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V2X Communications in Future 5G Automotive and Transportation

Prof. Dr. Jérôme HÄRRI,

based on the PhD work of Dr. Laurent GALLO

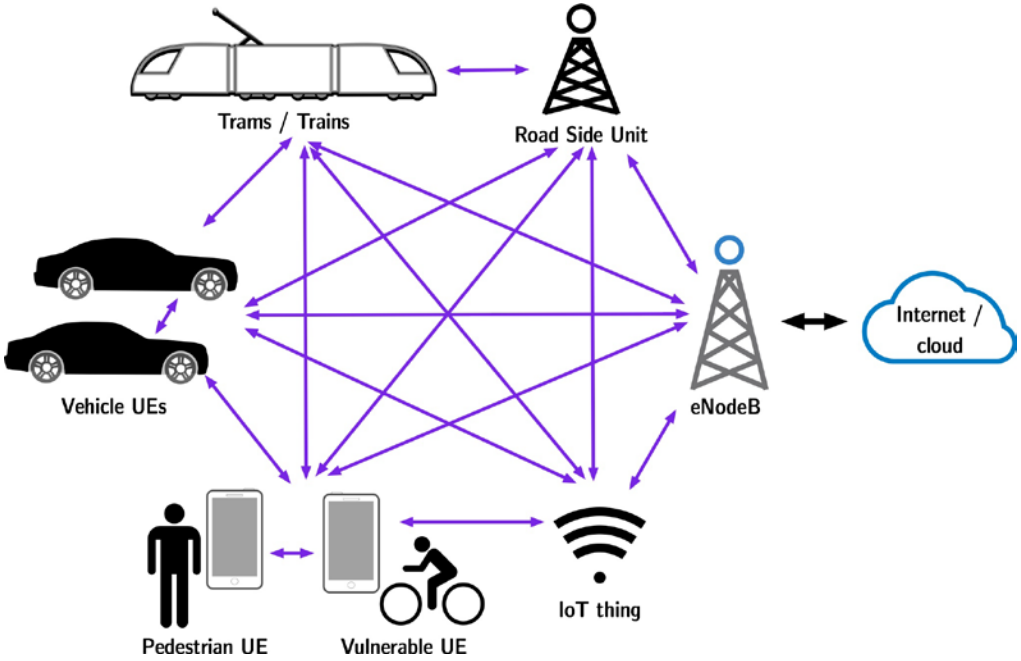
FCA 5G Workshop, Turin July 5th 2017

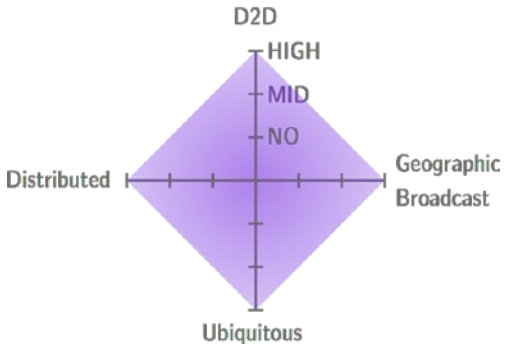
Cti
Commission des Titres d'Ingénieur

Objective: Ubiquitous Communications

Today

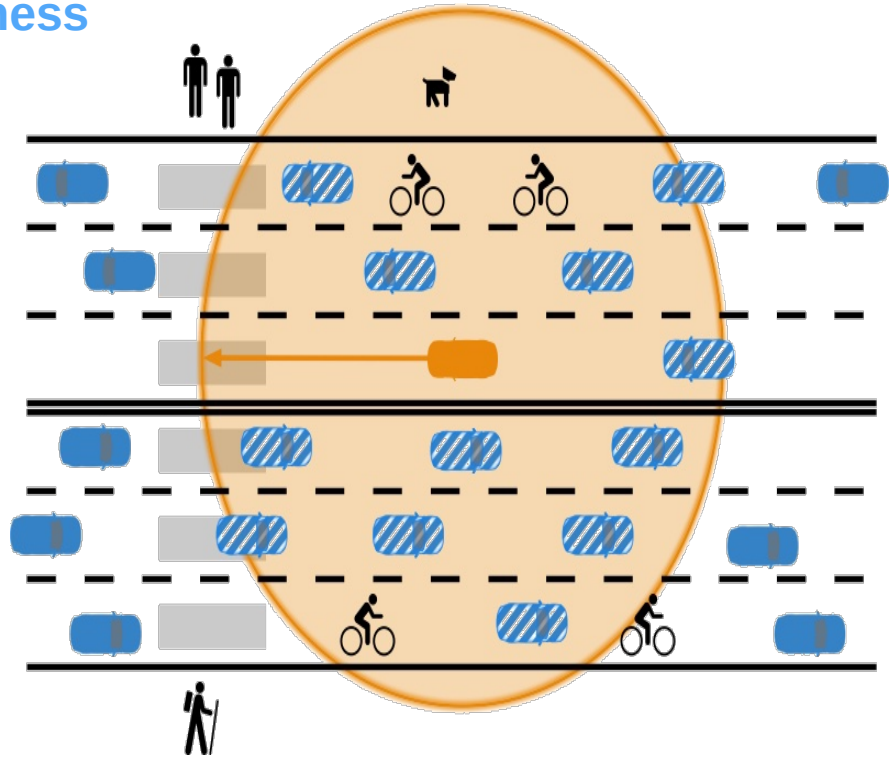
- **Entities connected everywhere**
- **Four pillars:**
  - **Device-to-Device**
  - **Geographic Broadcast**
  - **Distributed channel access**
  - **Ubiquitous**





FOCUS on: safety critical V2X

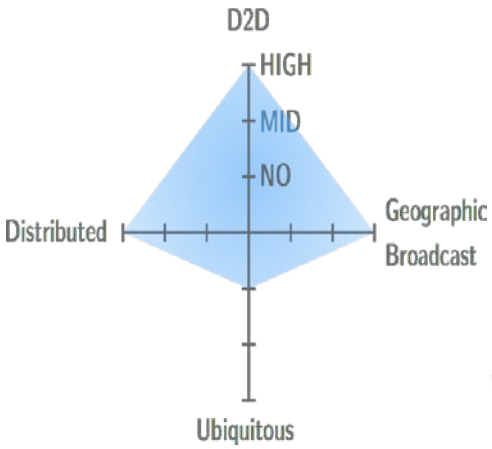
- **Periodical position / speed / heading updates (CAM / BSM)**
- **Geographic broadcast: all of the road users in proximity are recipients**
- **Purpose: spread and acquire awareness**
- **Local broadcast**
- **Delay-sensitive information**
- **Building block for Cooperative Intelligent Transportation Systems (C-ITS)**

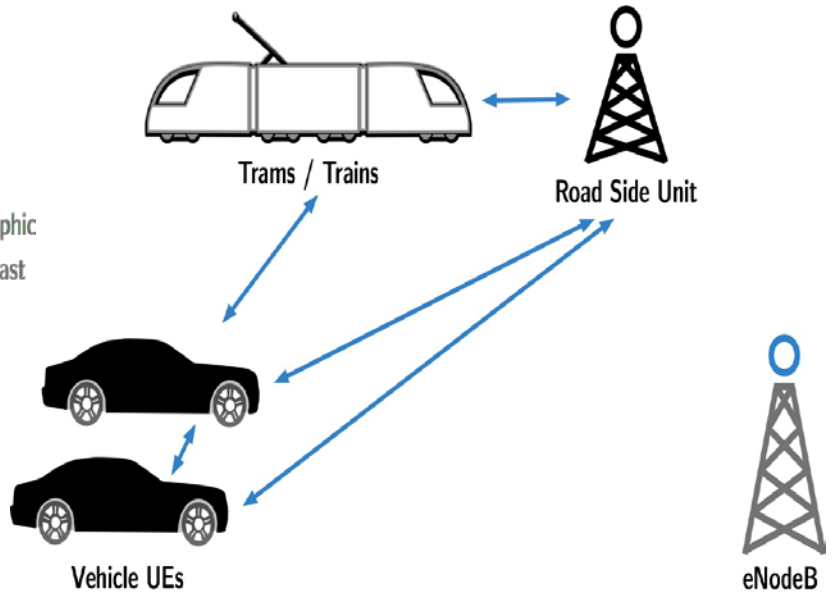


State-of-Art in 2012

2004 - present

IEEE 802.11p
ITS-G5 (EU)
DSRC (USA)





Extension of WiFi:

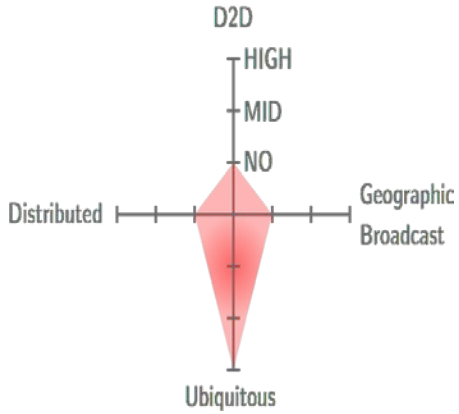
- **operates at 5.9 GHz**
- **out of the context of the BSS (full Ad-Hoc)**
- **designed for local D2D geographical broadcast**

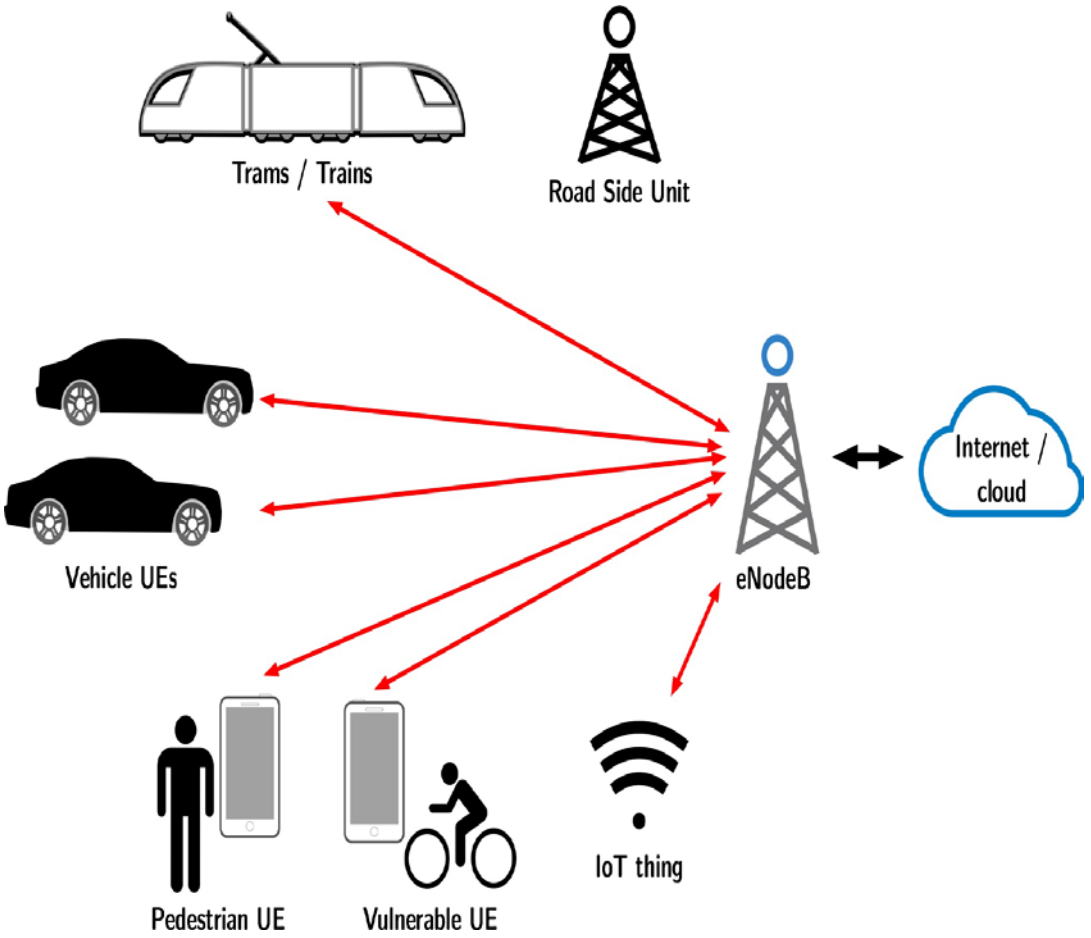
State-of-Art in 2012

2013

LTE (Rel 8 / 10)

Designed for network supervised communications





State-of-Art in 2014

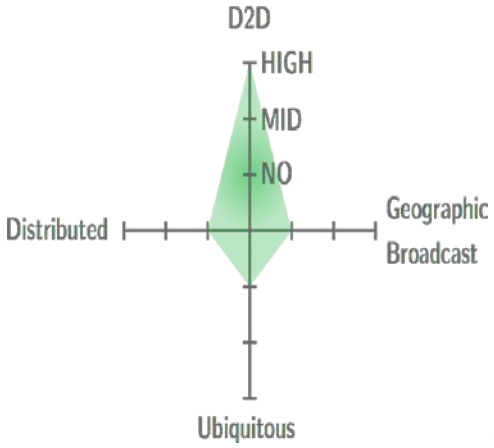
2014 +

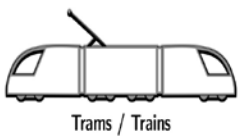
LTE Proximity Services (Rel 12)

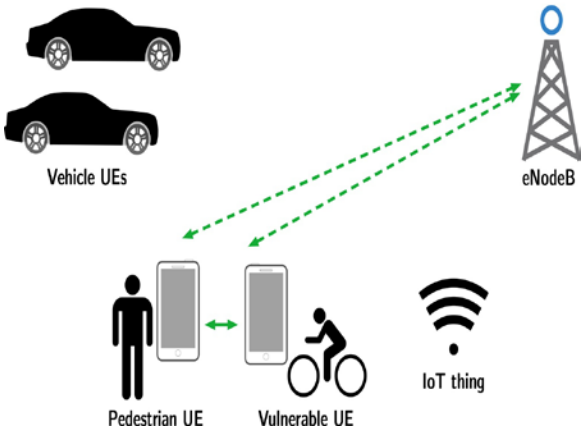
Direct D2D data path via the Sidelink

Mode 1: network supervised unicast transmissions.

Mode2: unsupervised transmissions, unicast / broadcast exclusively Public Safety UEs



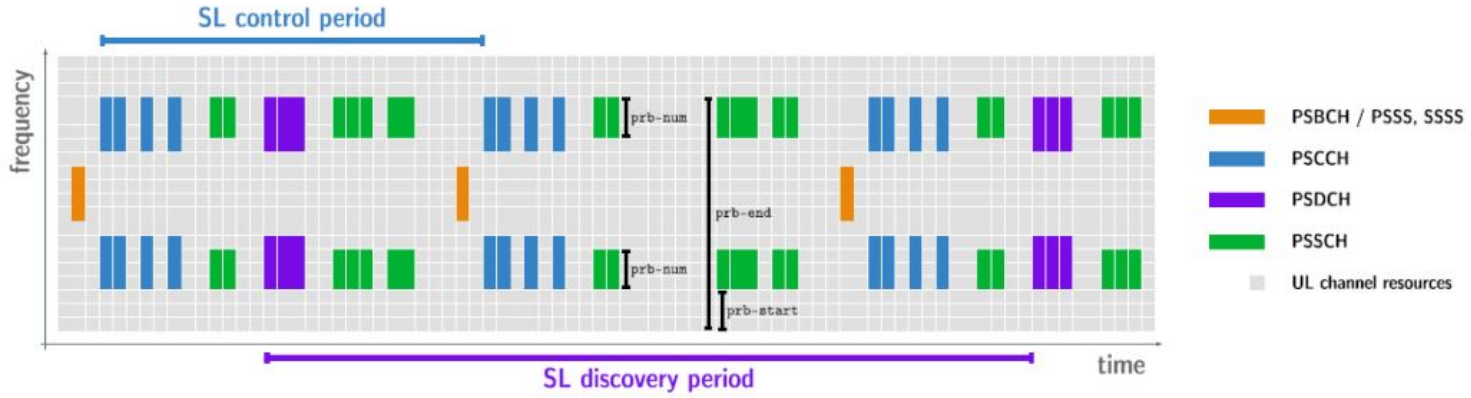




LTE V2X - LTE Rel. 14

2016

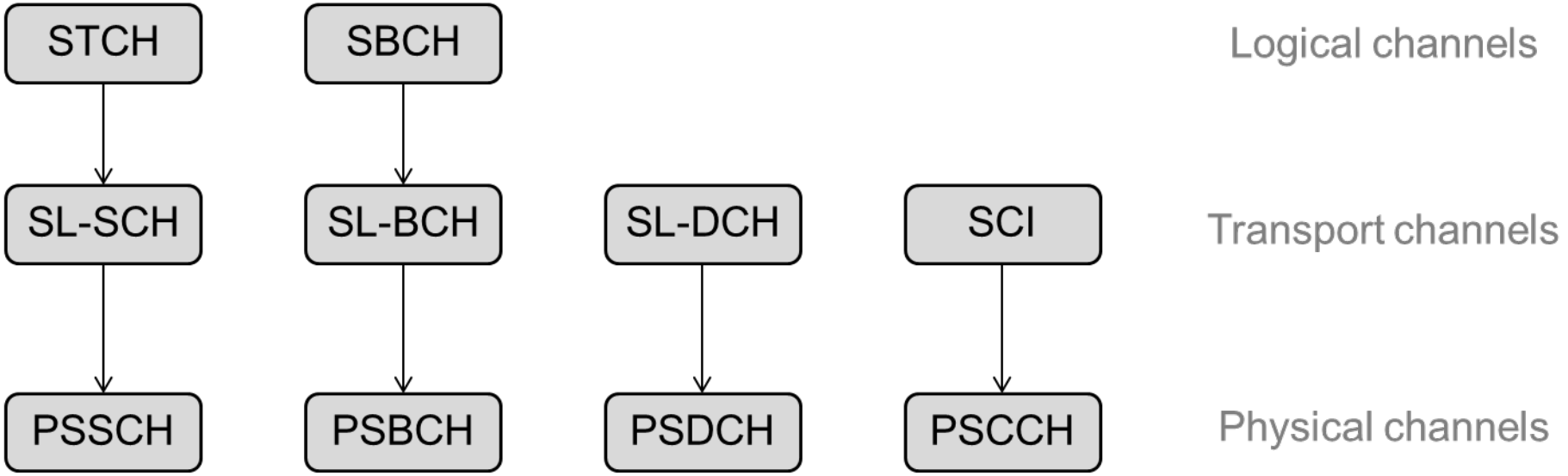
- **4 new Sidelink Channels**



- **Discovery: two modes (RBs pools indicated in SIB 19)**
  - Mode A: (I am here) – UEs advertise their presence to monitoring UEs
  - Mode B: (Who is here?) – UEs query other UEs about ProSe Services
  - Resource Allocation:
    - Mode 1: autonomous selection – random selection on PSDCH
    - Mode 2B: scheduled - eNB schedules resources on PSDCH
- **Communication: two modes (RBs pools indicated in SIB 21)**
  - Mode 3: Scheduled (by eNB) – eNB schedules resources on PSSCH
  - Mode 4: Autonomous (Ad-Hoc) – random selection on the PSSCH pool

LTE V2X - Sidelink Channels

2016



- ***PSCCH:*** Physical Sidelink Control Channel
- ***PSSCH:*** *Physical Sidelink Shared Channel*
- ***PSBCH:*** Physical Sidelink Broadcast Channel
- ***PSDCH:*** Physical Sidelink Discovery Channel

- **SL-SCH :** Sidelink Shared Channel
- **SL-BCH:** Slidelink Broadcast Channel
- **SL-DCH:** Sidelink Discovery Channel
- **SCI:** Sidelink Control Information
- **STCH:** Sidelink Transport Channel
- **SBCH:** Sidelink Broadcast Channel

3GPP rel. 14 'dissection' on V2X

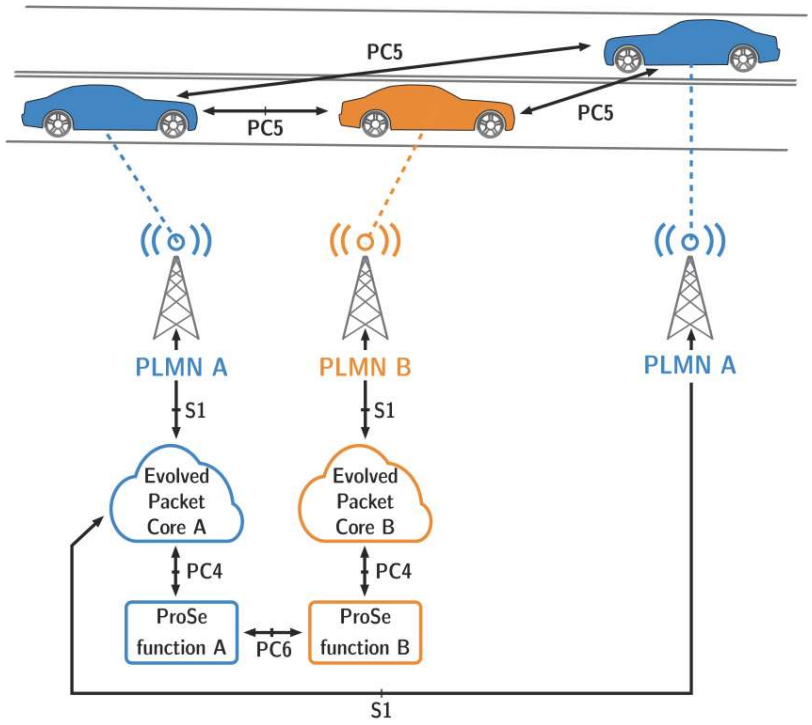
2016

- **Channels and UE functions:**
  - TS36.101 Evolved Universal Terrestrial Radio Access (E-UTRA); User Equipment (UE) radio transmission and reception
- **PHY:**
  - TS 36 213 Evolved Universal Terrestrial Radio Access (E-UTRA); Physical layer procedures
  - TS 36 212 Evolved Universal Terrestrial Radio Access (E-UTRA); Multiplexing and channel coding
  - TS 36 211 Evolved Universal Terrestrial Radio Access (E-UTRA); Physical channels and modulation
- **MAC:**
  - TS 36.321 Evolved Universal Terrestrial Radio Access (E-UTRA); Medium Access Control (MAC) protocol specification
- **RRL:**
  - TS 36.331 – Evolved Universal Terrestrial Radio Access (E-UTRA); Radio Resource Control (RRC); Protocol specification
- **Service:**
  - TS 23.303 –Proximity-based services (ProSe); Stage 2
- **EPC**
  - TS 36.300 – Evolved Universal Terrestrial Radio Access (E-UTRA) and Evolved Universal Terrestrial Radio Access Network (E-UTRAN); Overall description; Stage 2

LTE V2X – Why Mode 4 for Safety V2X Communications?

2016

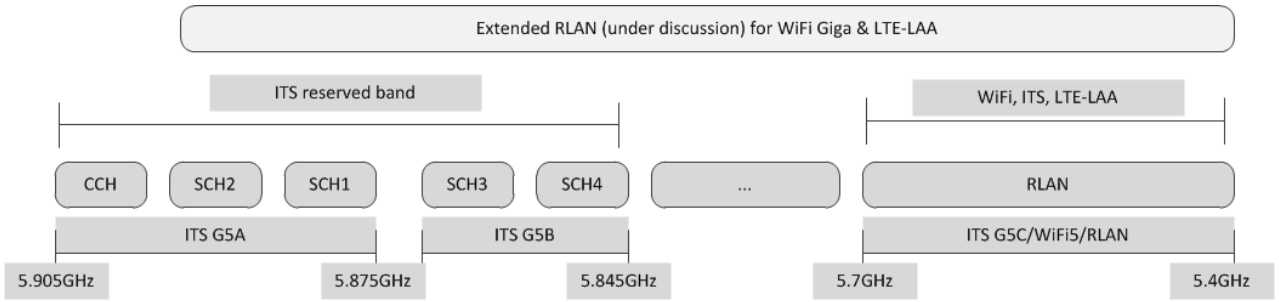
- **Safety-critical V2V Communication**
  - Need to reach any car at a given range
  - Regardless of:
    - being in coverage or not
    - being in same cell or not
    - being in same operator or not
- **ENB supervision is possible:**
  - Inter-cell D2D:
    - Synch between eNBs
    - Tx ‘borrows’ other cells RBs
  - Inter-operator D2D:
    - Synch between operators (PC6)
    - Tx ‘borrows’ other operator RBs
- **Yet…**
  - Standardization not complete
  - Delay not known
  - Broadcast still difficult
  - Not efficient from a spectrum & energy perspective



LTE V2X – Why Mode 4 for Safety V2X Communications?

2016

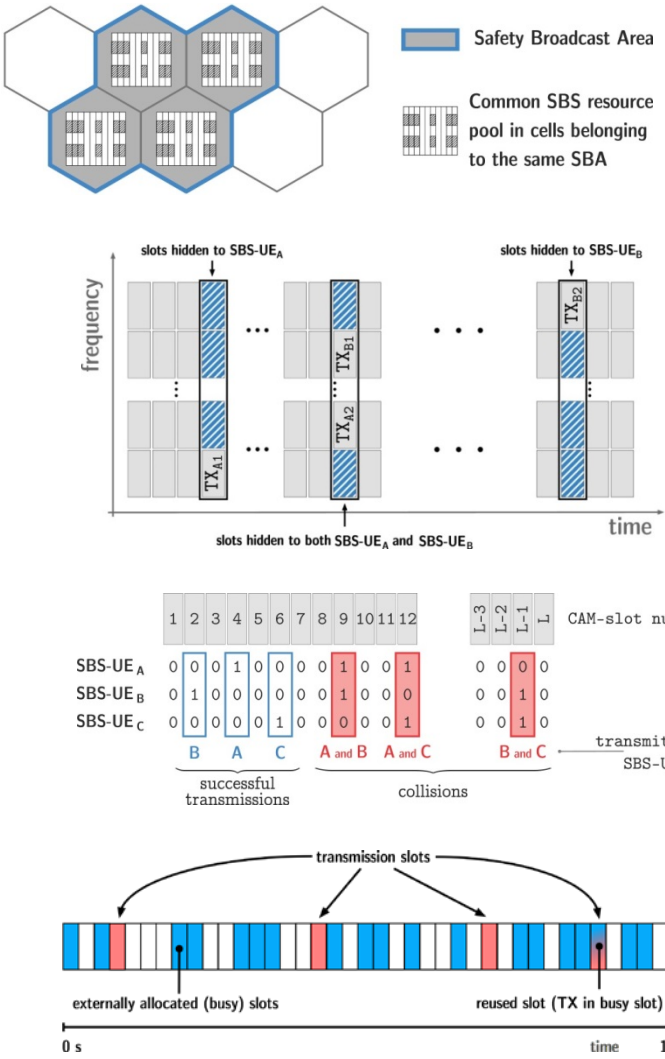
- **Supervised Deployment:**
  - Any car need to be within a cell and eNB at any time
    - Large cells: not enough D2D frequency reuse (broacast)
    - Small Cells: expensive deployment
  - Spectrum:
    - Commercial band: does not make any sense
    - ISM band: need to compete with WiFi and other LTE-U/LAA
    - Dedicated band: better and common to a given ‘service’
  - Requires mutualization of infrastructure (MuLTEFire/Slicing??)



LTE V2X Mode 4 – Distributed RRM

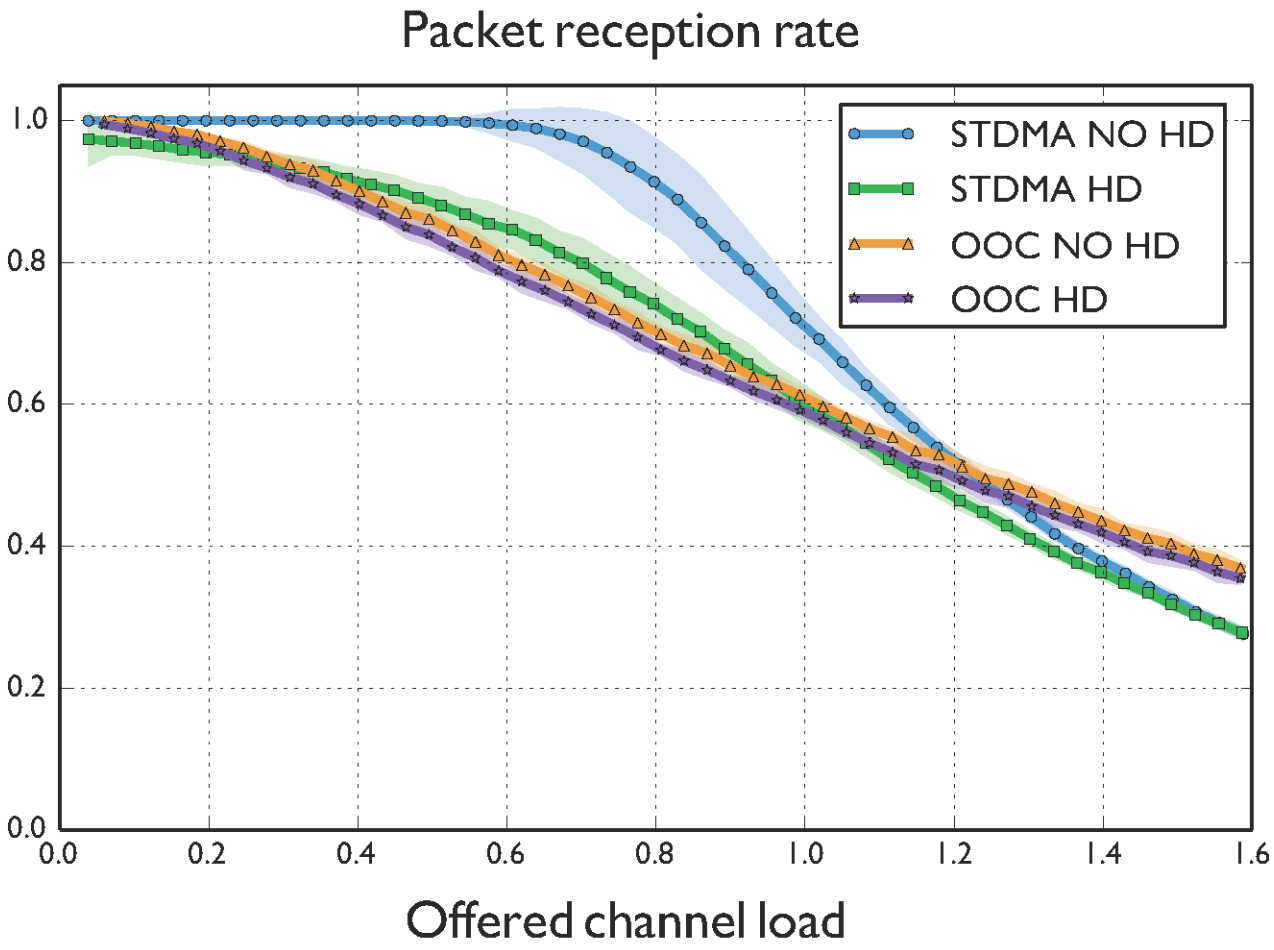
2016

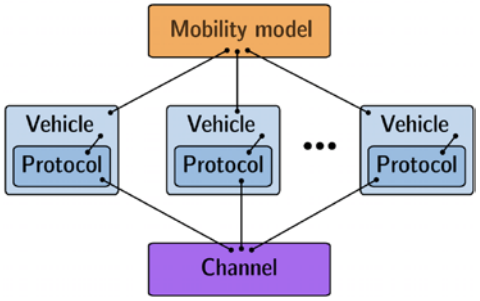
- **Safety Broadcast Area**
  - Pan operator resource ‘reservation’
  - Dedicated spectrum (not commercial)
  - RR coordinates ‘known’
    - Hardcoded
    - or Shared as a ProSe service
    - or transmitted by SIB19 when under coverage
- **Radio Resource Allocation**
  - Mode 4: resource selected at random from a pool
    - How?
- **Our Proposals:**
  - **Orthogonal Optical Codes**
    - Each UE draws a distribution of 1 and 0 from an orthogonal distribution
    - Tx=1 , whille RX=0
  - **S-TDMA Schema**
    - Bounded delay & quasi-deterministic transmission



LTE V2X – Why Mode 4 for Safety V2X Communications?

2016





Coexistence ITS-G5 – LTE-V2X

2017

- **5GAA White Paper (under work)...**
- **Based on the technology neutrality of the ITS-G5 band**
  - Both ITS-G5 and LTE-V2X can be granted access
- **Three phases coexistence:**
  - Phase 1 – LTE-V2X and ITS-G5 on different 10Mhz isolated bands
  - Phase 2 – LTE-V2X and ITS-G5 may coexist on additional shared band based on 'detect and avoid'
  - Phase 3 – LTE-V2X and ITS-G5 coexist on the full ITS-G5 band based on the detect and avoid mechanism

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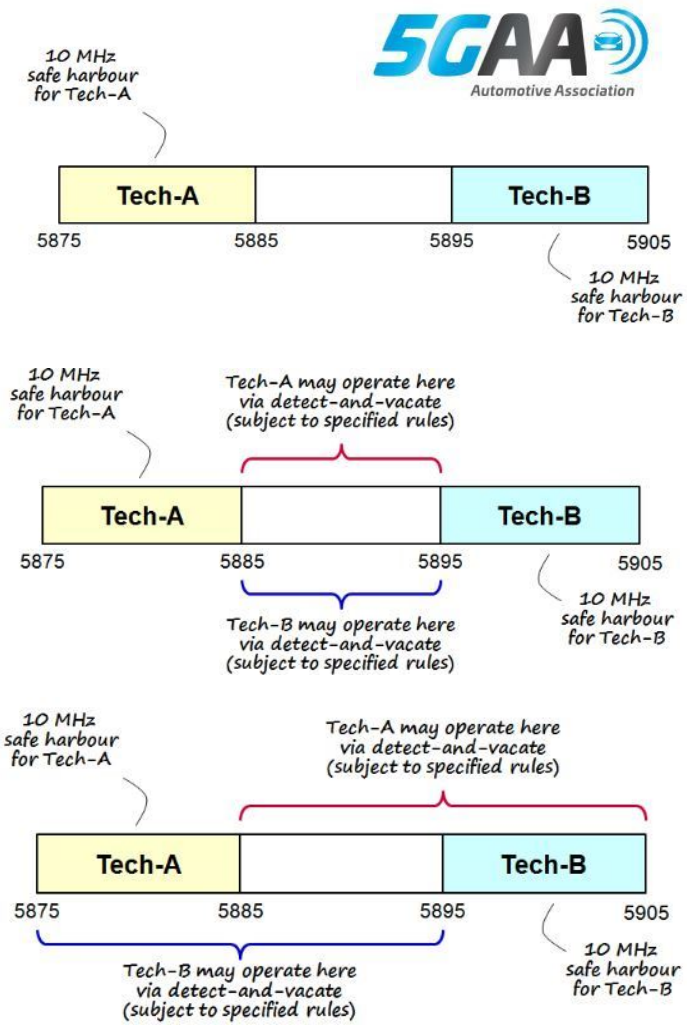
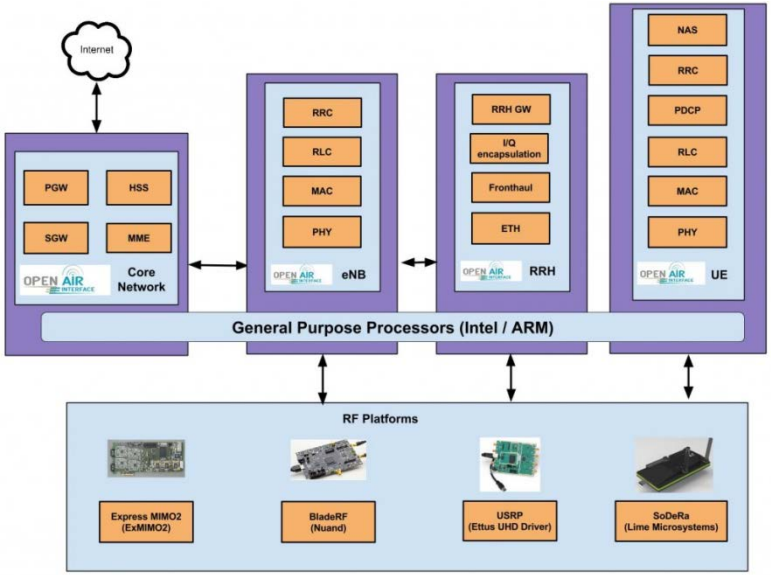


On-Going Work – D2D/V2X Prototyping

2017+

- **OpenAirInterface™, Open5G Software Alliance democratising wireless innovation**
  - http://www.openairinterface.org/



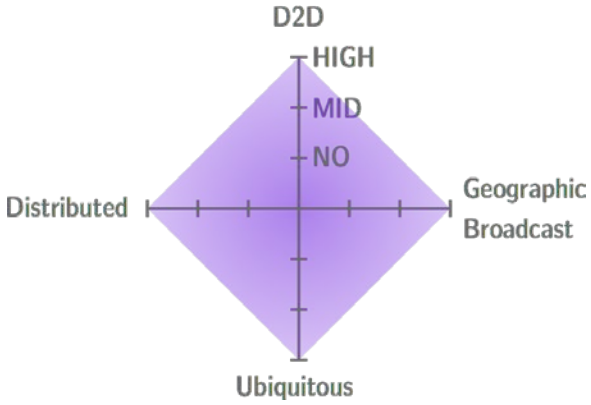
- **Implementation of LTE-V2X (rel. 14) on OAI**
  - Mode 3 and Mode 4
  - MAC/RRC and PHY
  - Prototype and Emulation
  - Objective: first open LTE-V2X implementation/prototype

Contributions

VENUE	TOPICS
IEEE VNC 2013 Vehicular Networking Conference	eMBMS resource reservation Optical Orthogonal Codes
IEEE ICC DVC 2015 Dependable Communications Workshop	Analytical model STDMA
IEEE VTM 2017 Vehicular Technology Magazine Special Issue on Emerging Technologies, Applications, and Standardizations for Connecting Vehicles	Sidelink-based LTE V2X
Elsevier Vehicular Communications Journal (currently under review)	Distributed RRM OOC over LTE V2X Congestion control
Research Report RR 17-329 2017	STDMA over LTE V2X OSTDMA SH-STDMA

Conclusions

- **LTE-V2X at 5.9GHZ**
  - **Wide area resource reservation**
  - **Distributed Scheduling**
  - **Ad-Hoc operation mode for Automotive Safety**
- **Challenges ahead…**
  - **synchronization, Timing**
  - **decentralized congestion control (DCC)**
  - **Tx power vs. half duplex**
  - **deterministic MAC**
  - **Coexistence on 5.9 GHz**



Laurent Gallo, gallo@eurecom.fr
Jérôme Härri, haerri@eurecom.fr