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Coexistence Challenges between RLANs and ETSI ITS-G5 at 5.9GHz for Future Connected Vehicles

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Smart Mobility Workshop, Luxembourg

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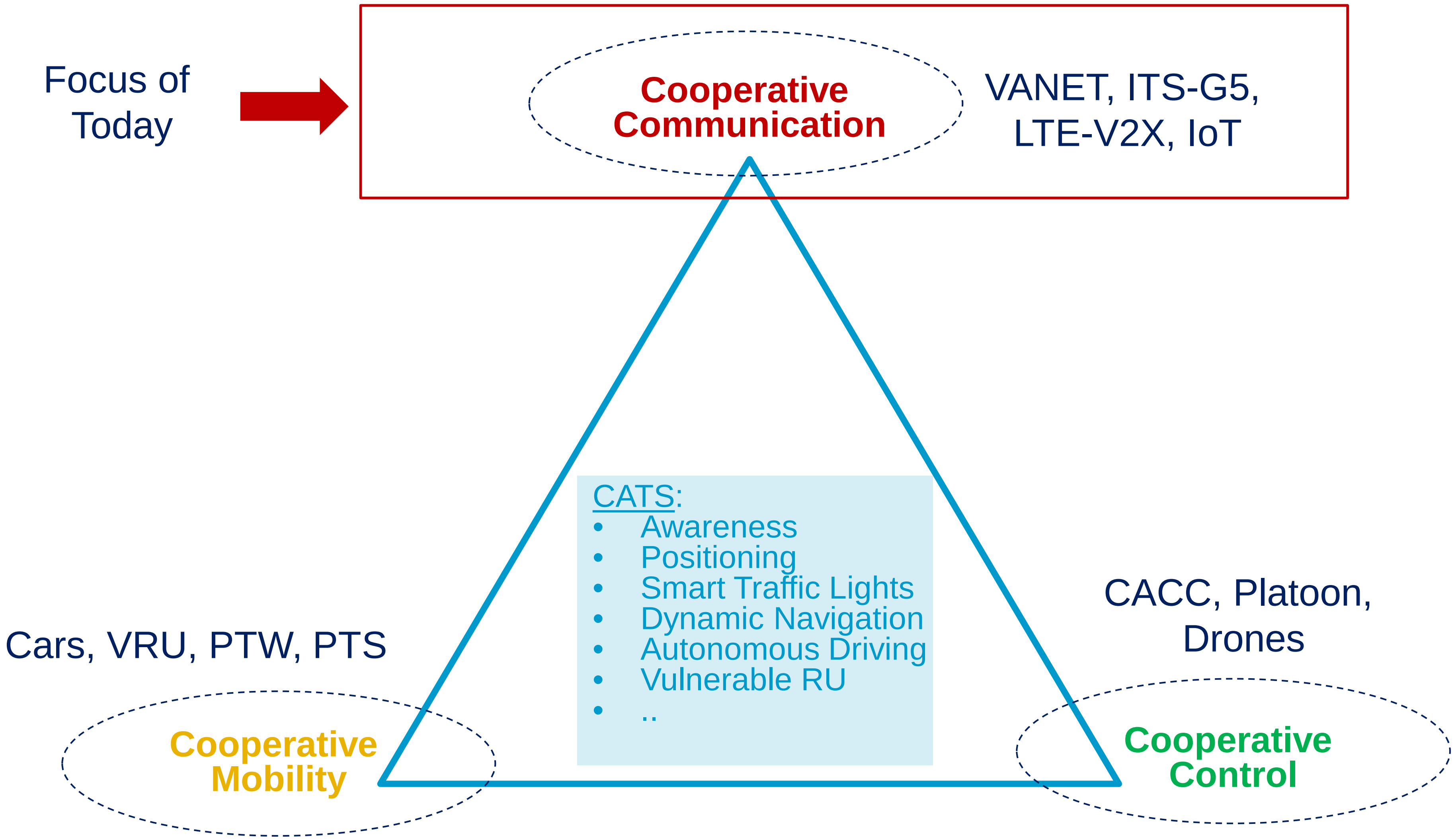
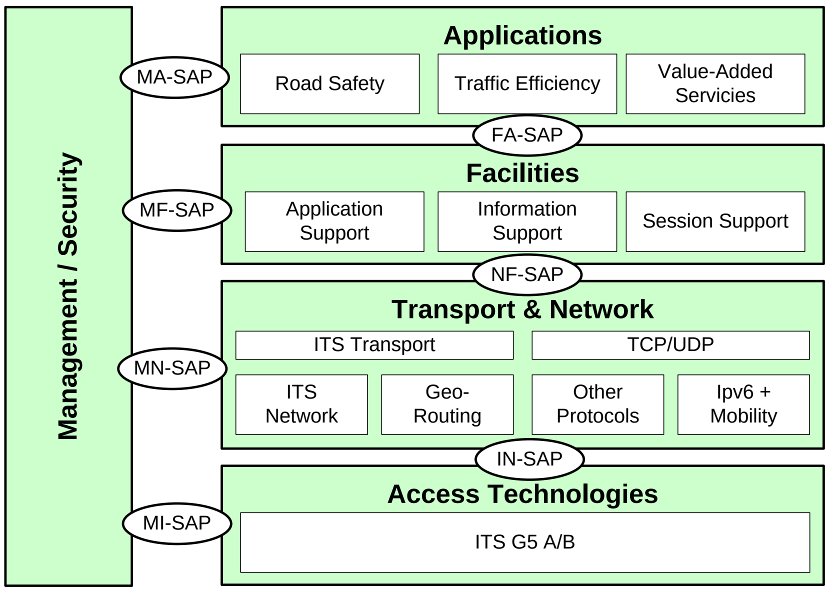
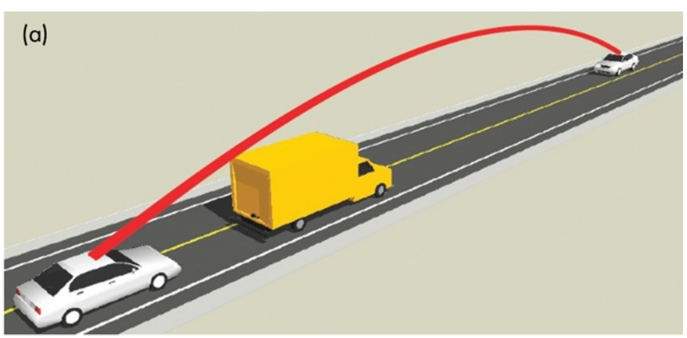
Cooperative Automated Transport Systems (CATS)



V2X Cooperative Communications - Architecture, Technologies & Applications

ETSI Technical Committee on ITS



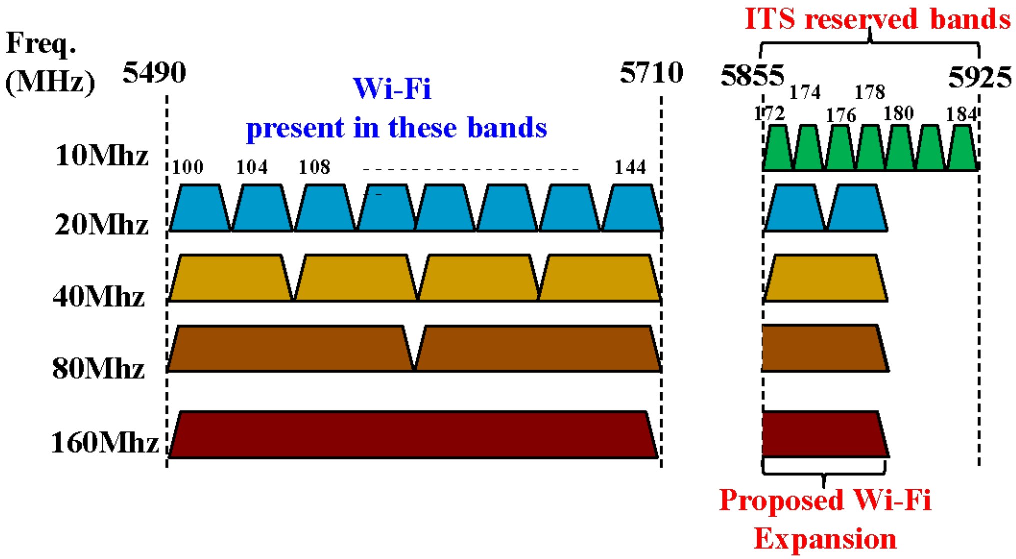


Source: C2C-CC

- **Applications**
  - Active Road Safety
    - Cooperative awareness
    - Hazard warning
  - Cooperative Traffic Efficiency
    - Adaptive speed management
    - Cooperative navigation

- **Technology**
  - ETSI ITS-G5
    - IEEE 802.11 for vehicular environment
    - a.k.a: 802.11p, DSRC in the US

Coexistence Challenge in the ITS-G5 band



- **ITS-G5 (A) band is restricted to safety-related V2X communications**
  - ITS-G5 (B) is reserved for non-safety-related but not EU-wide available
- **Altogether, 70Mhz spectrum is reserved for ITS**
  - But only 10Mhz is currently used !!
- **RLAN/WiFi has 220 Mhz spectrum for WiFi at 5.5GHz**
  - New IEEE 802.11ac allows 80Mhz and 160Mhz channels
  - The RLAN band is not sufficient anymore..
- **The WiFi industry requested access to the ITS band**
  - EU/US regulators are expected to allow them access under the principle of '**detect and avoid**' with ITS-G5

Coexistence between WiFi and ITS-G5

- **General Principles of coexistence**
  - WiFi may use the ITS spectrum as long as no harmful interference against ITS-G5 is created
  - WiFi must constantly attempt to 'detect' ITS-G5 traffic
    - If ITS-G5 is detected, WiFi must avoid transmitting WiFi traffic

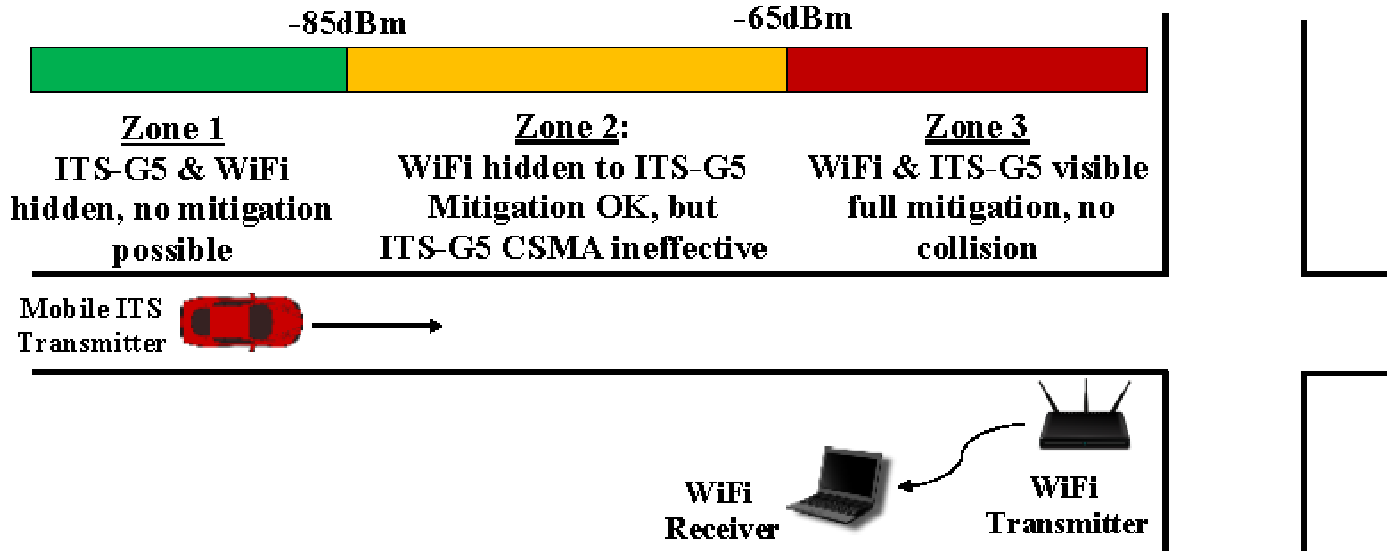
- **Can WiFi detect ITS-G5?**
  - WiFi is 20Mhz, while ITS-G5 is 10Mhz…
  - From IEEE 802.11-2016:
    - CCA classify the channel as busy when another WiFi traffic is detected with energy > -85dBm
    - CCA requires to be able to decode a preamble !!
    - If the preamble cannot be detected, CCA returns channel busy for (any) energy only > -65dBm
  - Answer is: **it can't !!**

- **WiFi industry proposed two coexistence protocols**
  - <u>Detect and Mitigate</u> – detect ITS-G5 and mitigate interference through adapted EDCA
  - <u>Detect and Vacate</u> – detect ITS-G5 and vacate the channel when detected

- **ETSI BRAN finishes the Technical Report TR 103 319**
  - '5GHz RLAN sharing with transport' to be published in June 2017
  - Two coexistence proposal evaluated
  - Detailed parameters evaluated and defined in the regulation process

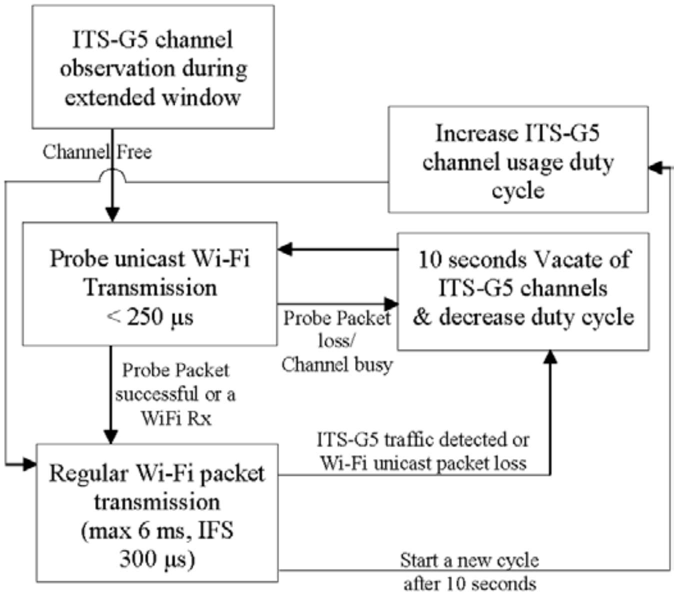
WiFi - ITS-G5 Coexistence – the Asymmetric Detection Challenge

- **Energy Detection:**
  - ITS-G5 – no adaptation
    - Detect ITS-G5 preamble at -92dBm
    - Detect any other traffic at -65dBm
  - WiFi – requires a 10Mhz preamble detector
    - Detects ITS-G5 AND WiFi at -85dBm
  - **Leads to Asymmetric detection…**

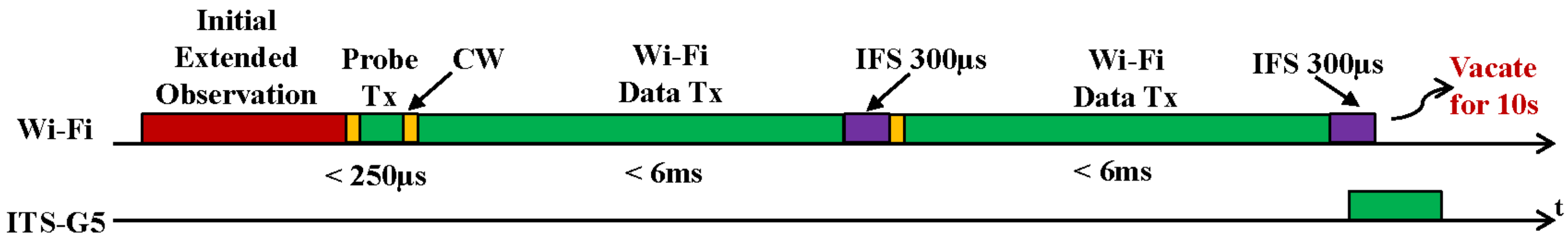


Detect and Vacate Proposal

- **Energy Detect:**
  - DAV – WiFi <u>MUST</u> have a 10Mhz preamble detector
  - WiFi channel busy:
    - ITS-G5 energy > -85dBm



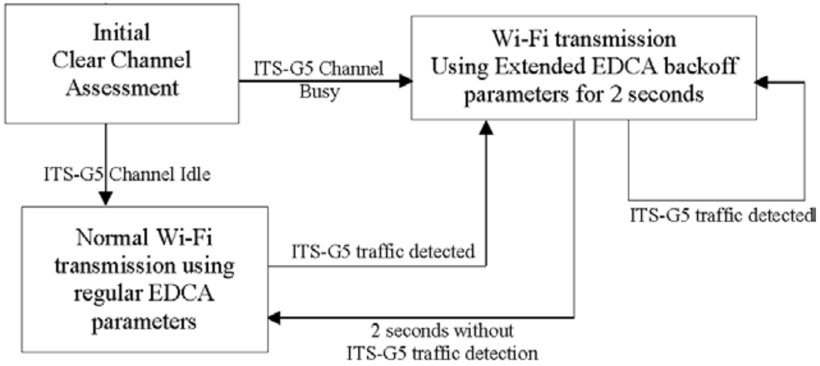
- **Mitigation**
  - Monitor 1ms
  - Send a probe packet
  - Leave a gab between two large packet
  - If at any step, ITS-G5 detected, vacate 10s

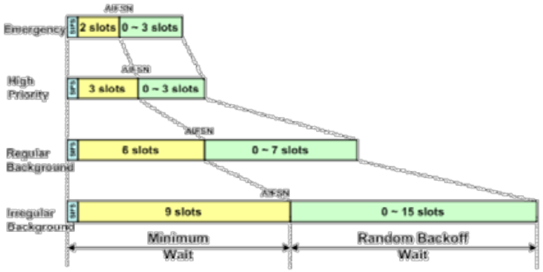


Detect and Mitigate Proposal

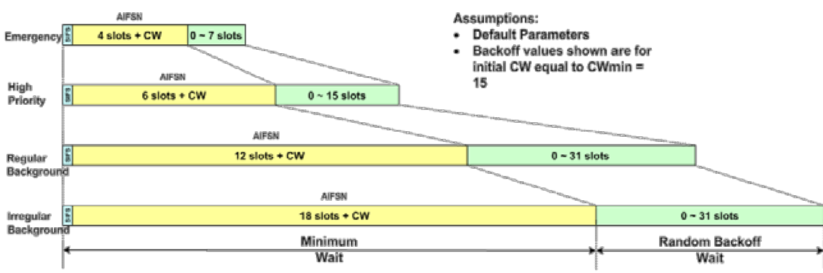
- **Energy Detect:**
  - DAV – WiFi <u>MUST</u> have a 10Mhz preamble detector
  - WiFi channel busy:
    - ITS-G5 energy > -85dBm/10Mhz
- **Mitigation**
  - If ITS-G5 detected, enter a DAM EDCA mitigation for at least 2s
  - For each AC:
    - DAM EDCA > ITS-G5 EDCA
  - Three variations:
    - Reduced EDCA: ITS-G5 priority on first detect
    - Absolute EDCA A: ITS-G5 priority also during mitigation
    - Absolute EDCA B: slow return to Relative EDCA once no ITS-G5 traffic detected (instead of mitigation stop)

AC	CW min	CW max	AIFSN (Reduced)	AIFSN (Abs)	TXOP Limit (Reduced)	TXOP Limit (Abs)
BK	31	2047	49	2065	2528 ms	2258 ms
BE	31	2047	43	2059	2528 ms	2258 ms
VI	15	31	21	1029	3000 ms	3008 ms
VO	7	15	11	515	2080 ms	1504 ms





(a) ITS-G5 EDCA parameters



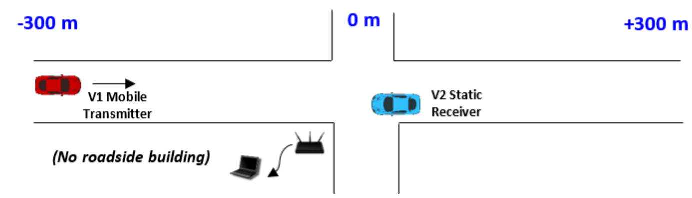
(b) DAM extended EDCA parameters for RLAN

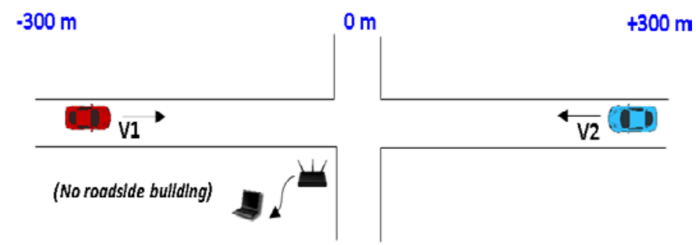
Coexistence Evaluation

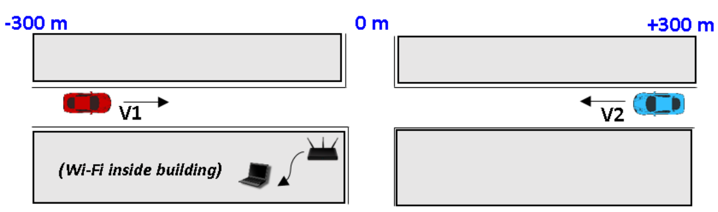
Simulation Parameters:

Parameter	Value
Transmit Power	23 dBm
Transmit Rate	ITS-G5: 10 [Hz], 300 [Bytes] RLAN: ~300 [Hz] @ 2250 [Bytes]: 6.0 [Mbps]
Packet Transmit time	ITS-G5: 0.5 [msec] RLAN: 1.9 msec / 3 [s]
Preamble Detection Threshold	ITS-G5 → ITS-G5: -92 [dBm/10MHz] ITS-G5 → RLAN: -65 [dBm/10MHz] RLAN → ITS-G5: -85 [dBm/10MHz]
Mobility	10 [m/s]
EDCA queue	ITS-G5: AC_BE RLAN: AC_VO, AC_VI / AC_BE
Fading	WINNER B1 (Urban Microcell) (Correlated Gaussian & Ricean)
Performance Indicators	Packet Reception Rate (PRR) Inter-Reception Time (IRT) (95 % Confidence Intervals; >1000 runs)

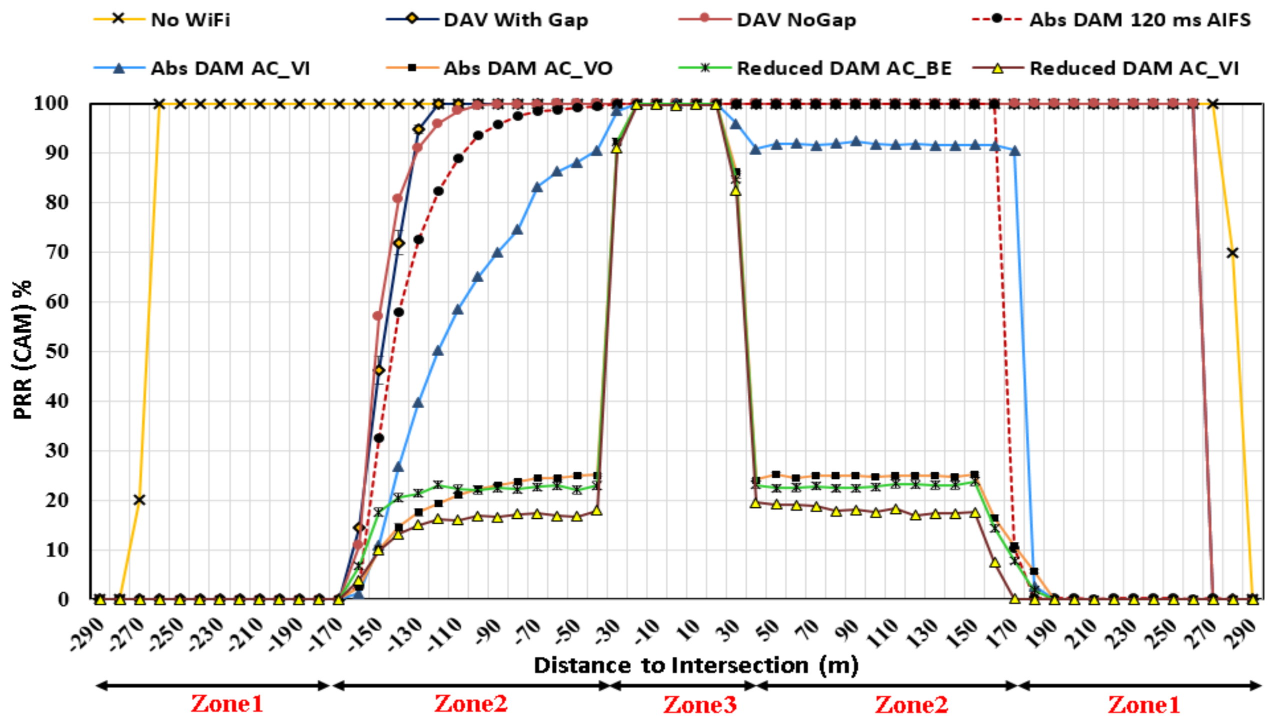
Simulation Scenarios:

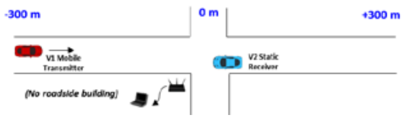






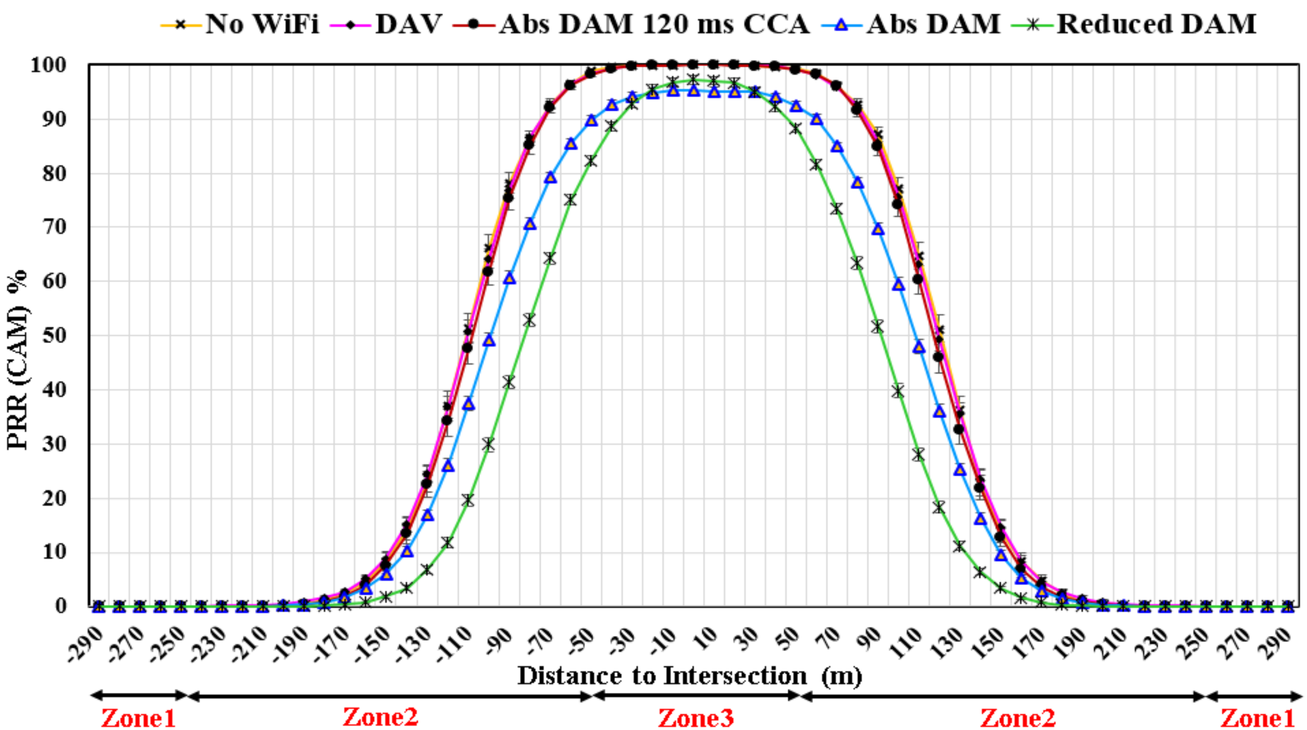
Scenario A – Static RX, Mobile TX, outdoor

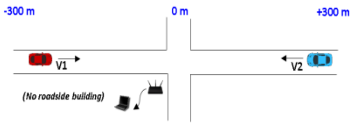




- ***DAM relative EDCA*** cannot ensure a sufficient protection of ITS-G5.
- ***DAM absolute EDCA (Plan A)*** cannot provide absolute priority to ITS-G5 traffic for WiFi traffic classes Voice (AC_VO) and Video (AC_VI)
- ***DAM absolute EDCA (Plan A) (120ms fixed AIFS)*** significantly improves the performance of the DAM protocol.
- **DAV** provides good protection at close range

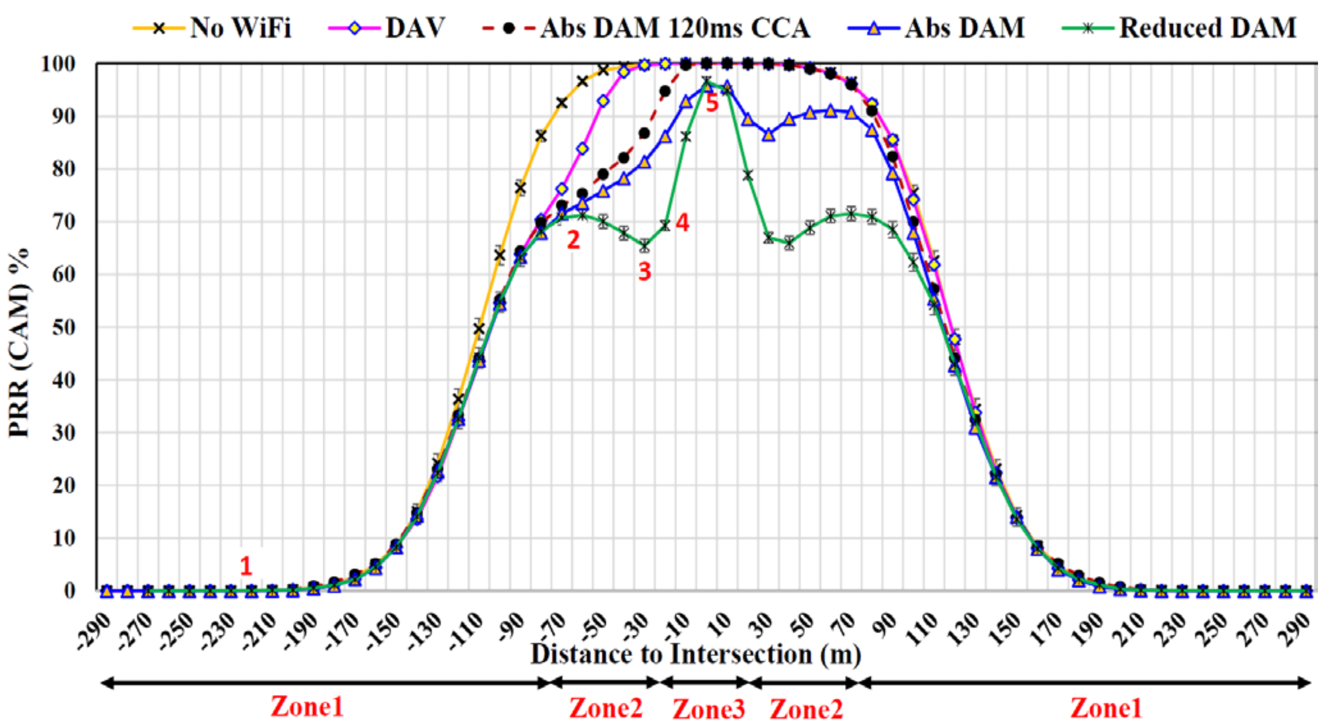
Scenario B –Mobile TX/RX, outdoor

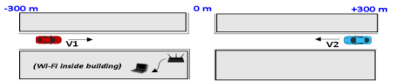




- **DAM reduced/absolute EDCA** - both generate non negligible interferences against ITS-G5
- **DAV and absolute EDCA (Plan A) (120ms fixed AIFS)** - provide similar performance as a case without WiFi
- **DAM relative/absolute EDCA do not provide sufficient protection compare to DAV** or DAM 120ms fixed AIFS

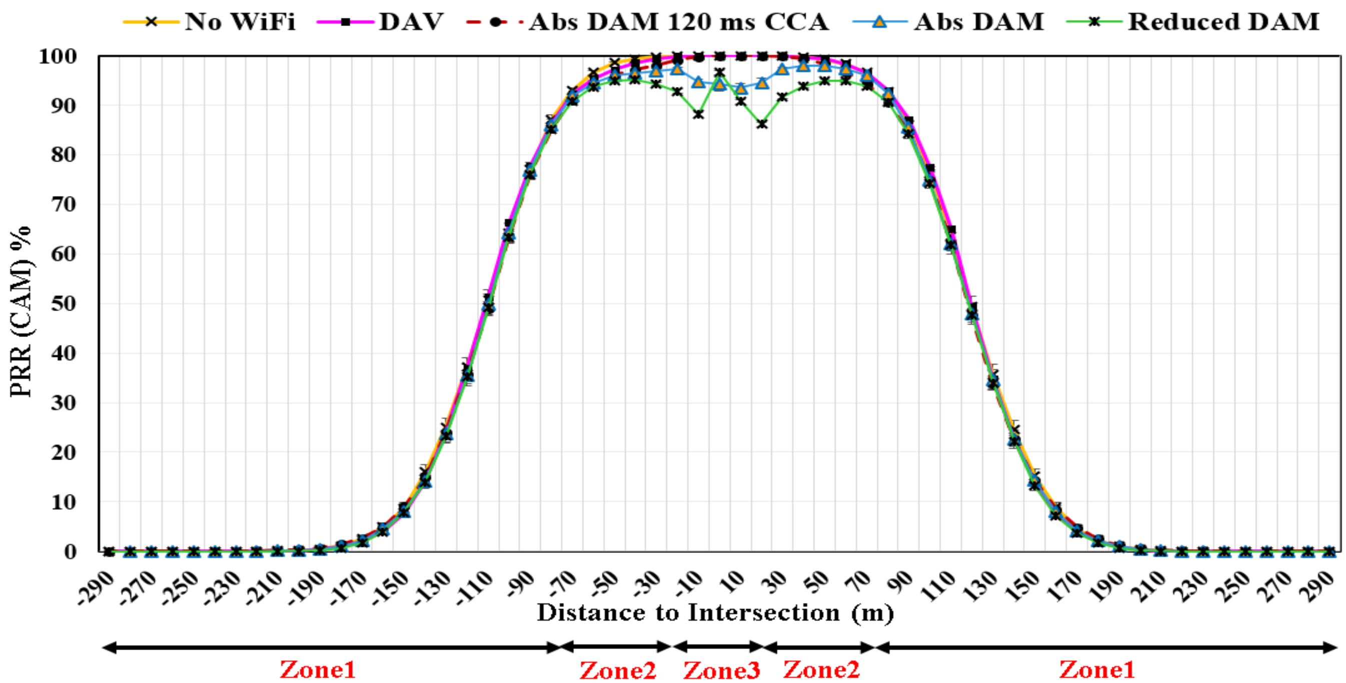
Scenario B –Mobile TX/RX, Indoor

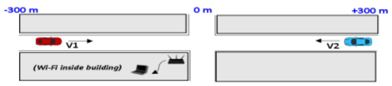




- **DAM provide significant interference to ITS-G5**
- **DAV cannot avoid minor interference on ITS-G5 either**
  - But its impact is smaller
- <u>Conclusion</u>:
  - Indoor WiFi is expected to be more problematic to ITS-G5 than Outdoor WiFi

Scenario B –Mobile TX/RX, Indoor, Reduced Tx

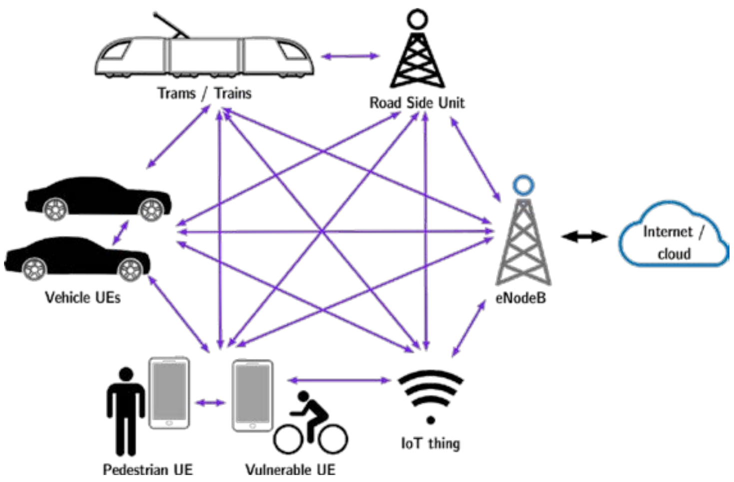




- **WiFi AP/MN Tx power is restricted to 10dBm (case study)**
  - ➢ Will generate less interference to ITS-G5
- **DAV follows the no-WiFi curve**
- **DAM still provides non negligible interference against ITS-G5**
  - ➢ Indoor WiFi is expected to have a restricted profile in 5.9Ghz

Next Challenge: Coexistence ITS-G5 – LTE-V2X

- **3GPP has started the specification of a LTE based V2X system in Q1/2016**
  - OFDMA based (resource allocation in time and frequency)
  - Cellular based with controlled ad-hoc component (D2D, sidelink)
  - TDMA with GPS synchronization in D2D mode



- **The LTE-V2X system should share the spectrum resources with ITS-G5**
  - Co-channel sharing not possible yet
  - Adjacent channel sharing might be solution

- **Regulatory status of LTE-V2X is not clear**
  - Coexistence assumptions with incumbent services have to reviewed
  - Issues: communication with any ‘thing’

RLAN Coexistence with ITS-G5

- **ITS-G5 will no longer have its 'own' band…**
  - Coexist with ITS-G5 and LTE-V2X and (…)
- **WiFi technology will be granted access to the ITS-G5 under the basis of 'detect-and-avoid' rule**
  - ITS-G5 is primary user, WiFi secondary (non-safety-related traffic)
- **WiFi needs to detect ITS-G5 (and differentiate against other technologies)**
  - WiFi in 5.9Ghz must have a 10Mhz ITS-G5 preamble detector…but this is not enough !!
- **Two Protocols proposed by industry: DAM & DAV**
  - Both lead to interference with ITS-G5
- **Coexistence will need to be integrated in future C-ITS**
  - Impacts ITS-G5 communication and as such Smart Mobility applications !!

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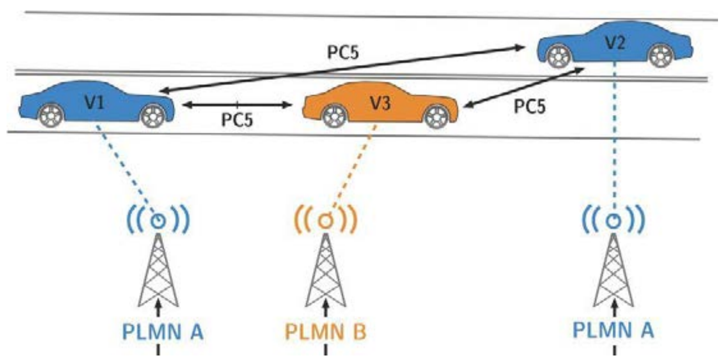
Backup Slides

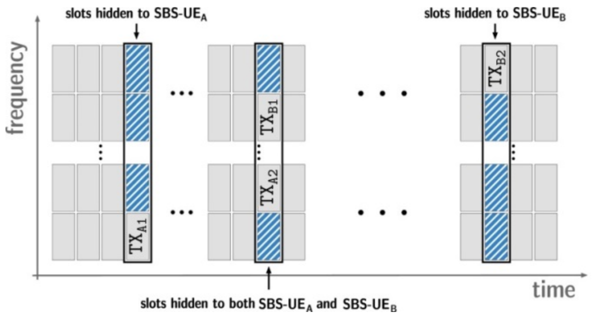
CATS LAB – RELATED WORKS

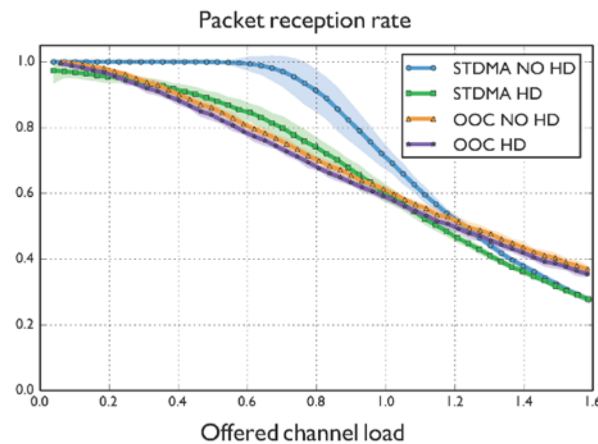
Cooperative Awareness– Cellular Ad-Hoc LTE-V2X

- **LTE-V2X Radio Resource Management**
  - <u>Supervised</u>: centralized RRM (eNB)
  - <u>Unsupervised</u>: distributed RRM
    - <u>Challenge</u>: avoid collision !!
  - Resource Allocation Mechanism:
    - <u>Random</u> – Optical Orthogonal Codes
    - <u>TDMA</u> – Self-Organized TDMA



- **LTE-V2X Mode 4 (unsupervised)**
  - <u>Advantage:</u>
    - Does not rely on any infrastructure
  - <u>Drawback</u>
    - Synchronization
    - Half-duplex
    - <u>…</u>

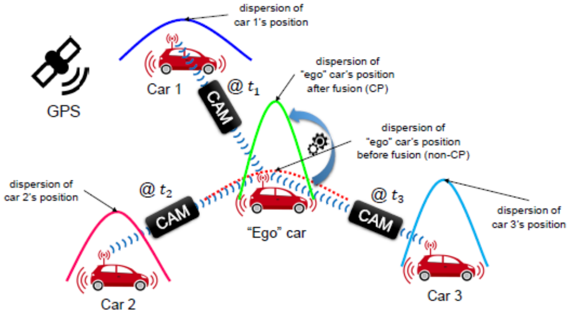


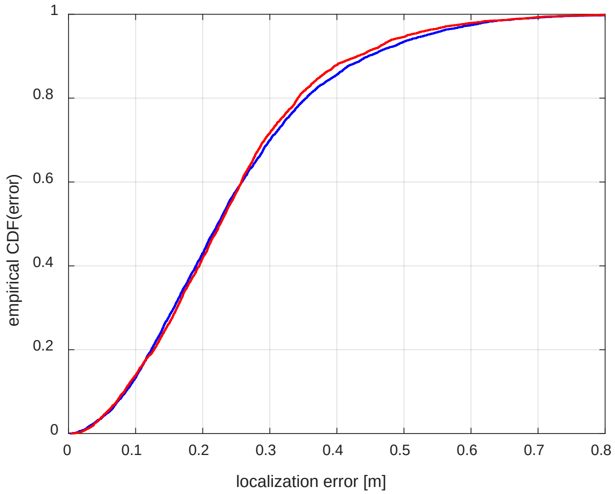


- **Selected Publications:**
  - Laurent Gallo, Jérôme Härri, **Unsupervised LTE D2D -– Case Study for Safety-Critical V2X Communications**, *IEEE Vehicular Technology Magazine, 2017.*
  - Laurent Gallo, Jérôme Härri, **Analytical Study of Self-organizing TDMA for V2X Communications**, *1st IEEE ICC Workshop on Dependable Vehicular Communications*, 2015
  - Gallo, Laurent; Härri, Jérôme**, Short paper: A LTE-direct broadcast mechanism for periodic vehicular safety communications**, *IEEE Vehicular Networking Conference (VNC)*, 2013.

High Precision Positioning – Cooperative V2X Localization

- **Non-cooperative Localization:**
  - Use of GPS and known fixed anchors
  - Use on-board devices (laser scanners, radars..)
- **Cooperative Localization:**
  - Use Cooperating vehicles as landmark
  - Neighbor selection for optimal tessellation
- **Challenges -**
  - Asynchronous sampling
  - Not all neighbors are born identical
  - Correlation (space and time) in samples
  - Fusion of heterogeneous sensors

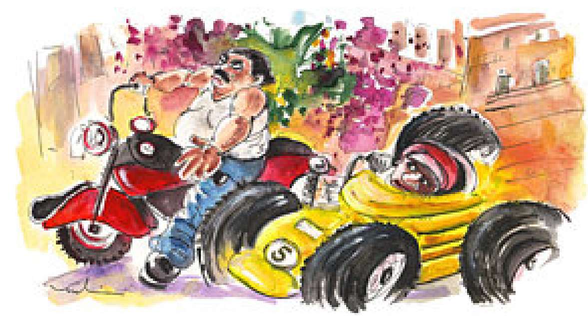




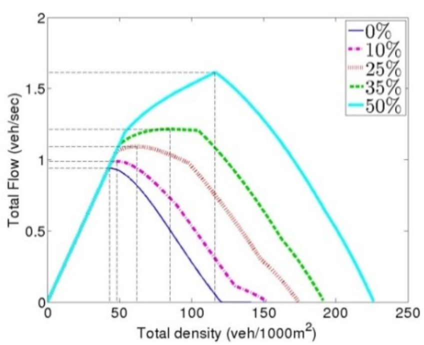
- **Selected Publications:**
  - Gia-Minh Hoang, Benoît Denis, Jérôme Härri, Dirk TM Slock, **Breaking the Gridlock of Spatial Correlation in GPS-aided IEEE 802.11p-based Cooperative Positioning**, *IEEE Transaction on Vehicular Technology*, 2016
  - Gia Minh Hoang, Benoît Denis, Jérôme Härri, Dirk TM Slock**, Select Thy Neighbors: Low Complexity Link Selection for High Precision Cooperative Vehicular Localization**, *IEEE Vehicular Networking Conference (VNC)*, 2016, Kyoto, Japan
  - Minh Gia Hoang, Benoît Denis, Jérôme Härri, Dirk TM Slock, **Cooperative Localization in GNSS-Aided VANETs with Accurate IR-UWB Range Measurements**, 13th *IEEE Workshop on 13th Workshop on Positioning, Navigation and Communications (WPNC)*,

Cooperative Mobility Modeling – Powered-Two Wheelers for Smart Traffic Lights

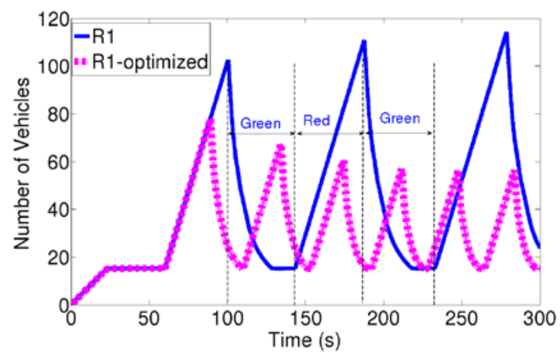
- **Powered-Two Wheelers (PTW):**
  - Increasing presence in road traffic
  - Lack of knowledge of their influence on traffic flows
  - Critical impact on Smart Cities and Road Automations
  - C-ITS applications are not adapted to PTW
    - New WG at CAR 2 CAR in 2016



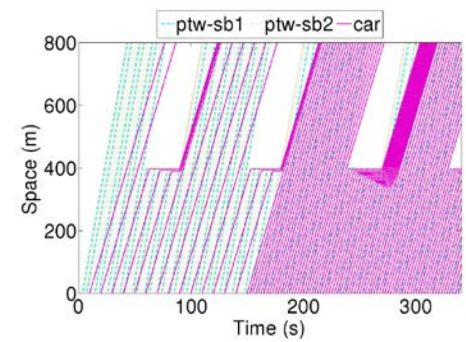
Improved Road Capacity



Optimized Traffic Lights



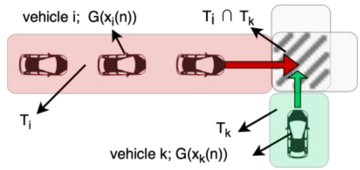
Enhanced Safety

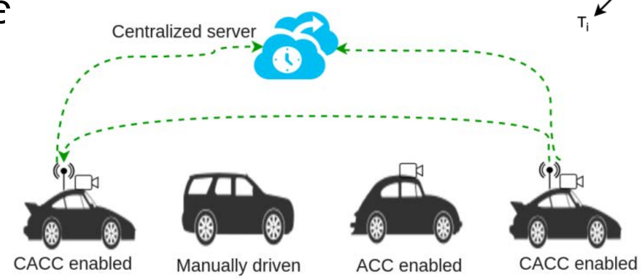


- **Selected Publications:**
  - Sosina Gashaw, Paola Goatin, Jérôme Härri, **Modeling and Analysis of Mixed Flow of Cars and Powered Two-wheelers**, *Elsevier Transportation Research Part C*, under review.
  - Sosina Gashaw, Paola Goatin, Jérôme Härri, **Analysis of the effect of Powered two wheelers on adaptive traffic signals operation,** *8th International Conference on Mobility and Transport (Mobil.TUM)*, TU Munich, Germany 2017.
  - Sosina Gashaw, Paola Goatin, Jérôme Härri, **Modeling and analysis of mixed flow of cars and powered two wheeelers**, *Transport Research Board (TRB) Annual Meeting*, Washington DC, 2017

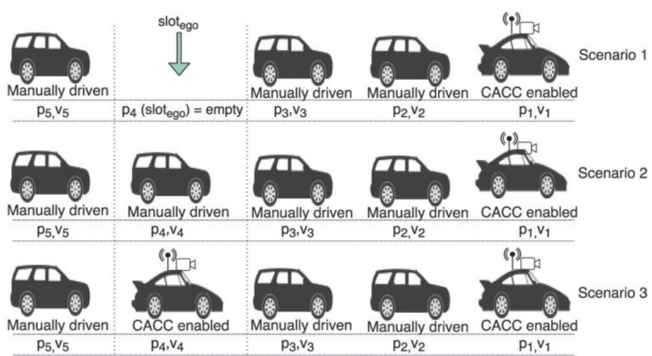
Cooperative Control – Mixed Automated Vehicles at Low Penetration

- **Mixed Automated / Legacy Traffic:**
  - Automated vehicles represents the future of transportation
  - They will need to share road with legacy vehicles
  - Challenge: how can automated vehicle help avoid collision ?





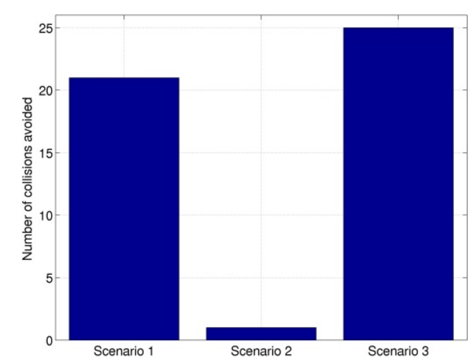
Scenario:



Benefits

- Automated vehicle allows capacity increase at no safety reduction
- Already at low penetration !!

Collision mitigation



- **Selected Publications:**
  - Raj Haresh Patel, Jérôme Härri, Christian Bonnet, **Cooperative Braking in Mixed Traffic Scenario considering Imperfect Position Information,** *8th International Conference on Mobility and Transport (Mobil.TUM)*, TU Munich, 2017..
  - Raj Haresh Patel, Jérôme Härri, Christian Bonnet, **Braking strategy for an autonomous vehicle in a mixed traffic scenario,** accepted, *3rd IEEE Conference on Vehicle Technology and Intelligent Transport Systems*, 2017, Porto, Portugal.