Impact of 5.9 GHz Spectrum Sharing on DSRC Performance

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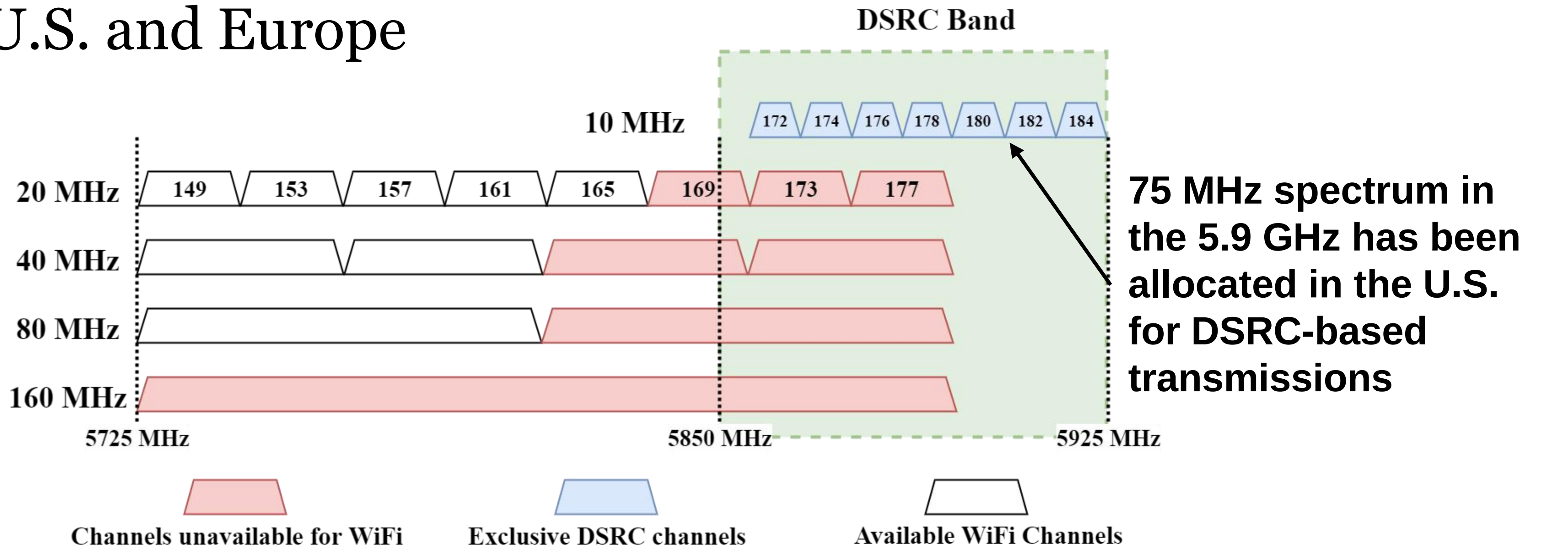
Outline

- Motivation
- Background---Spectrum sharing algorithms
  - Detect & Vacate
  - Detect & Mitigate
- Methodology
  - Pre-detection Study
  - Post-detection Study
- Conclusion

Motivation

- Wi-Fi industry seeks to share DSRC [1] band in both the U.S. and Europe

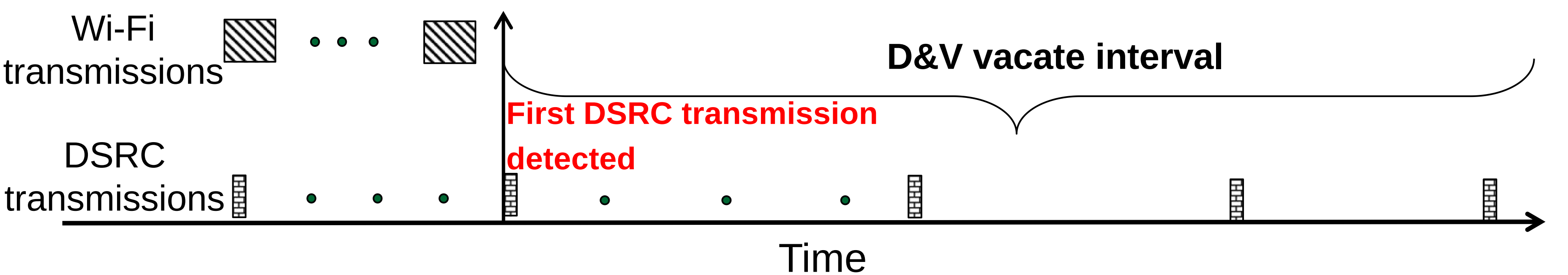


- This spectrum sharing would allow Wi-Fi to access additional and wider channels
- However, the impact of spectrum sharing on the performance of DSRC systems is unclear

[1] In Europe the communication referred to in this paper as DSRC is typically called Cooperative-ITS or ITS G5.

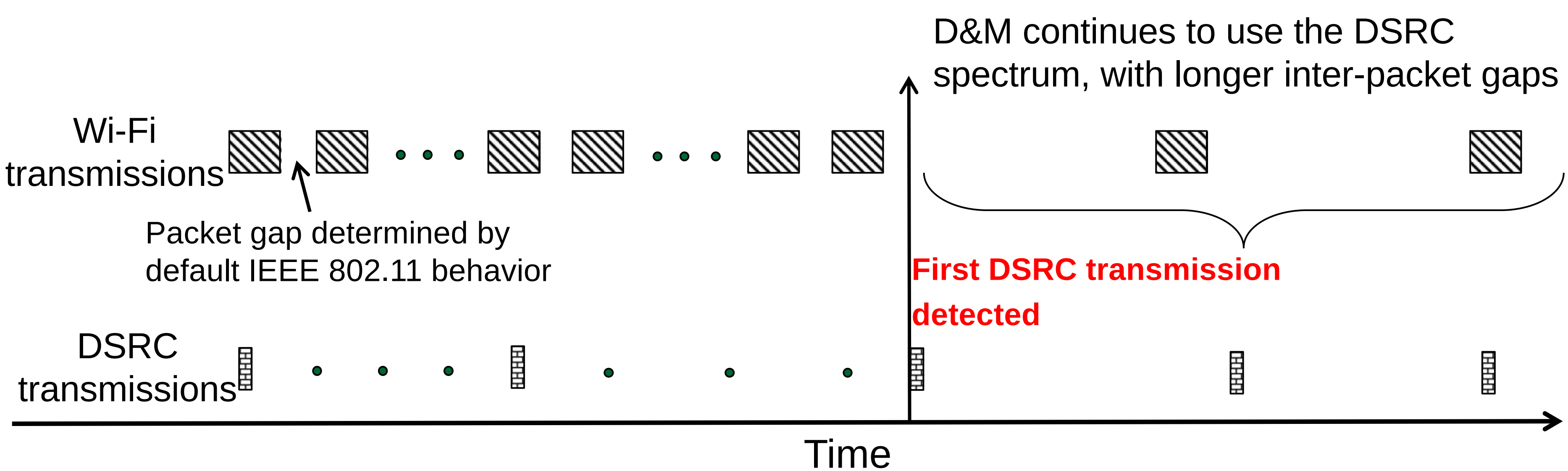
Background—I

- Two spectrum sharing algorithms were proposed to the European ETSI BRAN committee
  - Detect & Vacate (D & V)—also proposed in the U.S.
  - Detect & Mitigate (D & M)
- D & V algorithm: introduced by Cisco
  - DSRC detection
    - Each Wi-Fi device integrates a set of 10 MHz DSRC preamble detectors
  - Post-detection
    - Wi-Fi vacates DSRC band after DSRC detection for at least 10 seconds



Background—II

- D & M algorithm: introduced by Broadcom
  - DSRC detection: similar to D & V
  - After DSRC detection
    - **Packet-by-Packet Sharing:** Wi-Fi device would continue to use the DSRC band, but would use 802.11 QoS (called EDCA) to attempt to reduce Wi-Fi interference to DSRC

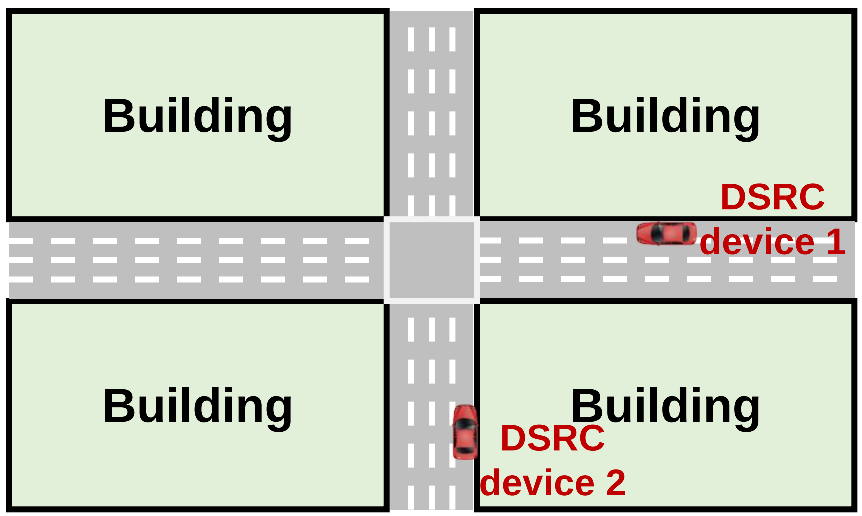


Methodology—I

- Compare D&V and D&M under realistic, challenging conditions
- Consider two phases:
  - Pre-detection of DSRC by Wi-Fi
    - A long pre-detection phase means delayed protection of DSRC transmissions, possibly causing severe interference
    - Metric: Number of DSRC transmissions before Wi-Fi detects and switches to mitigation state
  - Post-detection of DSRC by Wi-Fi
    - After detecting DSRC, continued use of channel by Wi-Fi can interfere with individual DSRC transmissions
    - Metric: DSRC Packet error ratio (PER)

Methodology—II

- Combination of analytical and simulation study of collision avoidance at a typical urban intersection
  - Wi-Fi devices placed in different locations in different scenarios
  - NLOS Communication between DSRC devices

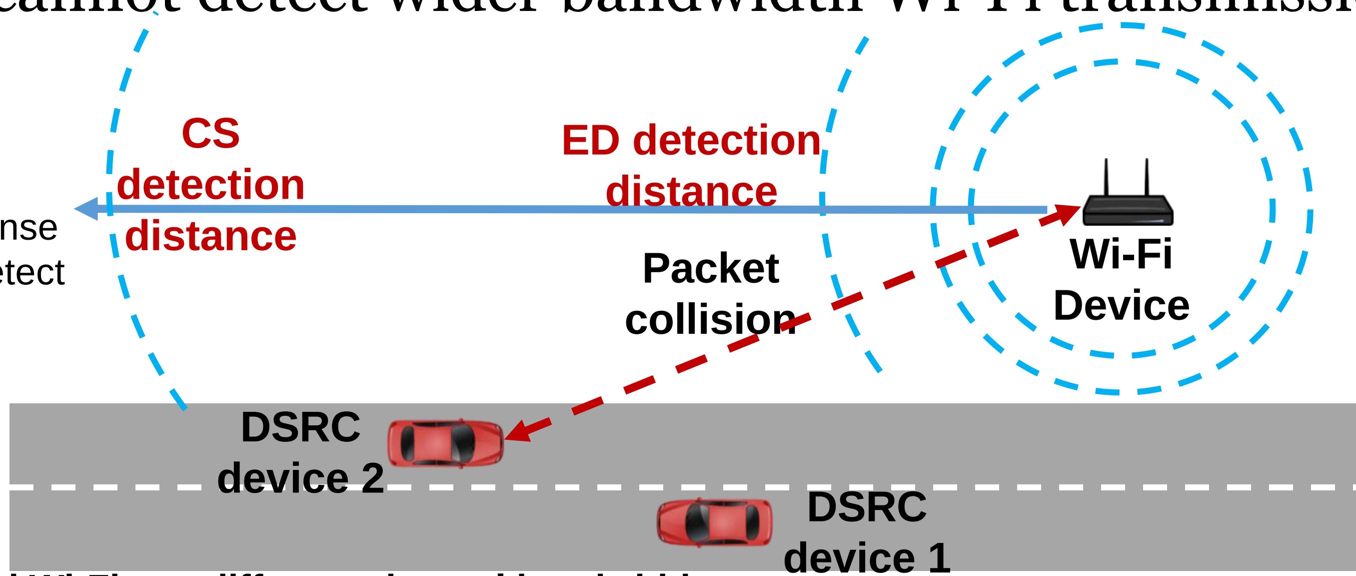


- Assume that Wi-Fi devices are already transmitting in the DSRC band when DSRC transmissions start

Pre/ detection Phase—Challenge #1

- Challenge
  - Unilateral hidden terminal: 10 MHz DSRC devices cannot detect wider bandwidth Wi-Fi transmissions

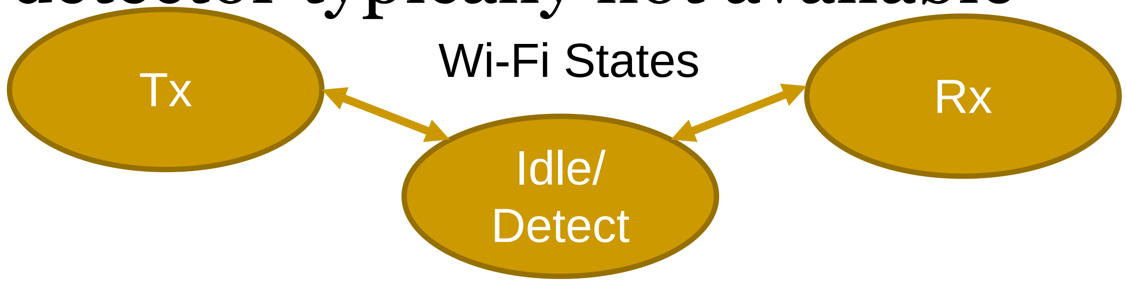
CS = Carrier Sense
ED = Energy Detect

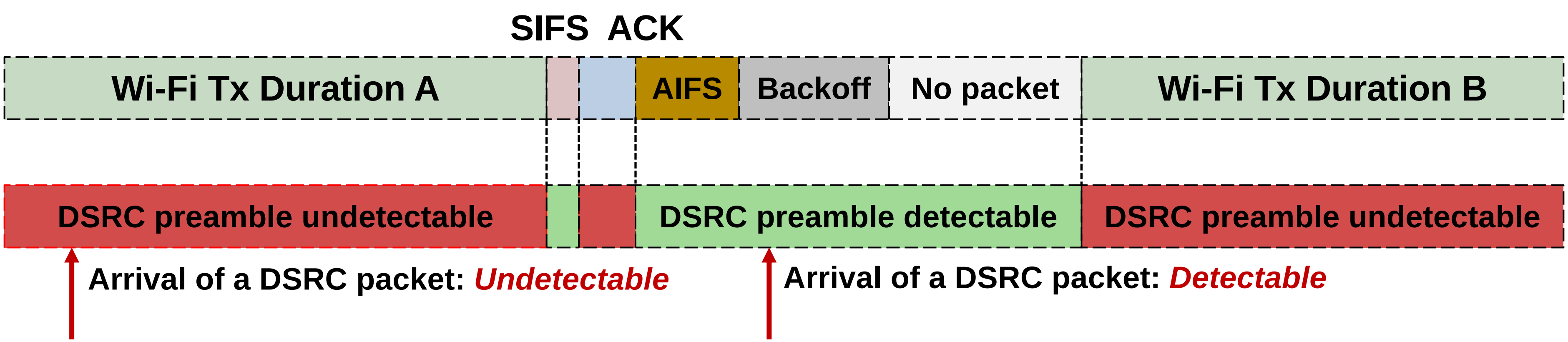


- DSRC and Wi-Fi use different channel bandwidths
- DSRC has no “unlicensed transmission detector”
- Wi-Fi transmissions are hidden from DSRC even if DSRC transmissions can be detected by Wi-Fi: unilaterally hidden
- DSRC will transmit even when Wi-Fi is already using the channel

Pre/ detection Phase—Challenge #2

- Challenge: DSRC detector typically not available in Tx or Rx state



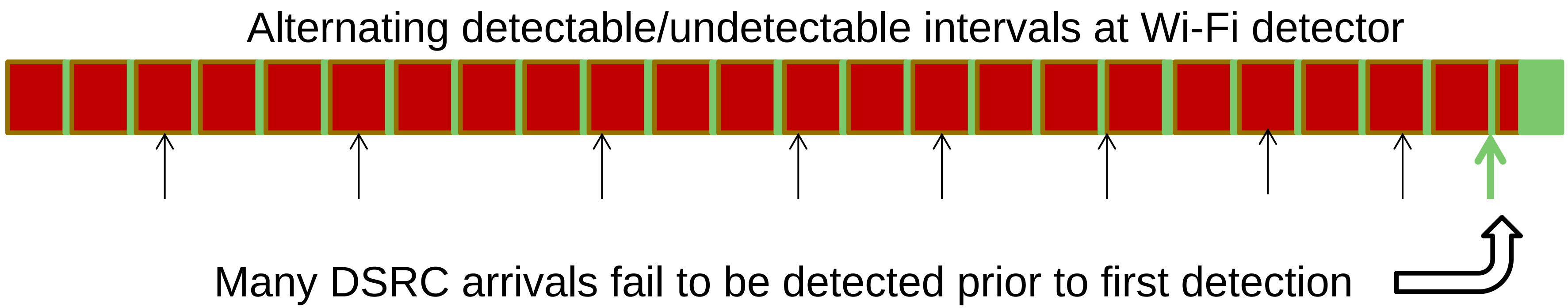


- Near-worst case: "*No packet*" period reduced to zero— Wi-Fi traffic is "saturated"

Note: intervals not drawn to scale. Undetectable interval typically much larger than detectable interval

Pre/ detection Phase—Challenges

- Combining
  - #1Unilateral Hidden Terminal and
  - #2Limited Availability Detector,
- DSRC packets can remain undetected for extensive intervals



Pre/ detection Phase—Analytical Study

- Model DSRC detection as a Bernoulli process
  - Assumptions:
    - DSRC and Wi-Fi transmission start times are independent
    - DSRC can be detected if none of Wi-Fi devices is transmitting
  - A successful Bernoulli trial: a DSRC packet starts while the Wi-Fi devices are not transmitting
    - Probability of successful trials can be estimated by the portion of time during which Wi-Fi is not transmitting, i.e.

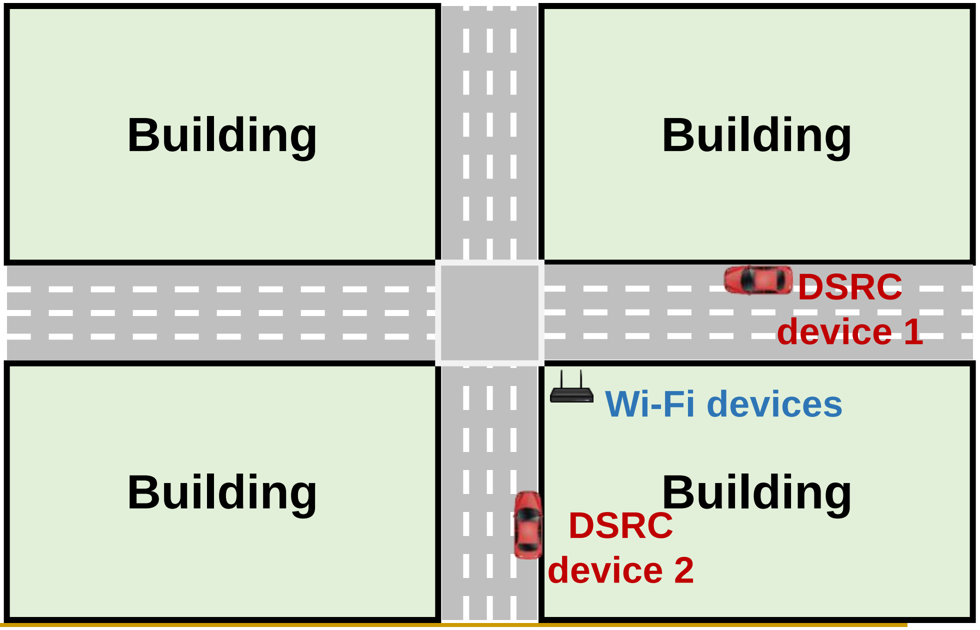
$$Prob_{detection} = \frac{WiFi\ idle\ period}{WiFi\ idle\ period + WiFi\ Tx\ duration + ACK\ duration}$$

where $WiFi\ idle\ period$ includes SIFS, AIFS, Backoff and "No packet"

- Ex: for a single Wi-Fi device with packet duration = 2 ms, using AC_BE with default parameters, the detection probability is only **5%**
- The average number of trials to the first success is: $\frac{1}{Prob_{detection}} = 20$

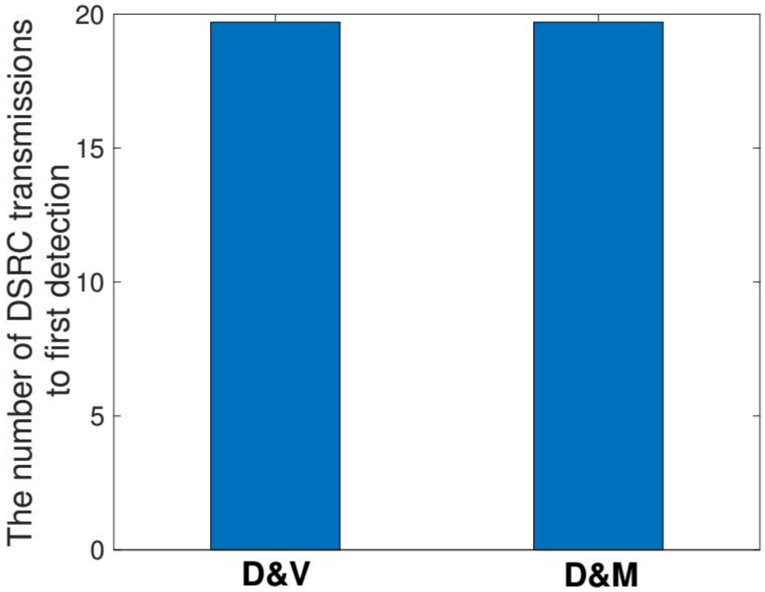
Pre/ detection Phase—Simulation Study

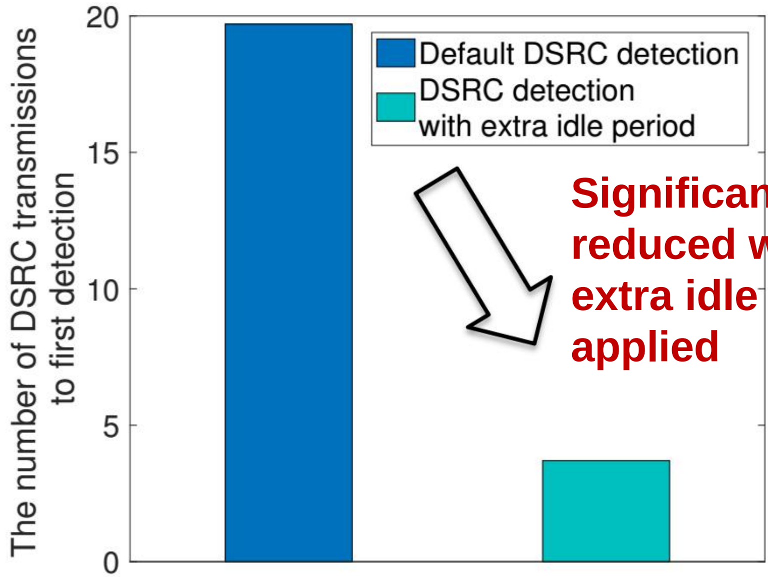
- Simulation configurations
  - One Wi-Fi AP-Client device pair located inside the building, e.g. coffee shop; AP is transmitting in saturation mode
  - DSRC packets generated at 2.5 Hz (typical for ETSI CAM)
  - 1) DSRC stationary mode
    - DSRC devices stand at 40m away from intersection center
  - 2) DSRC mobile mode
    - DSRC devices move from 200 m away to intersection center at 10 m/s



Pre/ detection Phase—Simulation Study

- DSRC stationary mode
  - Identical performance between D&V and D&M
  - On average, ~20 DSRC transmissions before Wi-Fi can detect one. This matches analytical results
- Performance improved by adding extra **266μs** idle period to Wi-Fi inter-transmission interval prior to detection



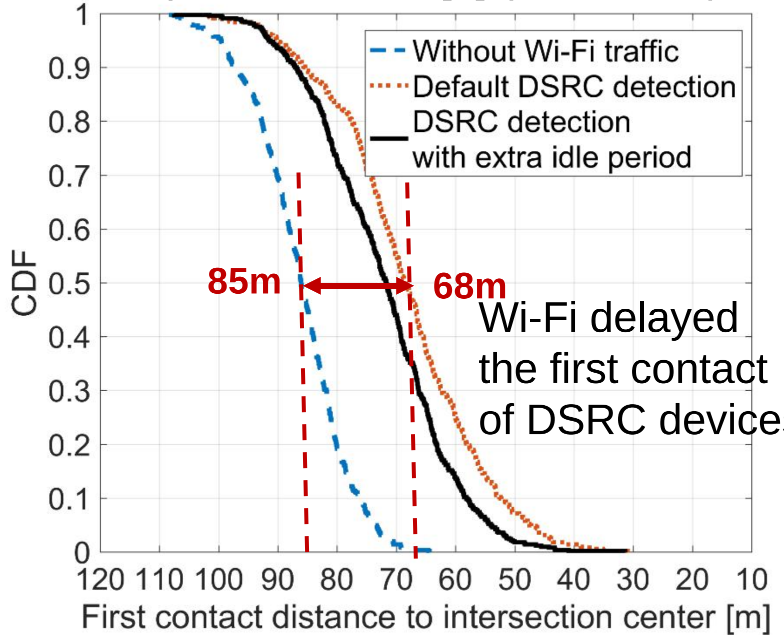


More precisely: the simulation models DSRC as detected if first 8 μsec of DSRC preamble are in a detectable interval

Pre/ detection Phase—Simulation Study

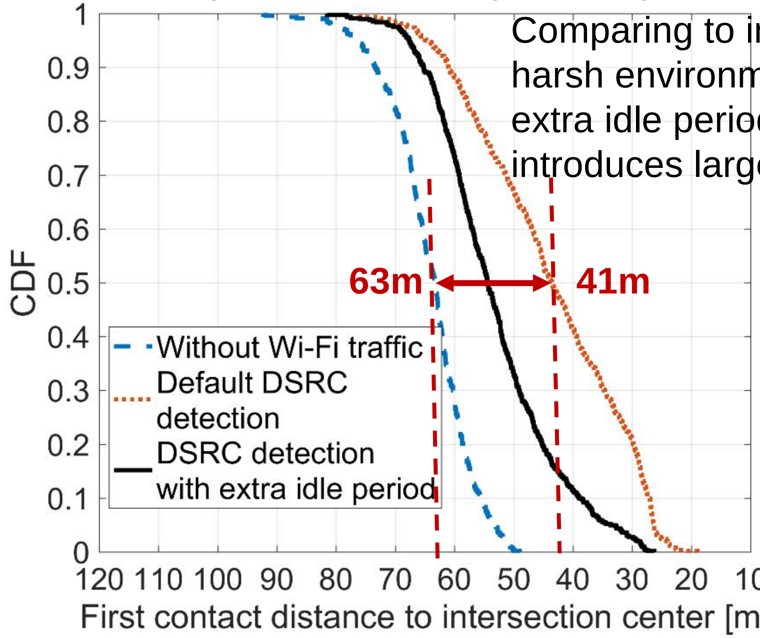
- DSRC mobile mode
  - The first contact distance to the intersection center: the distance at which both DSRC devices have received a packet from the other

DSRC channel path loss exponent = 2.69 [1] (less harsh)



Wi-Fi delayed the first contact of DSRC devices

DSRC channel path loss exponent = 2.85 (harsher)



Comparing to in the less harsh environment, the extra idle period introduces larger gain

[1] Thomas Mangel, Oliver Klemp and Hannes Hartenstein, 5.9 GHz inter-vehicle communication at intersections: a validated non-line-of-sight path-loss and fading model, EURASIP Journal on Wireless Communications and Networking 2011

Post/ detection Phase—Challenge

- Challenge
  - Unilateral hidden terminal
    - Lack of mutual detection between DSRC and Wi-Fi leads to overlapping Wi-Fi and DSRC transmissions and DSRC packet loss

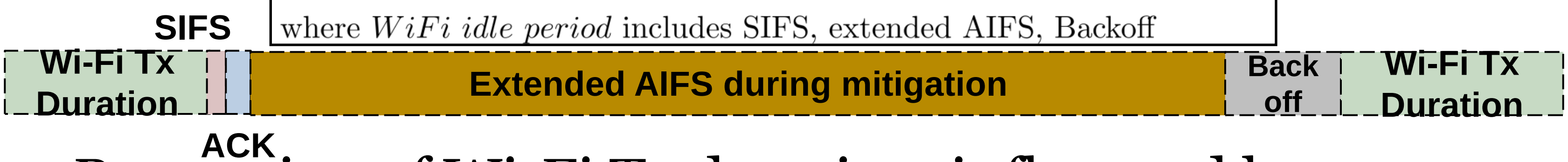
- Near-worst case:
  - D&M, because of its packet-by-packet sharing after DSRC detection
  - Long Wi-Fi transmission duration (up to TXOP limit)

Post/ detection Phase—Analytical Study

- Probability of DSRC/Wi-Fi packet collision equivalent to the proportion of time the Wi-Fi device is transmitting

$$Prob_{collision} = \frac{WiFi\ Tx\ period}{WiFi\ idle\ period + WiFi\ Tx\ duration + ACK\ duration}$$

where $WiFi\ idle\ period$ includes SIFS, extended AIFS, Backoff

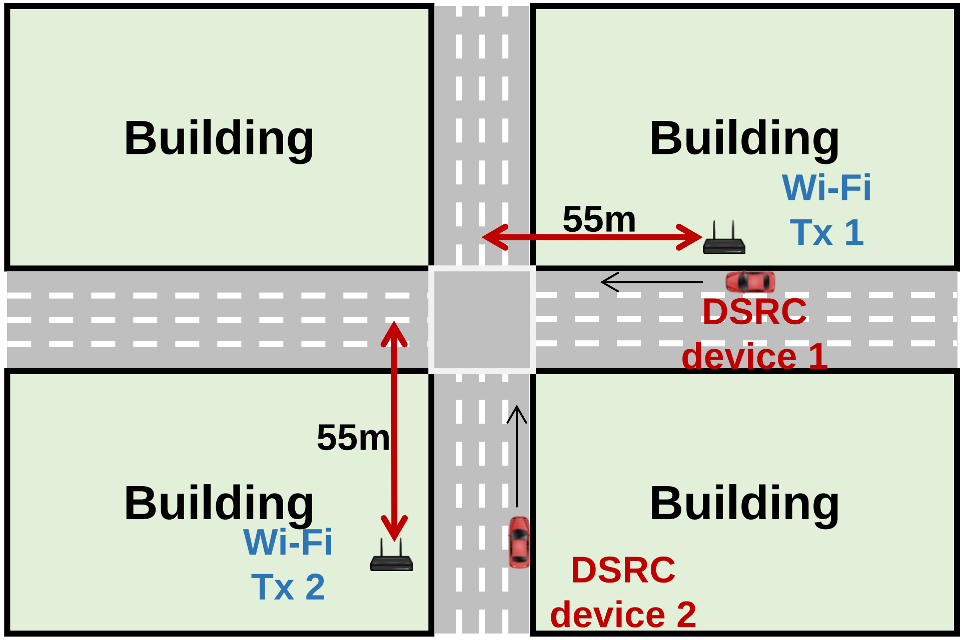


- Proportion of Wi-Fi Tx duration, influenced by:
  - The length of AIFS: different EDCA access categories have different values
  - The length of Wi-Fi Tx duration: limited by TXOP limit

EDCA AC	AIFS	TXOP limit	Packet collision probability
AC_BE	18.72 ms	2.2 ms	11%
AC_VI	9.32 ms	3.0 ms	24.3%
AC_VO	4.65 ms	1.5 ms	24.4%

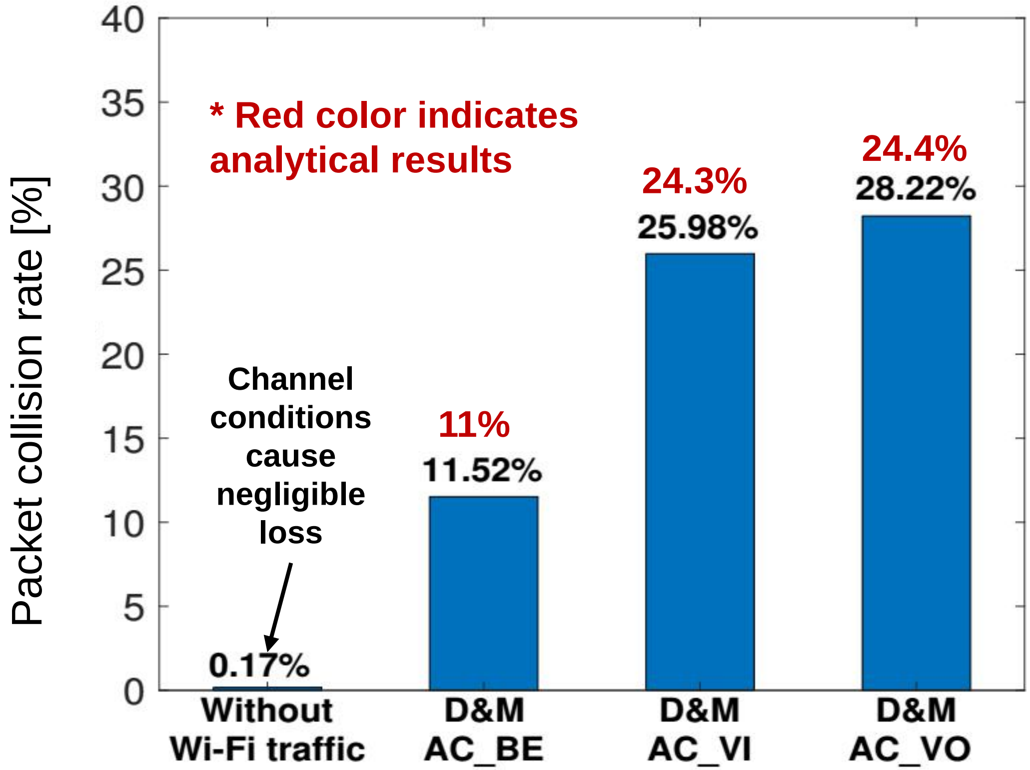
Post/ detection Phase—Simulation Study

- Simulation configuration
  - Two Wi-Fi device pairs located inside the buildings, Tx devices #1 and #2 always have packets ready to be sent
  - DSRC packets generated at 2.5 Hz
  - DSRC 2 cannot detect Wi-Fi 1 Tx and DSRC 1 cannot detect Wi-Fi 2 Tx
  - DSRC stationary mode
    - DSRC devices stand at 55m away from intersection center
  - DSRC mobile mode
    - DSRC devices move from 200 m away to intersection center at 10 m/s



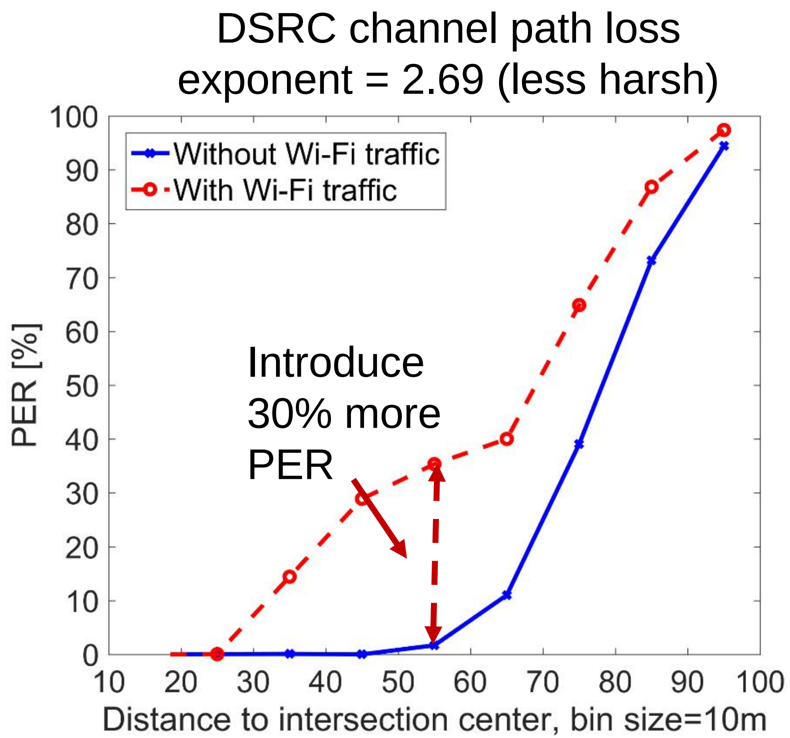
Post/ detection Phase—Simulation Study

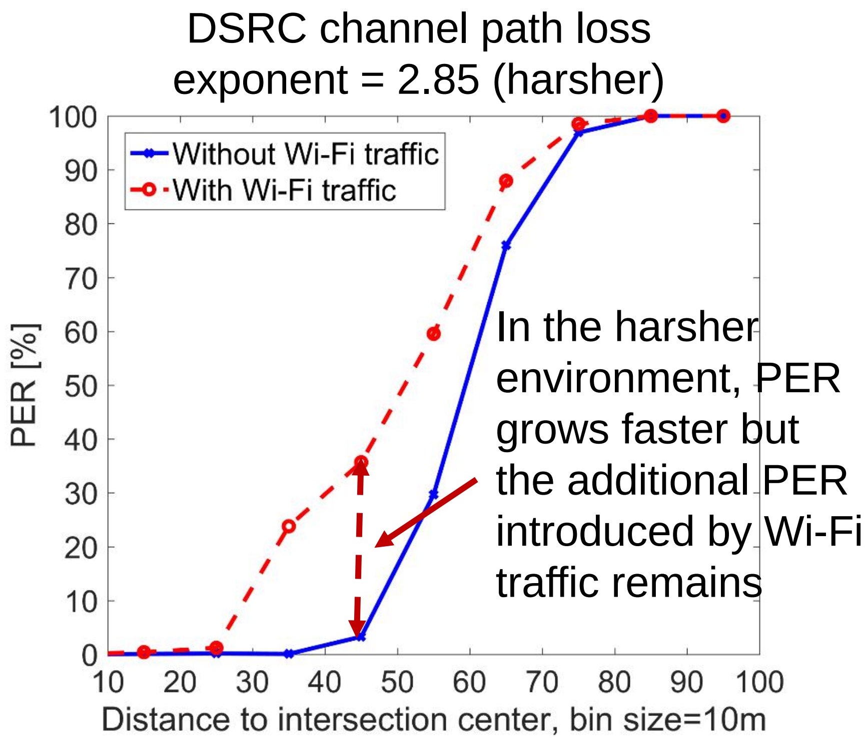
- DSRC stationary mode
  - All Wi-Fi cases induce non-negligible DSRC PER; AC_VO is worst
  - Simulation results and analytical results are close



Post/ detection Phase—Simulation Study

- DSRC mobile mode
  - The DSRC PER in the post-detection phase with Wi-Fi devices transmitting in AC_VO access category





Conlusion

- Studied the two mechanisms for sharing the DSRC band with unlicensed devices, such as Wi-Fi, in two phases, under realistic and challenging conditions
  - **Pre-detection phase**
    - Both D&V and D&M suffer from **delayed detection**
    - In the cases evaluated, about 20 DSRC transmissions are required before the Wi-Fi device can detect DSRC presence
    - By adding 266μsec to the Wi-Fi inter-transmission interval, the detection performance is significantly improved
  - **Post-detection phase**
    - Due to lack of mutual detection, D&M suffers from **unilateral hidden terminal** problem after DSRC detection
    - In the cases evaluated, up to 30% extra packet loss is introduced to DSRC transmissions by the Wi-Fi traffic

Thank you for listening