



# Impact of Wi-Fi Transmissions on C-V2X Performance

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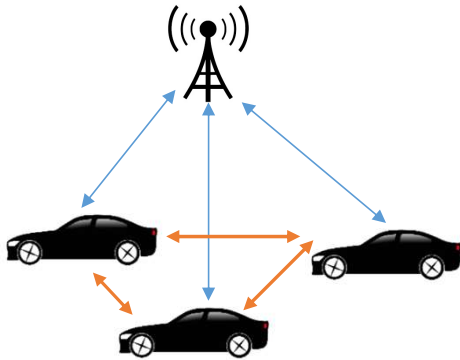
# Outline

- Cellular V2X
- Potential impact of Wi-Fi on C-V2X performance
- Part 1: Co-channel coexistence
  - Coexistence mechanisms
  - Simulation results
  - Why these mechanisms fail
- Part 2: Adjacent channel interference
  - Wi-Fi spectral mask
  - Potentially interfering channels
  - Simulation results
  - Mitigation

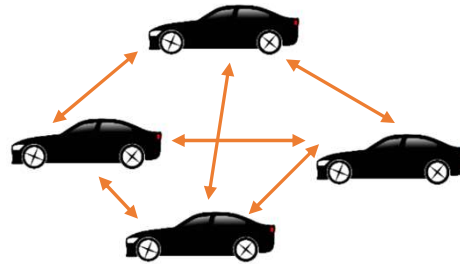
# Cellular Vehicle-to-Everything (C-V2X)

- C-V2X is a radio access technology that enables V2X communications
  - Standardized in 2017 by the 3GPP in its Release 14
  - PHY and MAC layers based on LTE
- The “sidelink” interface

**Sidelink Mode 3**  
Cellular coverage



**Sidelink Mode 4**  
No cellular coverage

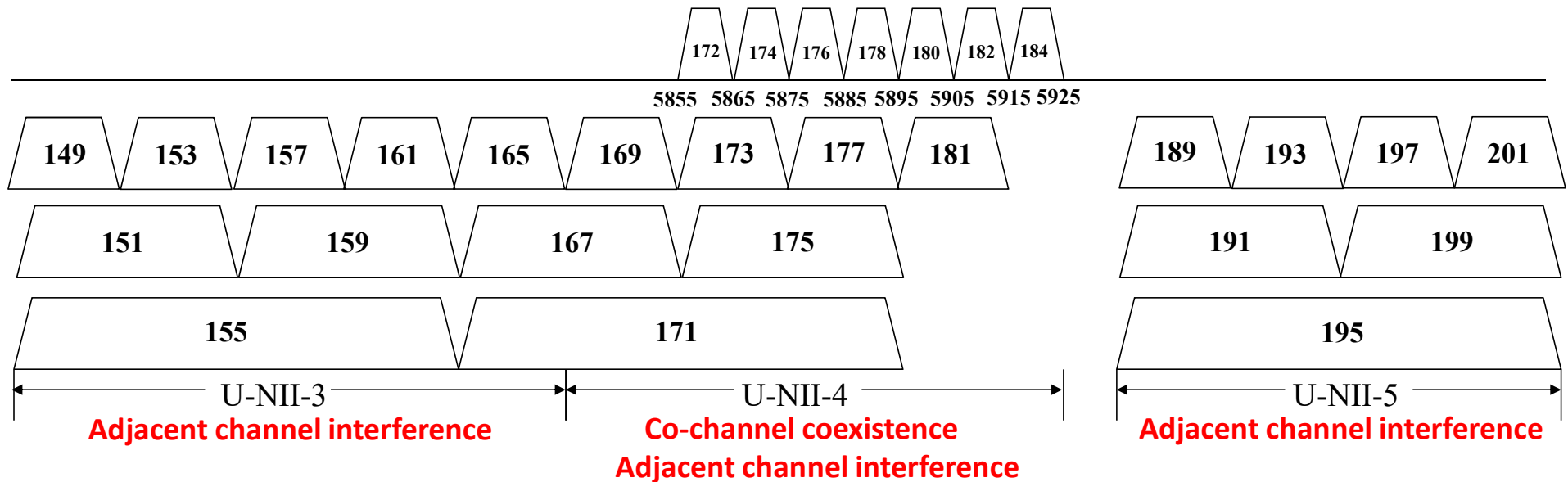


- Cellular coverage may be unreliable
- Rel 14 defines a [semi-persistent resource reservation algorithm](#) for sidelink mode 4
- We focus on sidelink mode 4

←→ Resource management (uplink/downlink)  
←→ Vehicular communication (sidelink)

# How does Wi-Fi come into the picture?

- The 5.9 GHz Intelligent Transportation Systems (ITS) band
  - Allocated in 1999 for ITS applications in the US, but limited deployments till date
  - Regulators in the US and Europe started considerations to allow Wi-Fi in this band (U-NII-4)<sup>1</sup>
- The ITS band is adjacent to the already operational U-NII-3 Wi-Fi band
- US and Europe additionally considering Wi-Fi in the U-NII-5 band<sup>2</sup>



1 – FCC, “Revision of Part 15 of the Commission’s Rules to Permit Unlicensed National Information Infrastructure (U-NII) Devices in the 5 GHz Band”

2 – FCC, “Unlicensed Use of the 6 GHz Band.”

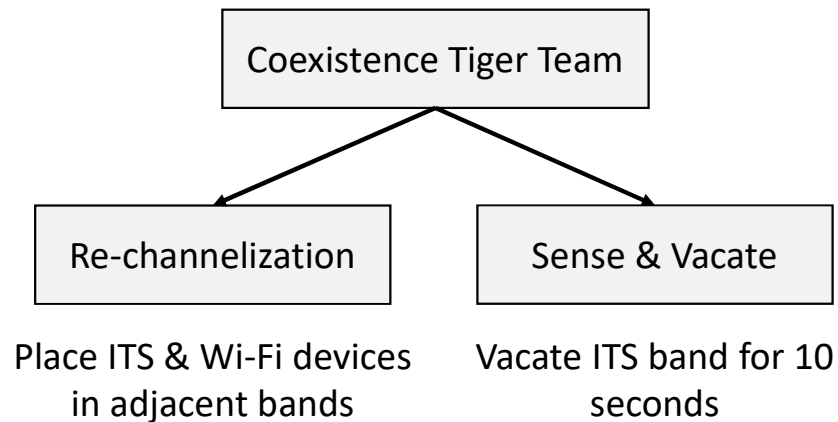
# Contributions

- Using ns-3 simulations, we investigate the impact of Wi-Fi transmissions on C-V2X sidelink mode 4 performance when
  - C-V2X and Wi-Fi operate in overlapping channels – Co-channel coexistence
    - Wi-Fi devices use existing coexistence mechanisms
  - C-V2X and Wi-Fi operate in adjacent bands – Adjacent channel interference
    - Wi-Fi devices transmit using the default spectral masks
    - Impact of *tighter* spectral masks and reduced Wi-Fi transmission power

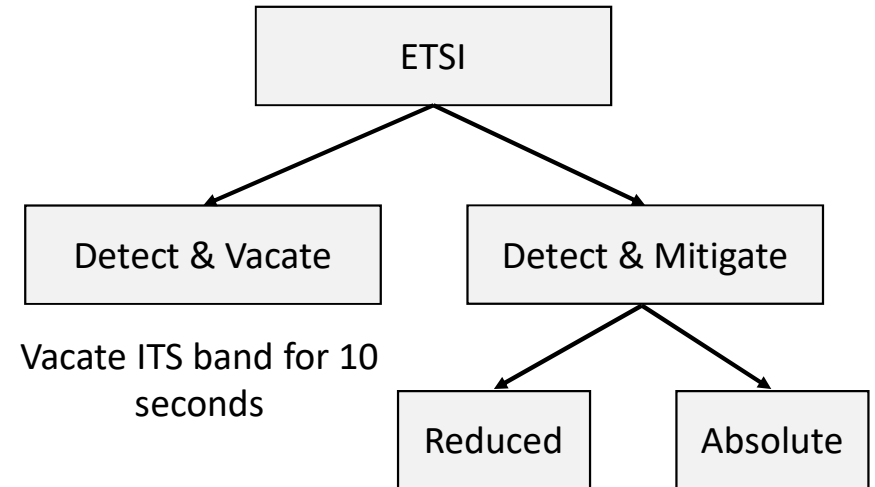
# Co-channel Coexistence

- Considerations to allow Wi-Fi in the ITS band began in 2013
  - Back then, the only technology that supported V2X communications was DSRC
  - Many mechanisms were proposed for DSRC–Wi-Fi coexistence

US<sup>3,4</sup>



Europe<sup>5</sup>



3 – Cisco, "Proposal for U-NII-4 Devices."

4 – Qualcomm, "Proposal for DSRC band Coexistence."

5 – ETSI, "Mitigation techniques to enable sharing between RLANs and Road Tolling and Intelligent Transport Systems in the 5725 MHz to 5925 MHz band."

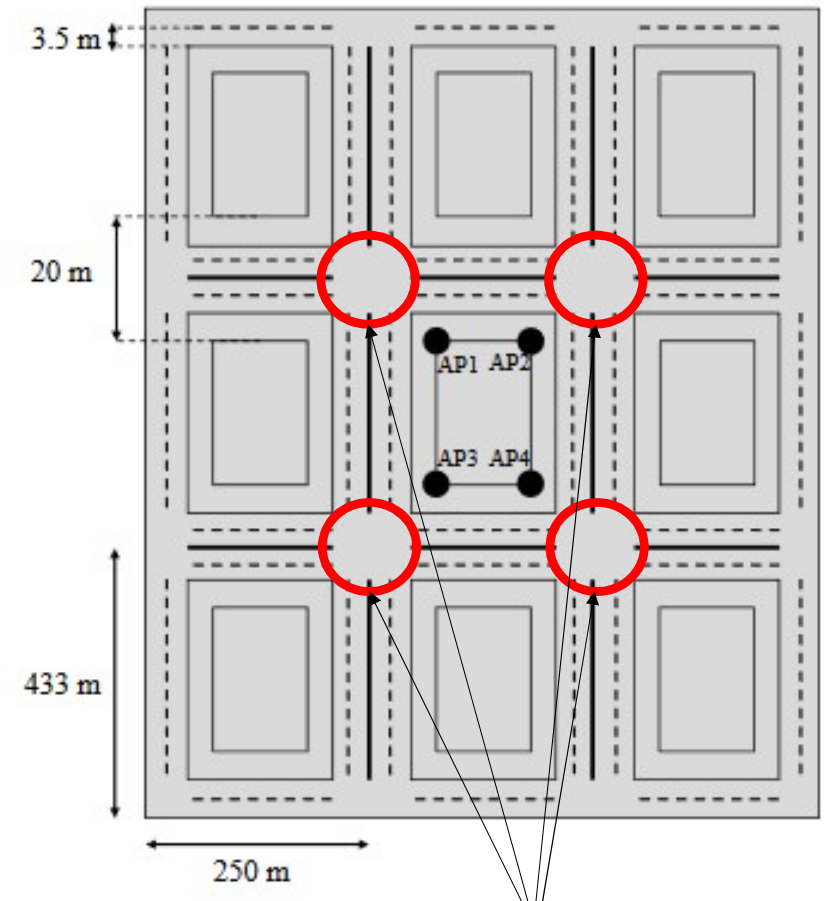
DSRC – Dedicated Short Range Communications

ETSI – European Telecommunications Standards Institute

# Simulation Setup

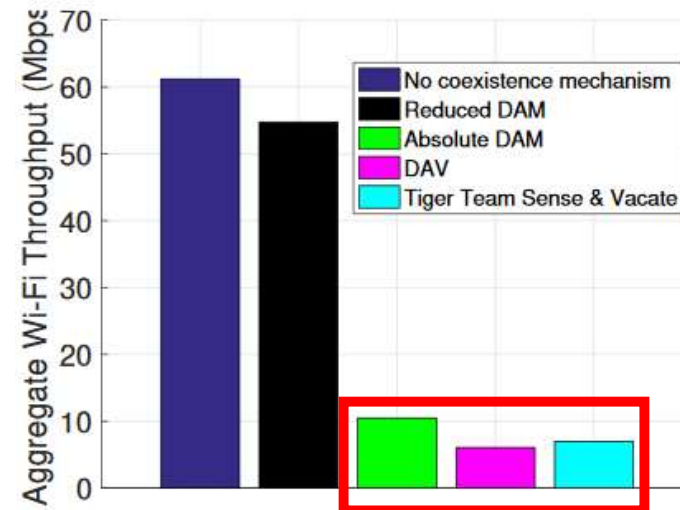
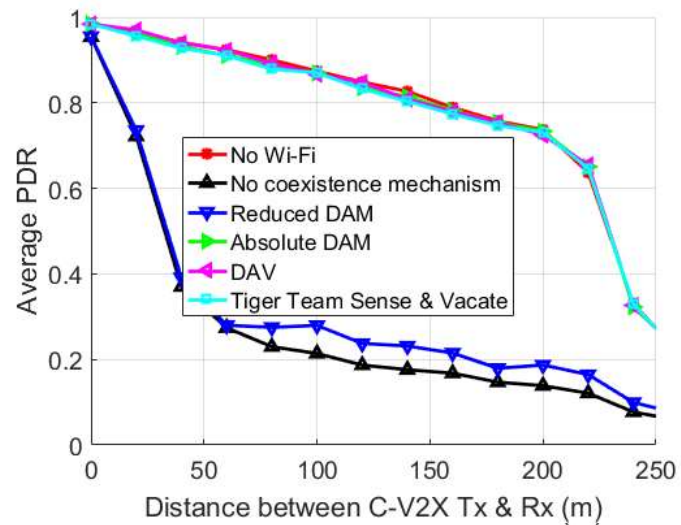
- The urban environment
  - 3GPP-recommended Manhattan grid deployment<sup>6</sup>
  - Wi-Fi APs deployed along intersections
    - Emulates Wi-Fi at restaurants

Parameter	Value	Parameter	Value
Number of vehicles	600	Inter-vehicle distance	41.67 meters
Propagation loss model	WINNER+ B1	C-V2X transmit power	23 dBm
C-V2X periodicity	10 Hz	C-V2X bandwidth	10 MHz
C-V2X re-transmissions	No	C-V2X packet size	190, 300 Bytes
Wi-Fi Rate	24 Mbps	Wi-Fi traffic	Saturated
Wi-Fi packet size	1024 Bytes	Wi-Fi bandwidth	20 MHz
Wi-Fi transmit power	30 dBm	Number of Wi-Fi clients	10 per AP



C-V2X performance observation points

# Simulation Results



- Unhindered Wi-Fi transmissions significantly affect C-V2X performance
- ETSI Reduced DAM is ineffective at protecting C-V2X transmissions
- Other mechanisms protect C-V2X transmissions
- But, offer very little Wi-Fi throughput
- None of the mechanisms achieve *meaningful* and *harmonious* coexistence

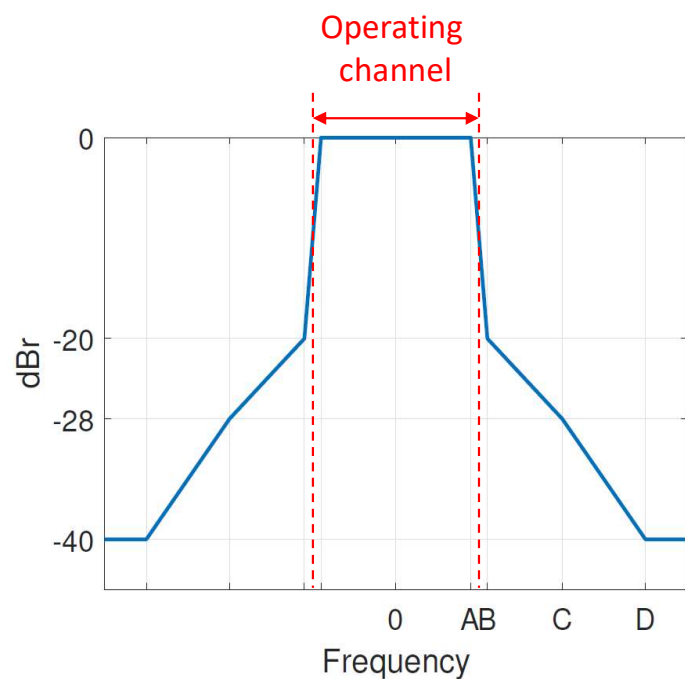


# Why do these mechanisms fail?

- All tested mechanisms were developed for DSRC – Wi-Fi coexistence
  - Detect & Mitigate leverages similarities in their MAC protocols
    - Fares poorly at coexistence ❌
  - Tiger Team's sense & vacate and ETSI's detect & vacate cease transmissions for 10 seconds
    - Technology agnostic ✔️
    - Provide negligible Wi-Fi utilization ❌
- *Effective C-V2X – Wi-Fi coexistence mechanisms needed*
  - Do not harm C-V2X performance *but* provide meaningful Wi-Fi throughput
  - Such mechanisms must be designed with C-V2X MAC protocol into consideration

# Adjacent Channel Interference

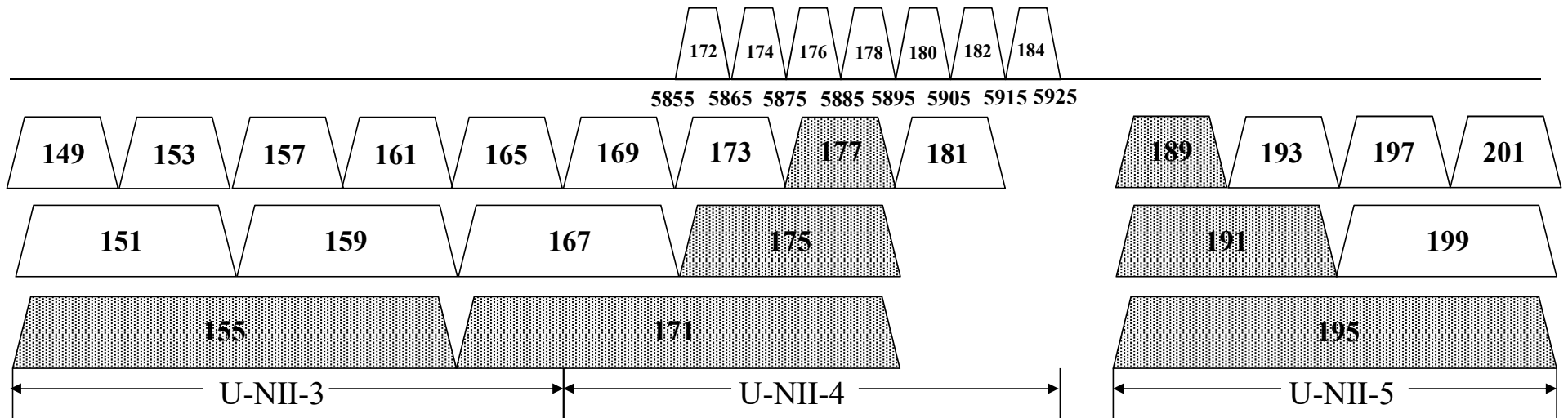
- Wi-Fi devices leak power in to adjacent channels
  - Maximum permissible leakage dictated by spectral masks



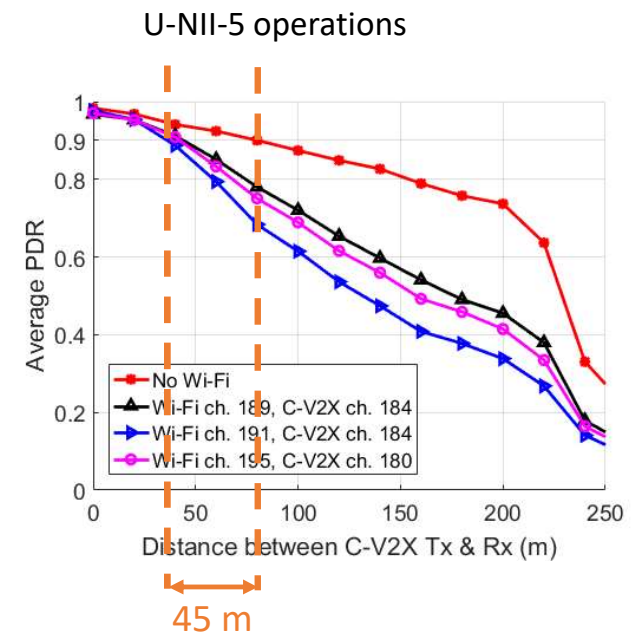
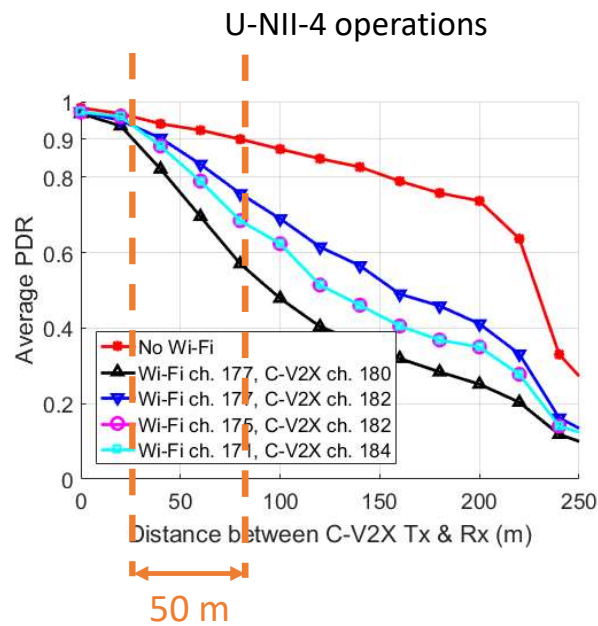
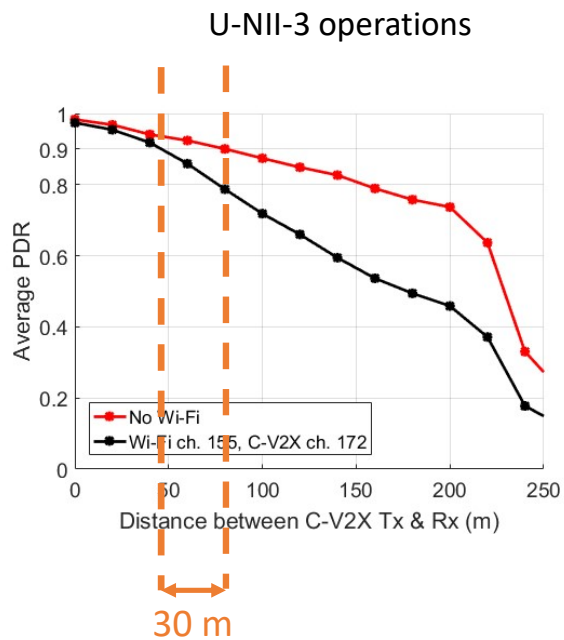
Bandwidth	A	B	C	D
20 MHz	9 MHz	11 MHz	20 MHz	30 MHz
40 MHz	19 MHz	21 MHz	40 MHz	60 MHz
80 MHz	39 MHz	41 MHz	80 MHz	120 MHz
160 MHz	79 MHz	81 MHz	160 MHz	240 MHz

If an ITS channel falls within point "D" of a Wi-Fi channel, Wi-Fi can interfere with C-V2X

# Which Wi-Fi channels affect C-V2X performance?



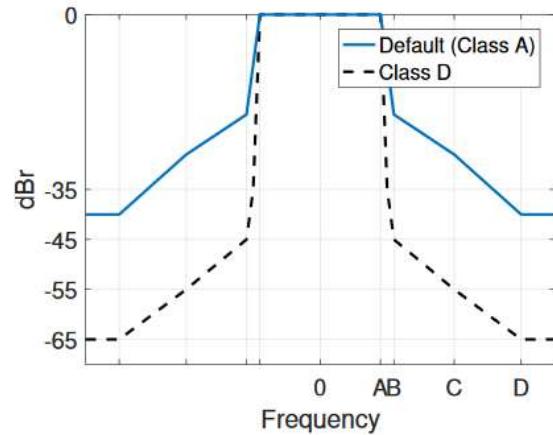
# Simulation Results



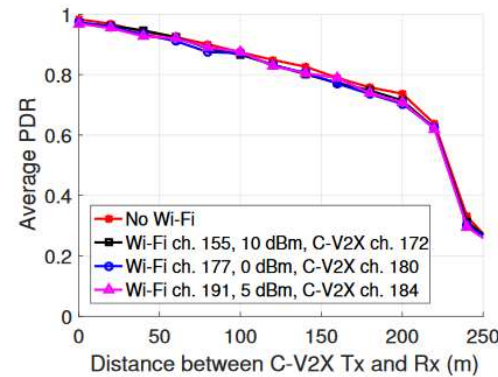
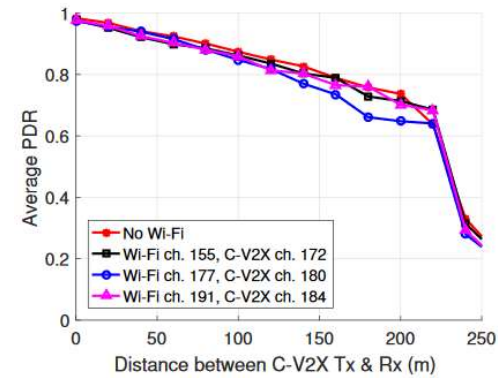
Significant performance loss, especially in U-NII-4 and U-NII-5 cases

# Mitigating Adjacent Channel Interference

- Option 1: Tighter spectral masks



- Option 2: Reduced Wi-Fi transmission power



# Adjacent Channel Interference: Lessons Learnt

- Wi-Fi in adjacent bands can significantly affect performance at nearby C-V2X devices
- Serious concern in the US!
  - 5GAA has requested channel 183 (182 + 184) for C-V2X operations in the US<sup>7</sup>
  - Outdoor deployment of U-NII-5 Wi-Fi AP allowed<sup>2</sup>!
- However, both U-NII-4 and U-NII-5 band planning is still under consideration
  - Impact on C-V2X performance must be taken into consideration

<sup>2</sup> - FCC, "Unlicensed Use of the 6 GHz Band."

<sup>7</sup> - 5GAA, "5GAA Petition For Waiver (In the matter of Petition For Waiver to Allow Deployment of Intelligent Transportation System Cellular Vehicle to Everything (C-V2X) Technology)"

# References

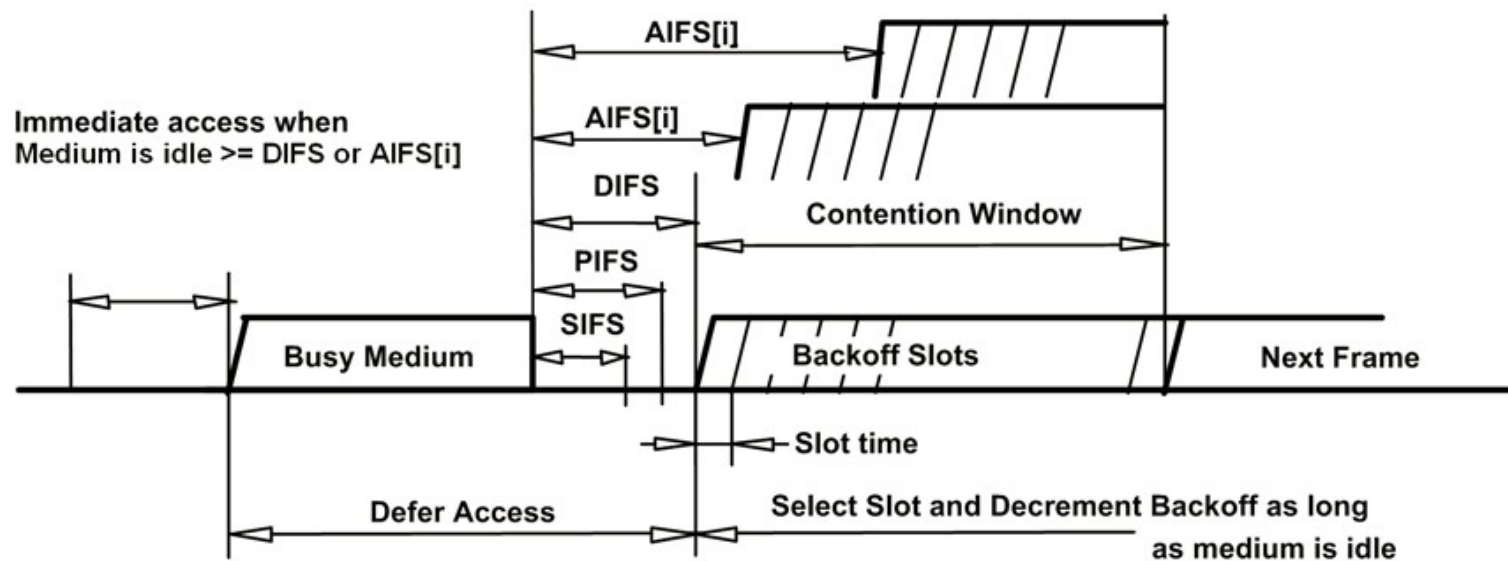
- [1] FCC, “Revision of Part 15 of the Commission’s Rules to Permit Unlicensed National Information Infrastructure (U-NII) Devices in the 5 GHz Band”
- [2] FCC, “Unlicensed Use of the 6 GHz Band.”
- [3] Cisco, “Proposal for U-NII-4 Devices.”
- [4] Qualcomm, “Proposal for DSRC band Coexistence.”
- [5] ETSI, “Mitigation techniques to enable sharing between RLANs and Road Tolling and Intelligent Transport Systems in the 5725 MHz to 5925 MHz band.”
- [6] 3GPP “TR 36.885: Technical Specification Group Radio Access Network; Study on LTE-based V2X Services (v14.0.0).”
- [7] 5GAA, “5GAA Petition For Waiver (In the matter of Petition For Waiver to Allow Deployment of Intelligent Transportation System Cellular Vehicle to Everything (C-V2X) Technology)”

Thank you!

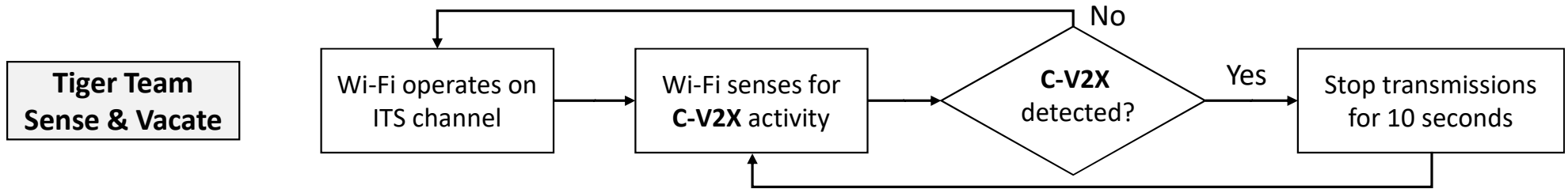


# Backup Slides

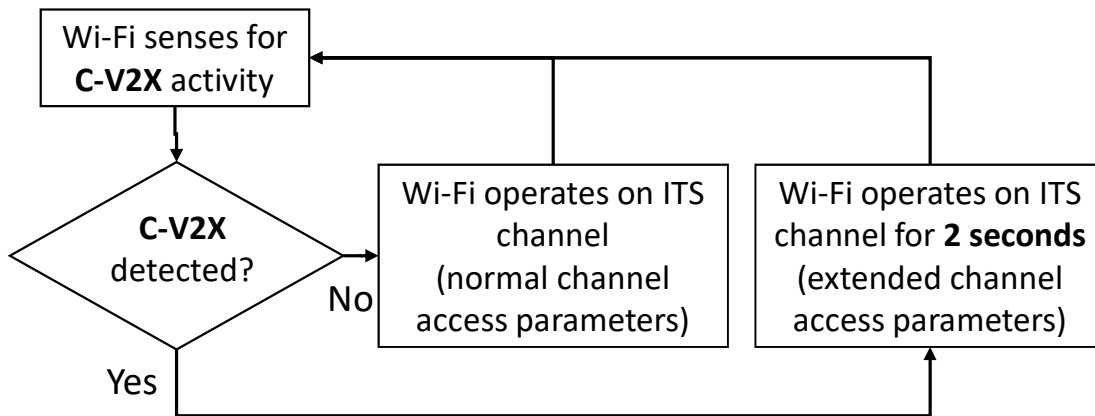
# 802.11 MAC Protocol



# Coexistence Mechanisms



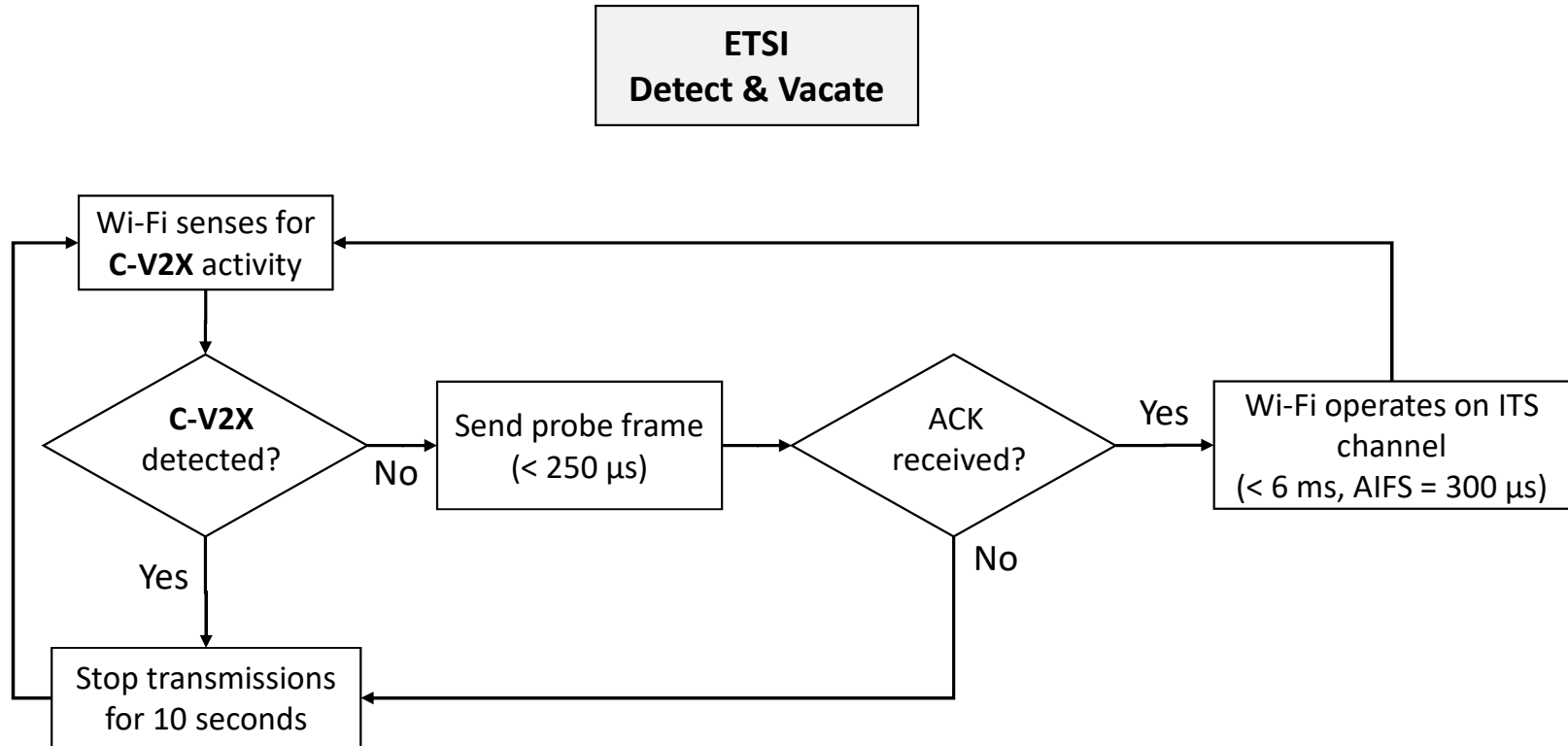
**ETSI Detect & Mitigate**



Access Category	Default			Reduced DAM			Absolute DAM		
	CW Min	CW max	AIFS N	CW Min	CW max	AIFS N	CW Min	CW max	AIFSN
Background	15	1023	7	31	2047	49	31	2047	2065
Best Effort	15	1023	3	31	2047	43	31	2047	2059
Video	7	15	2	15	31	31	15	31	1029
Voice	3	7	2	7	15	11	7	15	515

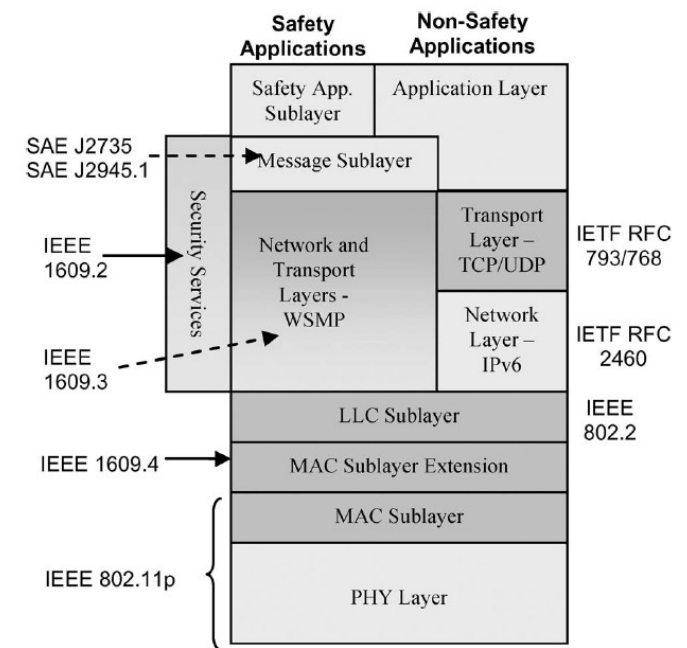
CW – Contention Window  
 AIFSN – Arbitration Interframe Space Number

# Coexistence Mechanisms



# Dedicated Short Range Communications (DSRC)

- DSRC is based on the IEEE 802.11a standard
  - Adopts 802.11a PHY and MAC layers
  - Enhancements to suit high-speed environments
- Enhancements Include
  - Halved bandwidth (10 MHz)
  - Defines outside-the-context-of-BSS (OBSS) MAC
  - No ACK frames and no exponential back-off
- Robust protocols that cover:
  - Security
  - Multi-channel operations



Source: Dedicated Short-Range Communications (DSRC) Standards in the United States, John Kenney

# C-V2X Sidelink Mode 4

- Mode 4 allows direct UE-to-UE communications in the absence of cellular infrastructure
  - 3GPP defines a semi-persistent scheduling (SPS) algorithm for resource selection
  - Each vehicle senses the channel for 1 second and selects a *resource* for it's transmission
  - Selection is done for the next and a random number of future transmissions
  - Selection information from other vehicles is used in selecting a resource

