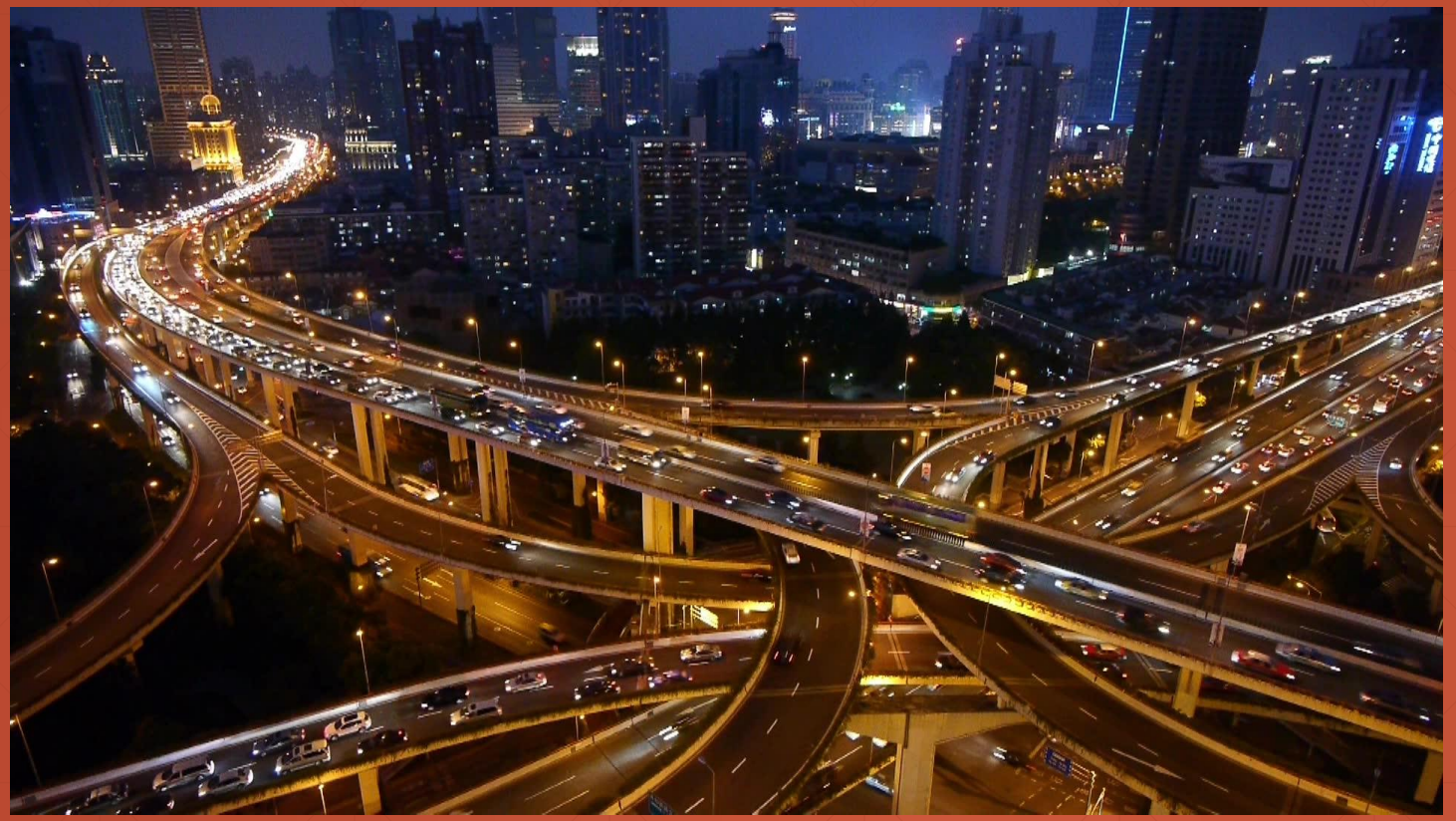


Intelligent Transportation Systems

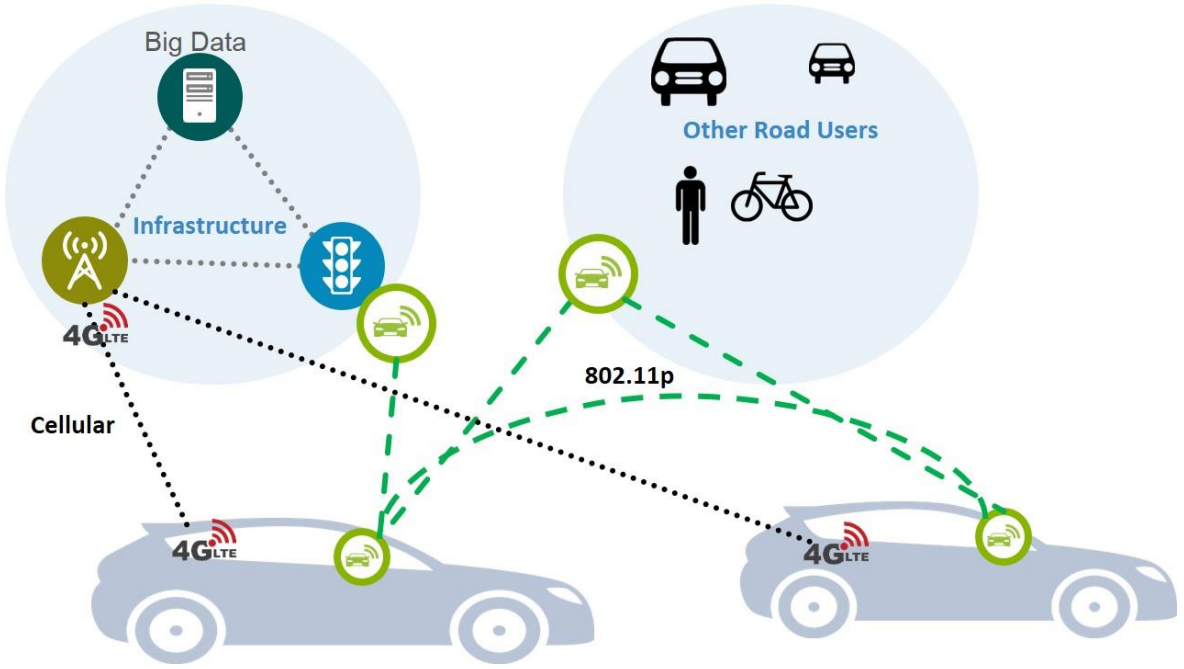
Rolland Vida, BME TMIT

802.11p or C-V2x?

- 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

C-V2x: Cellular Vehicle to Everything

Cellular and IEEE 802.11p for C-ITS



802.11p or C-V2x

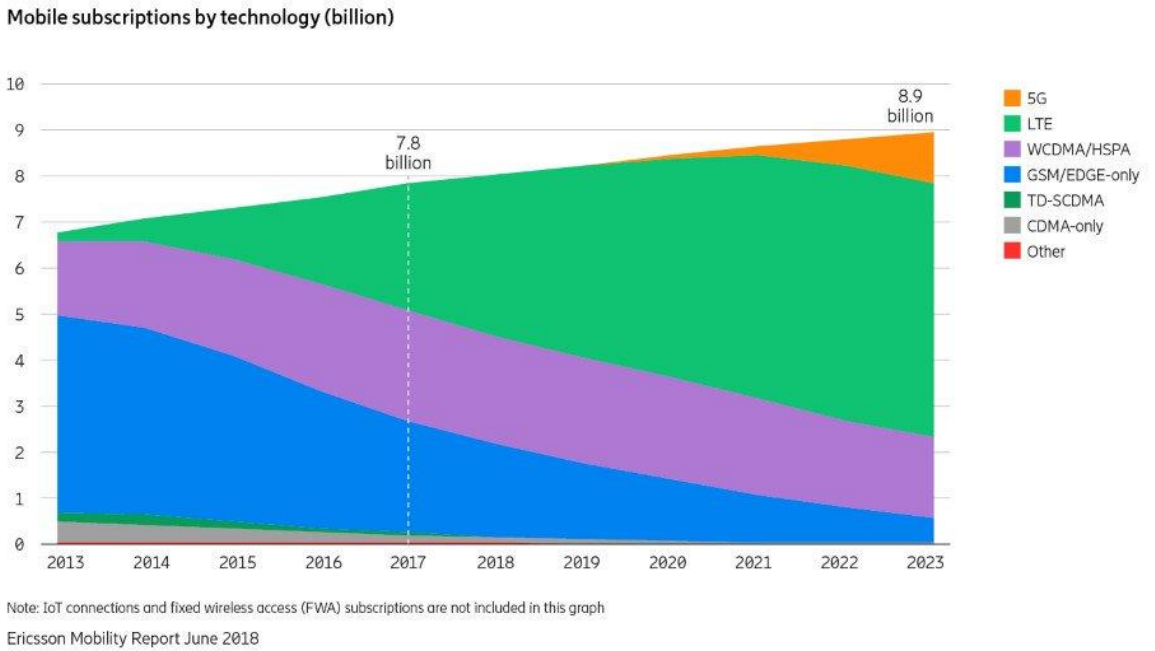
- **802.11p is here today**
  - Standard approved in 2009
  - Several ETSI ITS plug-test events
  - Extensive field trials
    - Safety Pilot, Drive C2X, Score@F, simTD, etc.

- Significant efforts in the last 10 years to validate 802.11p
  - This should be re-done for any other alternative technology

802.11p or C-V2x

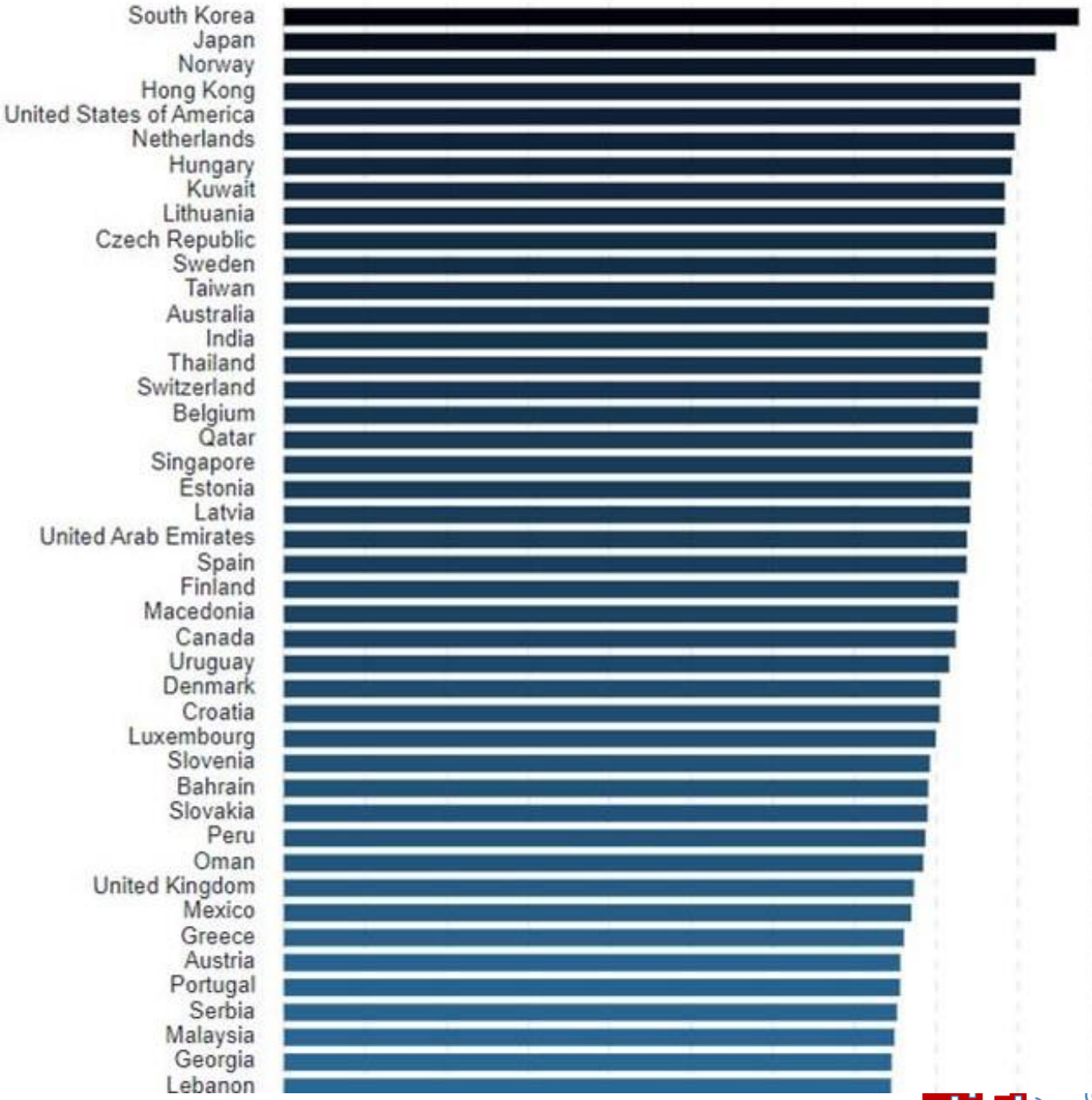
- **Some argue that Cellular-V2x is still far out**
- Cellular technology is by far the most successful wireless standard
  - 5.5 billion mobile broadband subscriptions in Q2 2018
- LTE (Rel. 8) dates back to 2009, 5G expected for 2020
  - Extensive cellular infrastructure, it takes time to upgrade
  - ~ 5.5 billion LTE subscribers still in 2023
- LTE Rel. 8. 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, June 2018



State of LTE in 2018

- LTE coverage still far from 100%
  - Not geographic coverage, but percentage of time when LTE signal available to users
  - Around 85-68% in Germany, France
  - 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 could 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

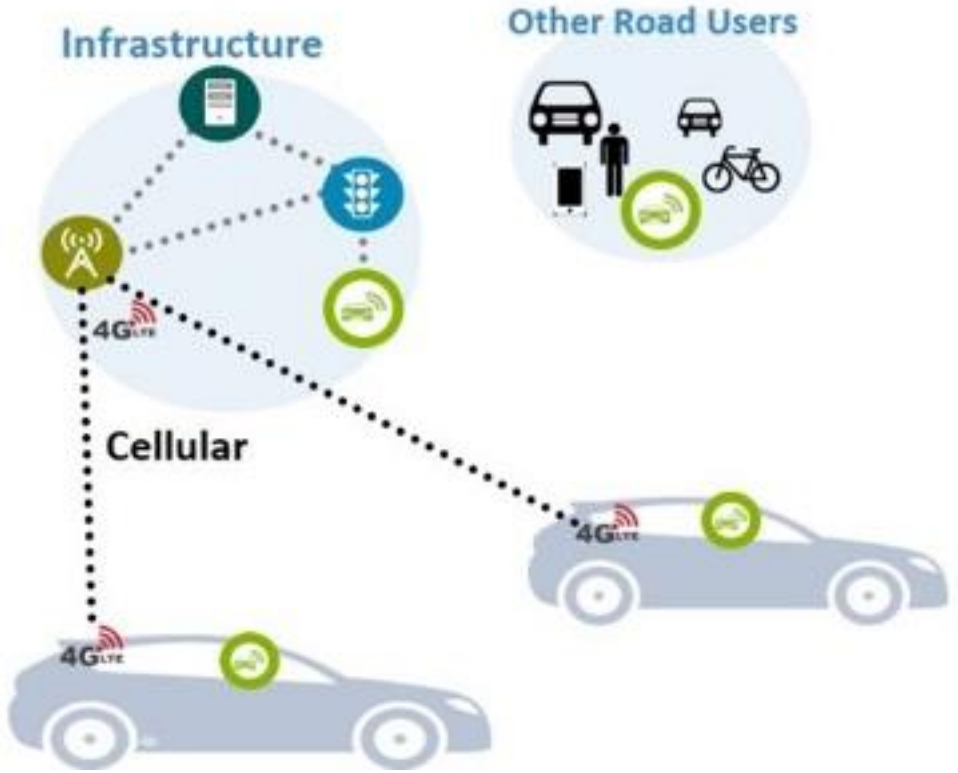
LTE support for V2x applications

- 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
    - **Example: 256 bytes/message, 10 Hz, 2 hours of driving/day = 0.5 Gbyte per month per car**
    - **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 (generated inside the car, not transmitted)**
- MNOs typically bill based on resources used ($ / bit / s), but V2V traffic should be free
  - Alternative business model to be developed to justify investments

THE COMING FLOOD OF DATA IN AUTONOMOUS VEHICLES

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



C-V2x evolution

- LTE-D2D – Release 12 (2012)
- C-V2x Phase I– Release 14 (started in 2014, publihed in 2016)
  - V2V, V2I, V2N support
- C-V2x Phase II – Release 15 (published in 2018)
  - 5G support (called also 5G-V2x)
- C-V2x Phase III – Release 16 (expected for 2019-2020)
  - Enhanced 5G support

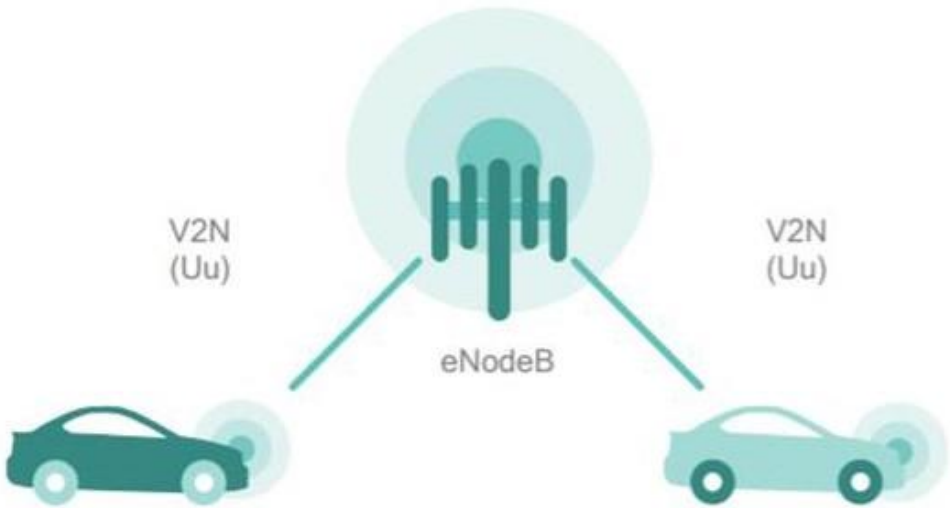
C-V2X defines two complementary transmission modes

Network communications

V2N on “Uu” interface operates in traditional mobile broadband licensed spectrum

Uu interface

e.g. accident 2 kilometer ahead



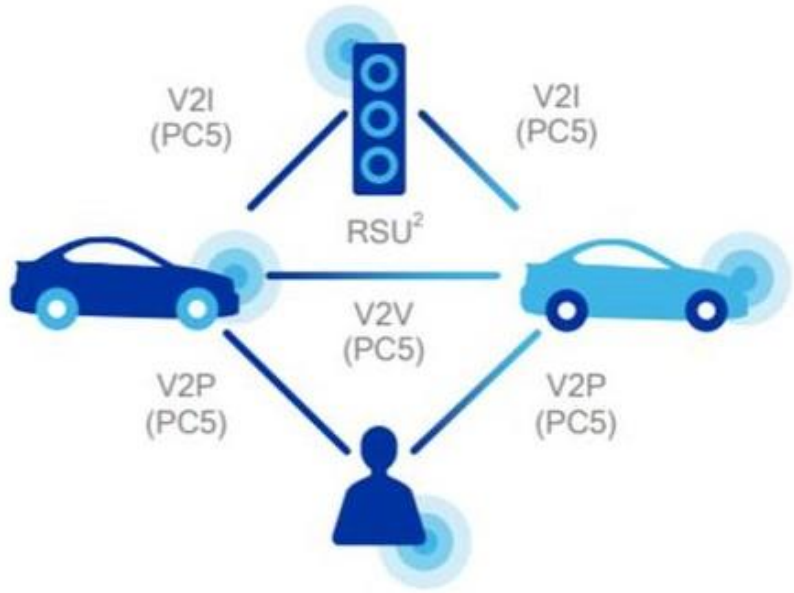
On the traditional cellular spectrum

Direct communications

V2V, V2I, and V2P on “PC5” interface[1], operating in ITS bands (e.g. ITS 5.9 GHz) independent of cellular network

PC5 interface

e.g. location, speed



On 5,9 GHz

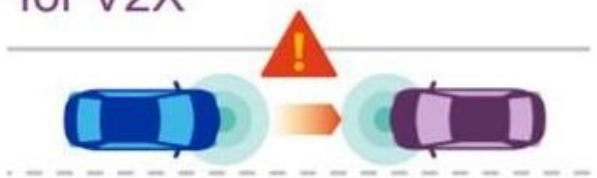
Continuous V2X technology evolution required

And careful spectrum planning to support this evolution

Evolution to 5G,
while maintaining backward compatibility

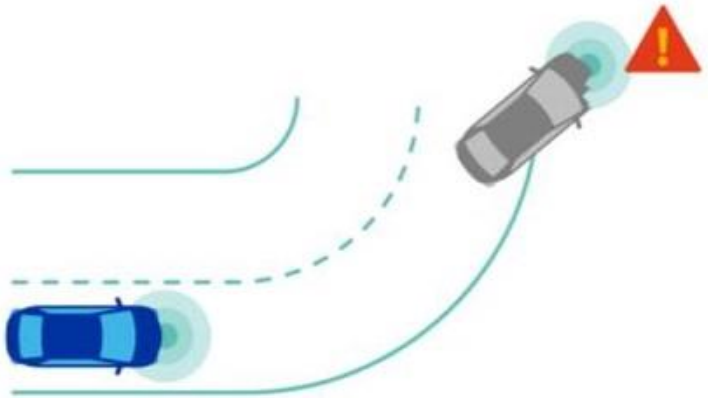
Basic safety
802.11p or C-V2X R14

Established foundation for V2X



Enhanced safety
C-V2X R14/15

Enhanced range and reliability



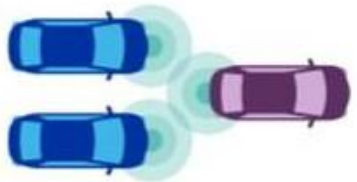
Advanced safety
C-V2X R16 (building upon R14)

Higher throughput

Higher reliability

Wideband ranging and positioning

Lower latency



Evolving C-V2X towards 5G for autonomous driving

D2D communications

R12/13

Enhanced safety

C-V2X R14 (Ph. I) C-V2X R15 (Ph. II)

Autonomous driving

C-V2X R16 5G NR support (Ph. III)
(Advanced safety applications)

Established foundation for basic D2D comm. → Enhanced communication's range and reliability for V2X safety → Ultra-reliable, low latency, high throughput communication for autonomous driving

Network independent	No	Yes	Yes
Communications[1]	Broadcast only	Broadcast only	Broadcast + Unicast/Multicast
High speed support	No	Yes	Yes
High density support	No	Yes	Yes
Throughput		High throughput for enhanced safety	Ultra-high throughput
Latency		Low latency for enhanced safety applications	Ultra-low latency
Reliability		Reliability for enhanced safety application	Ultra-high reliability
Positioning	No	Share positioning information	Wideband ranging and positioning

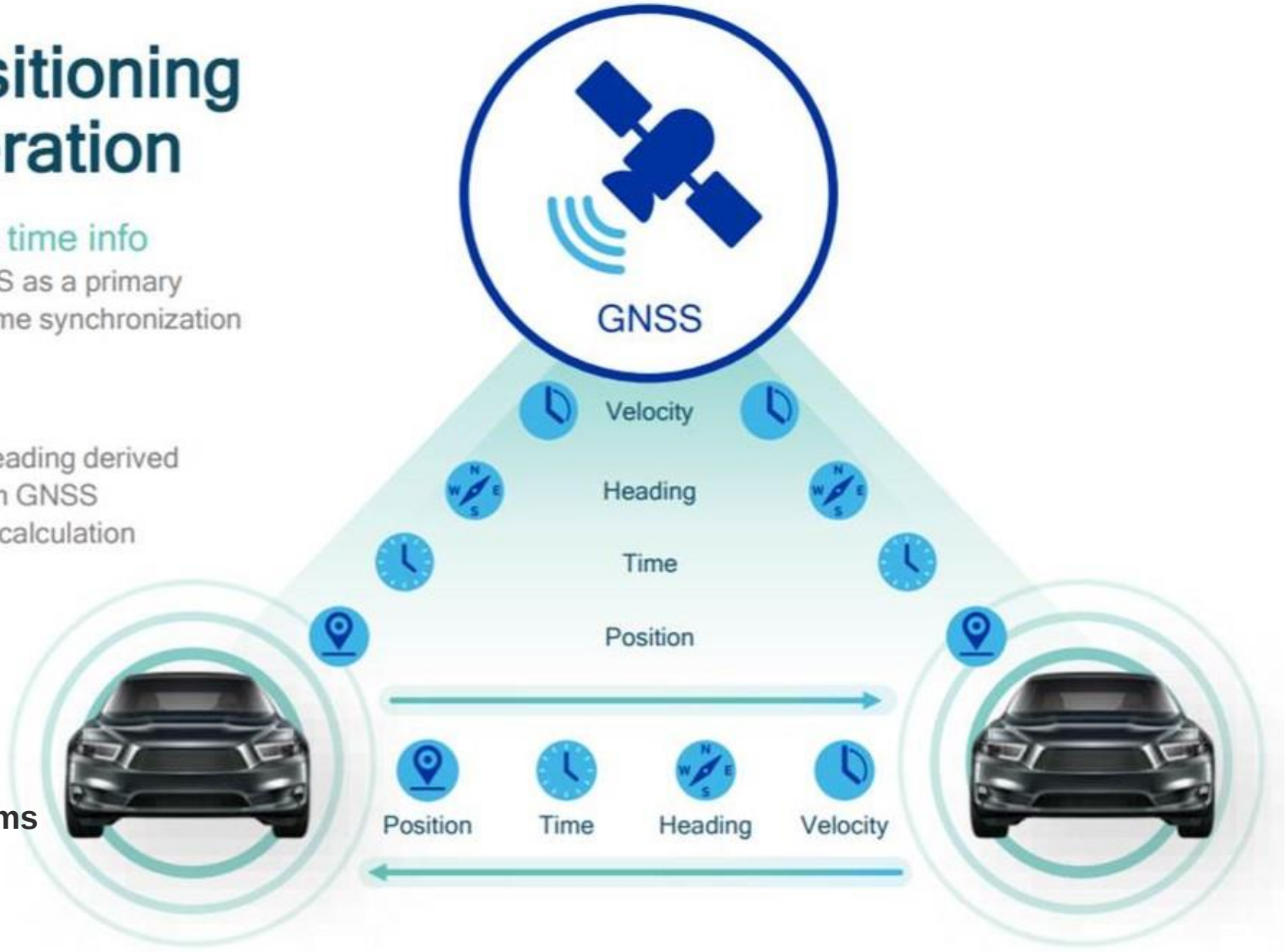
High precision positioning is key for V2X operation

Precise positioning
Use GNSS along with precise positioning services to get <1 meter accuracy

Accurate time info
Using GNSS as a primary source of time synchronization

Velocity
Accurate speed derived directly from GNSS positioning calculation

Heading
Accurate heading derived directly from GNSS positioning calculation



GNSS – Global Navigation Satellite Systems

- GPS (USA)
- GLONASS (Russia)
- Galileo (EU)
- BeiDou (China)

Enhancing positioning on multiple fronts

More accurate

Sub-meter level accuracy (e.g. lane-level accuracy) with high integrity for V2X and autonomous driving applications

Anywhere, anytime

Combined precise GNSS positioning with sensor inputs to provide accurate positioning everywhere, including dense urban environments, parking garages and multi-level interchanges

More frequently updated

Updated very frequently to provide fresh, accurate positioning information (e.g. vehicles send their most recent location at least every 100ms for V2X applications)

Timeline for cellular V2x