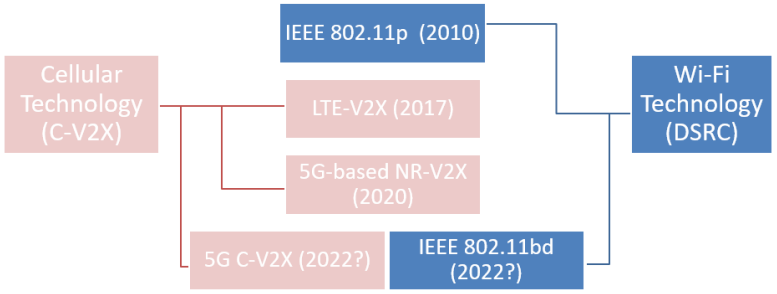
V2V Technologies: Part 1

Dedicated Short-Range Communications (DSRC)

Overview

V2V Technology Evolution

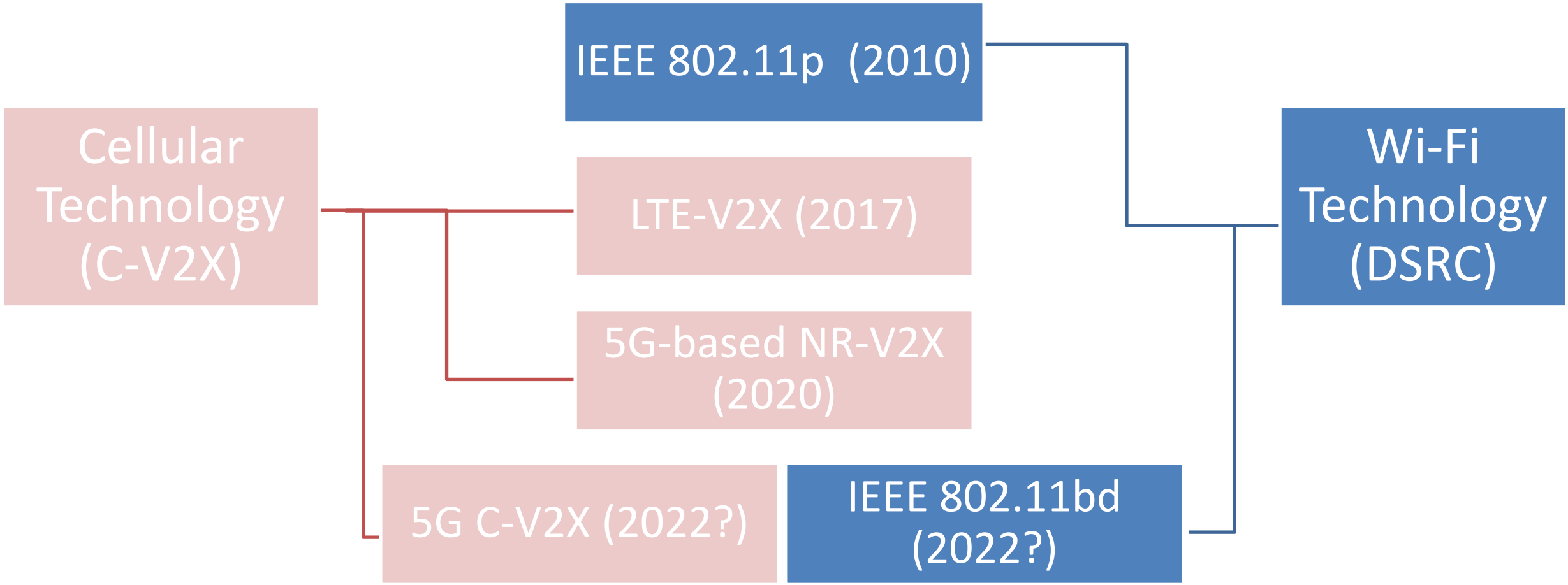


DSRC: Physical (PHY) and MAC Layers

DSRC: Network/Transport Layers

Next Generation V2X (NGV)

V2V Technology Evolution



DSRC Basics

- Dedicated Short-Range Communications
  - The "commonly" deployed V2V technology
    - Used in European Union, the US (very limited, $< 0.0057\%$ of the 274 million vehicles on the road), and Japan
  - Based on Wi-Fi technology (IEEE 802.11p or 802.11bd)
    - Layers 1 & 2 (PHY and MAC)
- Network/transport layers and security: IEEE 1609 family
- Payload definitions and performance requirements: SAE standards

DSRC: Physical (PHY) and MAC Layers

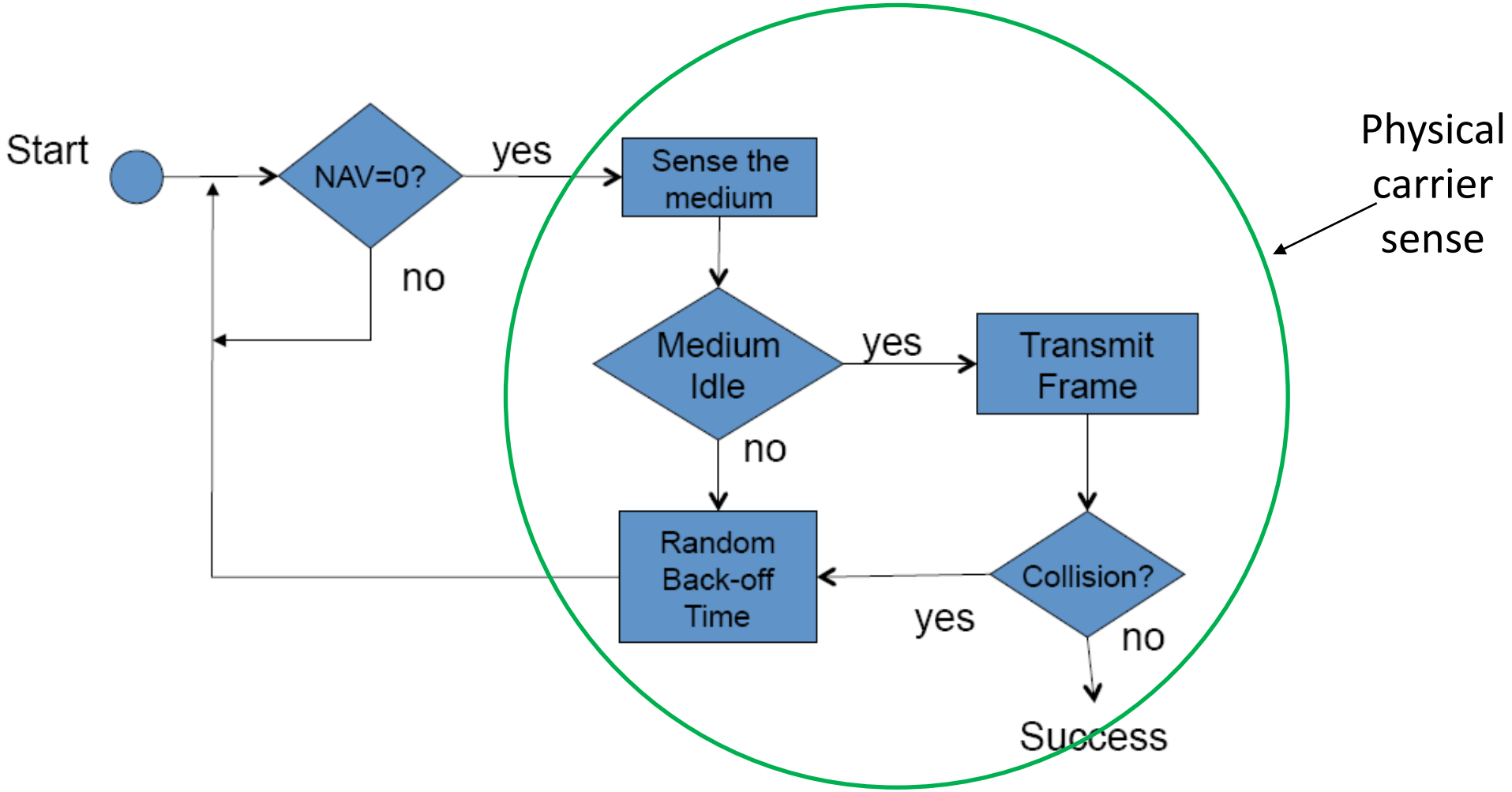
IEEE 802.11p (2010)

- Similar to 802.11a
  - 10 MHz bandwidth (vs 20 MHz in 802.11a)
- No association or authentication
  - Fast connection setup
  - Authentication and data confidentiality by upper layers
- Latency: $1 - 100\ ms$, good for basic applications
- Operates on 5.9 GHz band – vacated for C-V2X!
  - As of August 2021, no spectrum in the U.S. is allocated to DSRC

Limitations of 802.11p

- Many problems (reflecting age – concepts date to 1999)
- Performance concerns
  - Low data rate (~3 Mbps) supports BSMs, but little else
  - No retransmissions for lost/dropped packets
- Design problems
  - Only one vehicle can transmit at a time
  - 802.11 CSMA/CA → backoff timers → unacceptable latency
  - Exposed and hidden terminal problems

Review - CSMA/CA Algorithm

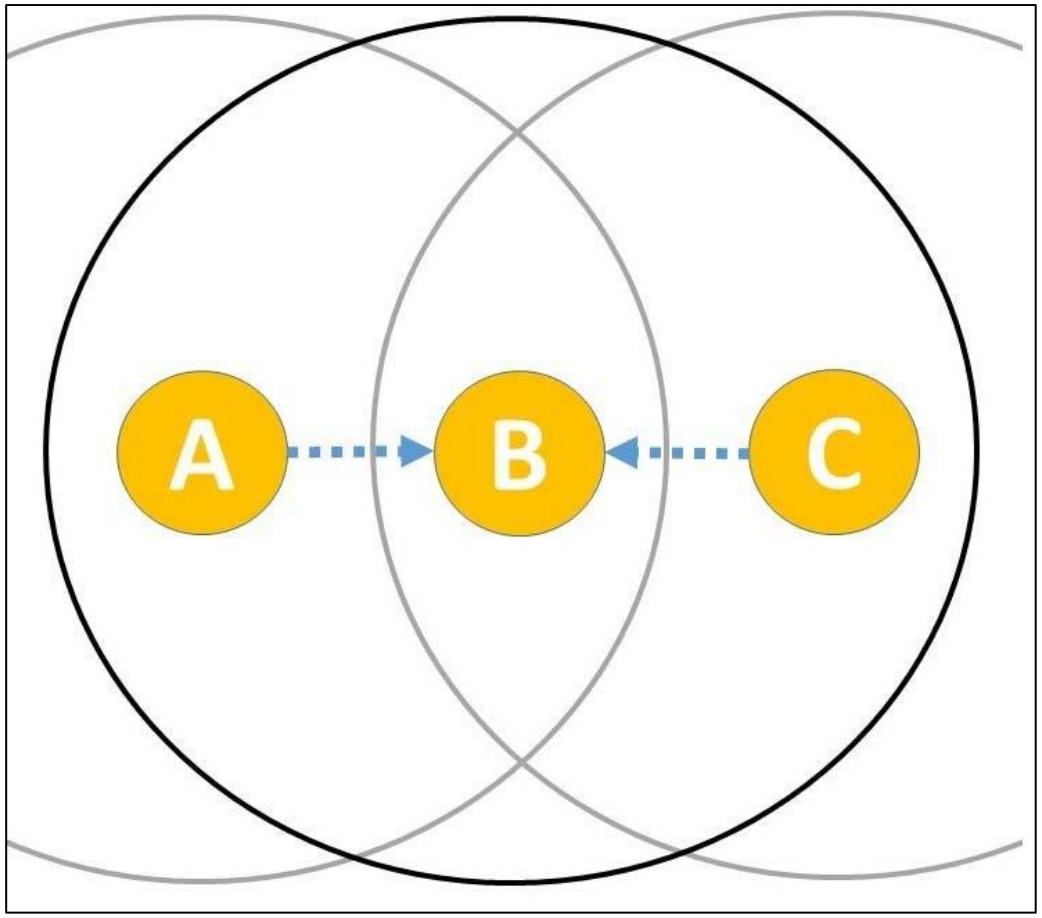


CSMA/CA Rules

- Sense the medium first
  - If idle for at least one inter-frame spacing (IFS), transmit immediately
  - If not (busy after IFS), defer transmission and wait
- Once it becomes idle again, wait another IFS
  - If still idle, back-off for a random time and set a timer
  - During back-off, if medium becomes busy, freeze timer until idle
  - If medium is idle after the timer expires: transmit!
- In DSRC, this causes unacceptable latency in dense scenarios

Hidden Terminal Problem

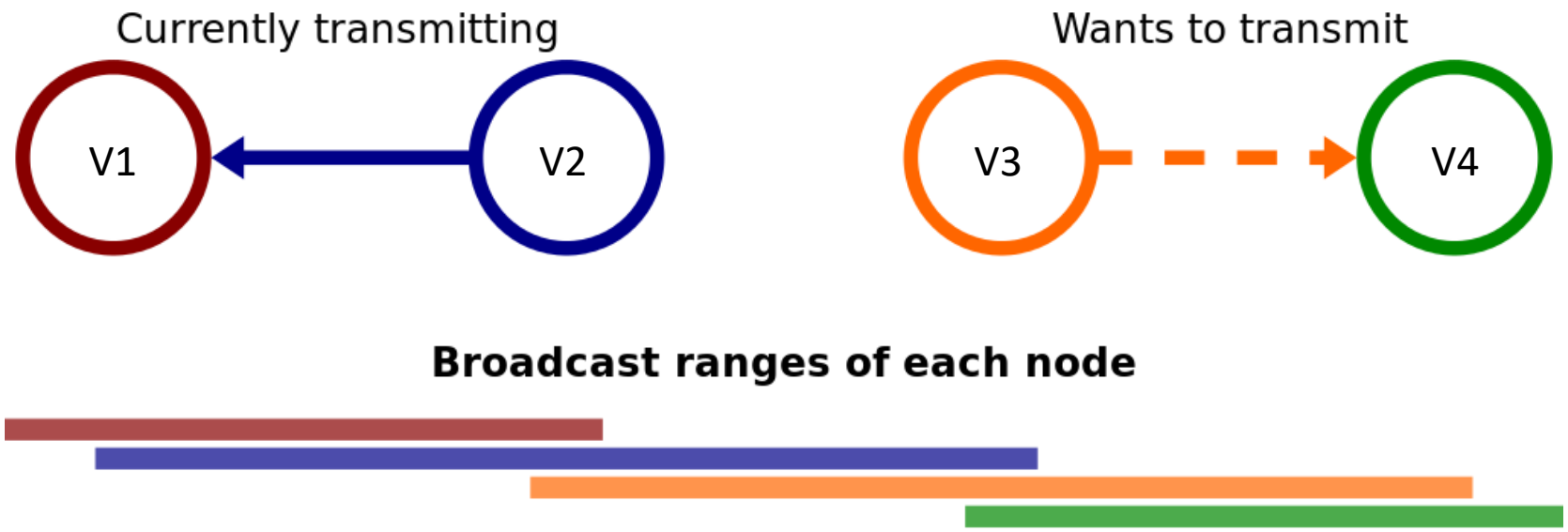
- Vehicles A and C are unaware of each other
- Vehicle B cannot receive messages from either if A and C transmit at once



From https://www.researchgate.net/figure/Hidden-Terminal-Problem_fig1_324594020

Exposed Terminal Problem

- V3 cannot transmit to V4 while V2 transmits even though V4 is out of range of V2, unnecessarily delaying V3's message

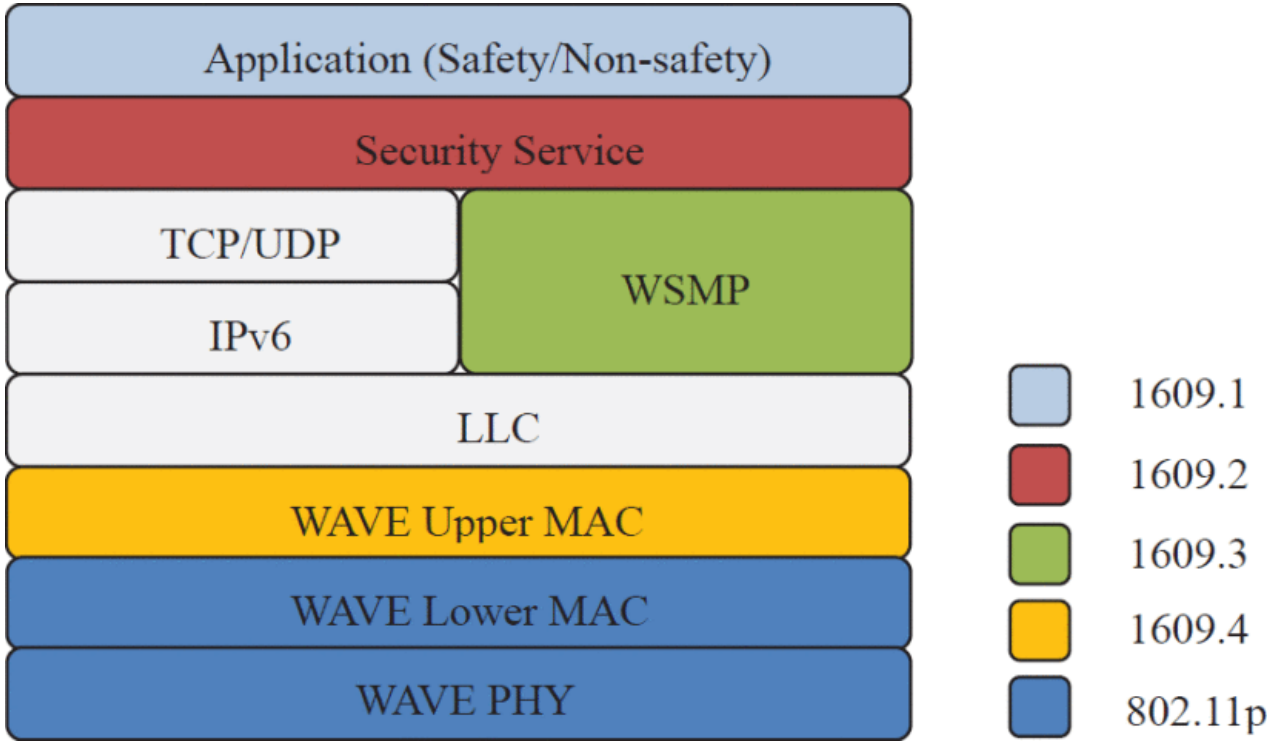


Adapted from original at https://en.wikipedia.org/wiki/Exposed_node_problem

DSRC: Network/Transport Layers

Wireless Access in Vehicular Environments (WAVE) Protocols

- Upper layers of DSRC
  - On top of 802.11p
- 1609 standards
- Not unique to DSRC
  - Except 1609.4



Y. Yao *et al.*, "Delay analysis and study of IEEE 802.11p based DSRC safety communication in a highway environment," *IEEE INFOCOM'13.*

DSRC Network and Transport Layers

- WAVE Short Message Protocol (WSMP)
  - IEEE 1609.3 (2016)
- Single, unified network/transport layer protocol
  - Simpler than UDP/IPv6
- Optimized for V2V requirements
  - Only a few bytes of extra overhead
  - No routing/addressing required
- Interfaces between upper layers and 802.11
  - Request transmit power, channel priority, etc.

Next Generation V2X (NGV)

IEEE 802.11bd (2022?)

- Enhancements for Next-Generation V2X (NGV)
  - Maneuver, live camera feeds, platooning, remote driving, …
- Design goals
  - Latency $< 5\ ms$
  - Double the data rate and range (to $> 1\ km$)
  - Support relative velocities up to $500\ km/h$
  - Coexistence & backward compatibility
- How? Using advanced PHY-layer technologies
  - MIMO, sub-THz bands, beamforming, midambles, ...

Courtesy: Keysight Technologies

New Features in 802.11bd

- Packet re-transmission improves reliability
  - Fixes major 802.11p packet-loss problem
- Midambles reduce bit error rate
  - Like a preamble, but positioned inside the frame
  - Allows channel re-estimation *during* transmission
- Dual Sub-carrier Modulation (DCM)
  - Introduced in 802.11ax (Wi-Fi 6)
  - Increased range and reduced error rate

More New Features in 802.11bd

- Low-density Parity-check Codes (LDPC codes)
  - Error correction in noisy channels
  - Helps alleviate spectrum crowding in the 5 GHz bands
- Channel access mechanism
  - 20 MHz set aside for channel contention
    - One primary “contention channel”
    - One secondary “extension channel”
  - Addresses CSMA/CA latency of 802.11p by moving contention into separate channels

For every problem solved...

- 802.11bd introduces new, unique challenges
  - MIMO is very challenging in mobile environments
  - Sub-THz communication largely untested for mobile scenarios
- Backward-compatibility may limit use of new features
  - MIMO, midambles, etc. are not understood by legacy devices