ISWCS'17
2017 August 28

National Research Council of Italy

Toward 5G vehicular networks

when vehicles will talk to each other

Barbara Mavì Masini
Alessandro Bazzi

CNR-IEIIT, Italy

Email: barbara.masini@ieiit.cnr.it, alessandro.bazzi@ieiit.cnr.it

Institute of Electronics Computer and Telecommunication Engineering

Part 4: toward 5G

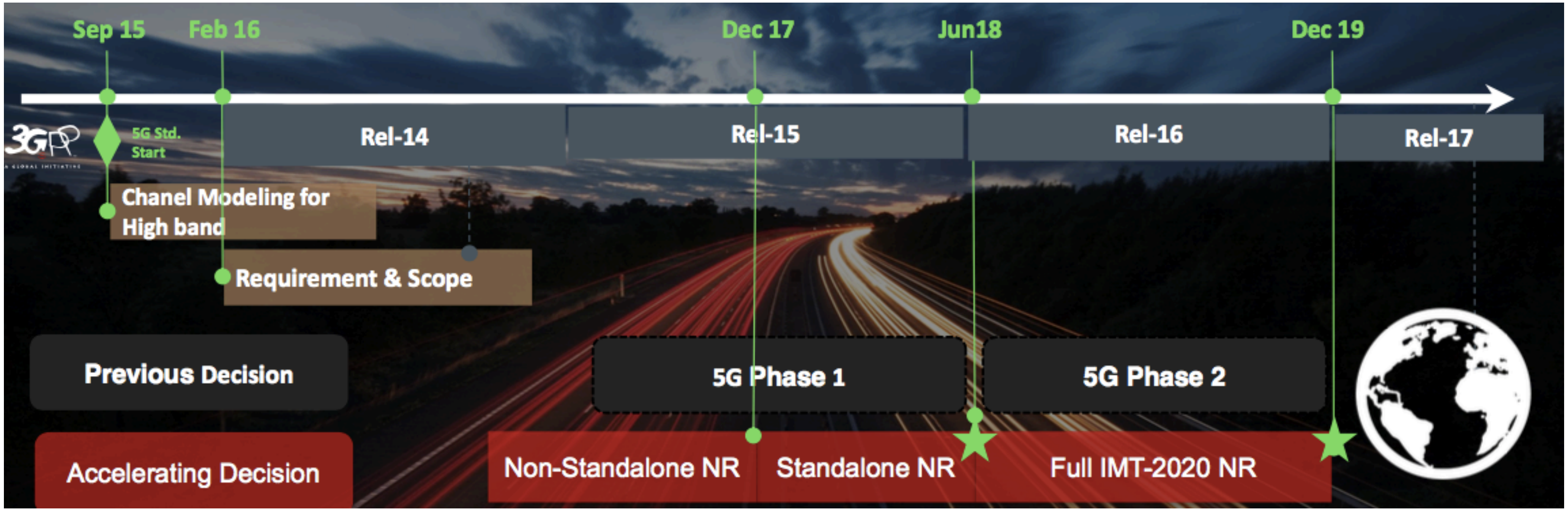
Toward 5G vehicular networks

Toward 5G

Challenging requirements:

- Very low latency: 1ms end-to-end delay
- Very high reliability: 99.999% transmission reliability
- High data rate: tens of Mbps per device in a dense environment.
- High dynamic mobility: 300 km/h absolute speed, 500 km/h relative speed
- Very high positioning accuracy: 0.1 m
- High density of connections for vehicles (e.g. the number of vehicles can exceed 10.000 in scenarios with multiple lanes and multiple levels and types of roads)
- High availability: coverage
- High security and privacy

3GPP accelerated 5G timeline



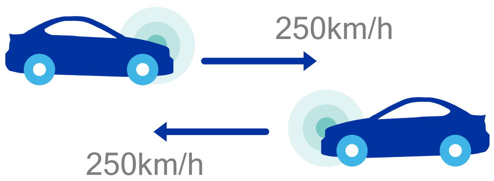
Source: Huawei

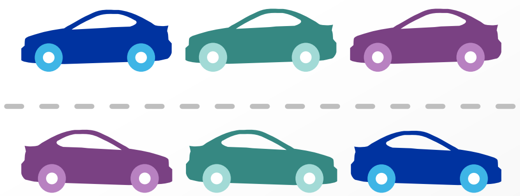
5G will support multiple use cases in diverse environments, meaning a range of heterogeneous capabilities and RATs

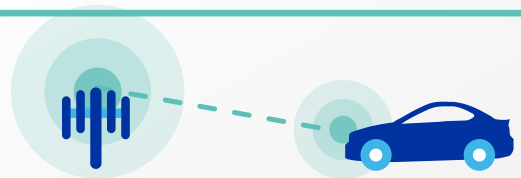
How 5G face the requirements

New Demodulation reference signal (DMRS) in uplink used for channel estimation and for coherent demodulation

Higher link budget (coding gain, transmit power, transmission period) for double the range (hundreds of meters)







	V2X Challenges	C-V2X Solutions 5G
1	**High relative speeds** Leads to significant Doppler shift / frequency offset	**Enhanced signal design** E.g. increasing # of ref signal symbols to improve synchronization and channel estimation
2	**High node densities** Random resource allocation results in excessive resource collisions	**Enhanced transmission structure** Transmit control and data on the same sub-frame to reduce in-band emissions **More efficient resource allocation** New methods using sensing and semi-persistent resource selection
3	**Time synchronization** Lack of synchronization source when out-of-coverage	**Allow utilization of GPS timing** Enhancements to use satellite (e.g. GNSS) when out-of-coverage

Source: Qualcomm

How 5G face the requirements (continue)

Very low latency

- Advanced driver-assistance systems (ADAS), safety, situational awareness (e.g. pre crash warning message)
- Obtaining radio resources for ProSe Direct Communication in SL mode 1 may take too long and incur excessive overhead for certain delay critical and small-sized V2X messages

Implication for 5G:

- Need a direct communication interface for both in-coverage and out-of-coerage
- Enhancement to LTE, enhanement to PHY/MAC, better channel estimation, OFDM variants

High data rate

- Multiple transmitters generating multiple messages result in high network load (e.g. 10 BSMs per second, 5 Kbyte/s)
- More than just status data – e.g. ADAS
- V2V messages (e.g. pre-crash warning message) are local, relevant only to other vehicles in the vicinity

Implication for 5G:

- Greater resource allocation efficiency: e.g. D2D enhancements
- Advanced antenna techniques (e.g. adaptive beam-forming / tracking)
- Full duplex

How 5G face the requirements (continue)

High reliability and availability

- Need high reliability and availability, especially for safety applications
- Need time synchronization when vehicles are out of network coverage

Implication for 5G:

- PHY / MAC enhancements
- Enhance LTE to use GPS timing / sync for out of network areas
- Provide for multiple connections for Uu failure survivability and link redundancy

High security and privacy

- SIM/IMSI only provides in network authentication, does not protect privacy
- MNOs must not be able to re-construct identity, location and speed
- Vehicles should communicate without pre-shared keys

Implication for 5G:

- Balance security, privacy, performance
- Public-Key Infrastructure (PKI) to distribute & manage digital certificates
- Separation of authorities among functions
- Re-use IEEE 1609 security? (SCMS)

5G research

- 5G mostly intended as an evolution of LTE
- C-V2X seen as the most probable final solution to connected vehicles challenging applications
- But 5G also foresees the integration of multiple radio access technologies (RATs) in the cellular system architecture
  - Multi-RAT is a reasonable approach for the integration of IEEE 802.11p/ITS-G5 and cellular
  - By taking advantage of multi-RATs, 5G will be able to take advantage of the unique characteristics of each RAT and improve the practicality of the system as a whole
  - Multi-Rat will enable 5G System to maintain network connectivity regardless of time and location, and open the possibility to connect all the connected devices without human intervention.
  - Also to provide support for up to a million simultaneous connections per square kilometers with higher data rate, enabling a variety of services.

Trends with higher V2X technology penetration

- Higher number of connected vehicles
- Periodic message exchanges with ultra low latency
- Longer packet size (to autonomous driving)

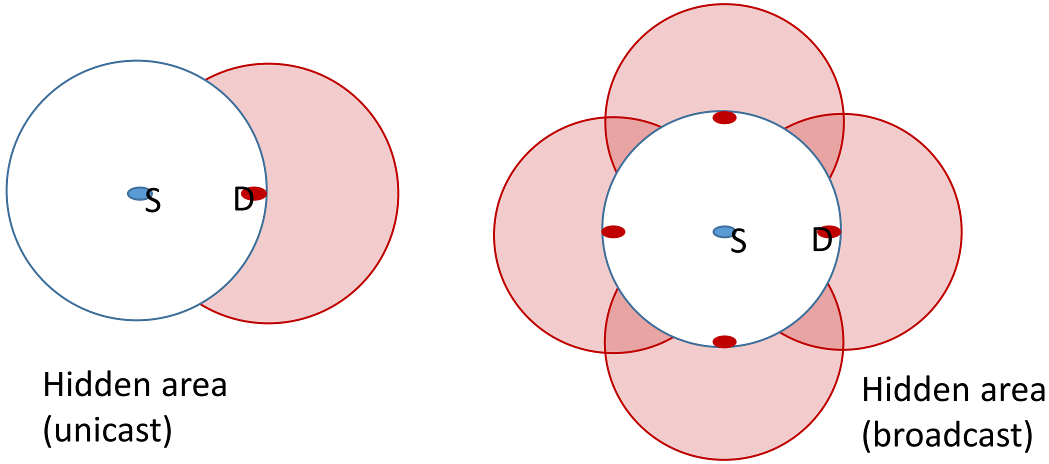
What about using full duplex?

Which is the main problem with 11p/ITS G5?

Full duplex radios and the possible impact on vehicular communications

Which is the main problem with 11p/ITS G5?

- The hidden terminal problem worsen the performance both in unicast and in broadcast mode of CSMA/CA

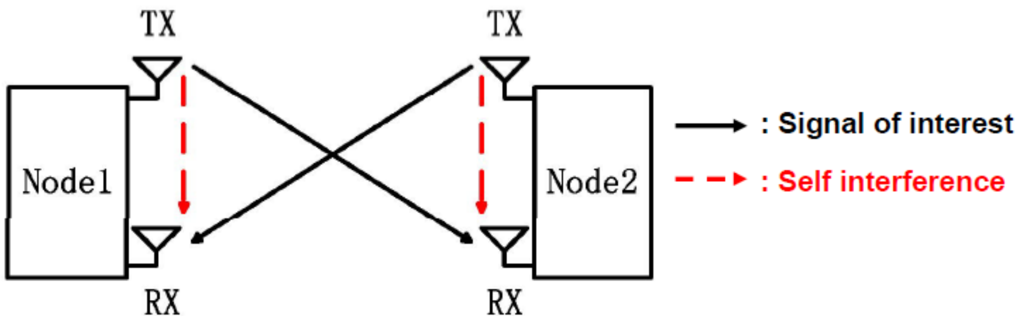


Potential hidden terminal area: terminals in the communication range of the receiver D but not in the range of the transmitter S

- Throughput and delay performance degrades quickly as network load increases (high density)
  - heavy packet collisions.

Full Duplex (FD): the dream of double capacity

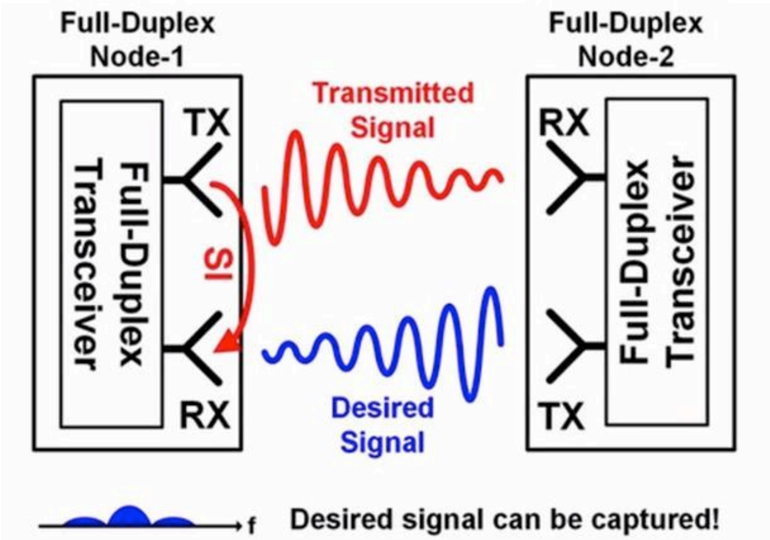
- Wireless systems are typically half duplex (HD), hence unable to transmit and receive at the same time
- Full duplex (FD) allows concurrent transmission and reception in the same bandwidth, and now considered as one of the key technologies for 5G
- FD can ideally double the capacity of a single link
- In practice, the increase in capacity is limited by the self- interference (SI) that is unavoidably generated when the transmitted signal couples back to the receiver in the in-band FD transceiver
- The problem of SI is more and more evident in high density networks



Full duplex (FD) and self interference (SI)

- FD benefits can be achieved if SI can be effectively canceled
- SI can be much higher than the desired signal, which is subject to attenuation due to path loss and fading phenomena (~ 100dB higher in Wi-Fi)
- Even though the Tx signal is perfectly known in the digital baseband, eliminating the generated SI is a challenging task due to the power difference between the Tx and Rx signals and the multiple sources of distortion (nonlinear effects of amplifiers or mixers) and RF imperfections (phase noise of the local oscillator, ADC, quantization noise, thermal noise, etc.) in the transceiver chain

SABHARWAL et al.: IN-BAND FULL-DUPLEX WIRELESS: CHALLENGES AND OPPORTUNITIES, IEEE JOURNAL ON SELECTED AREAS IN COMMUNICATIONS, VOL. 32, NO. 9, SEPTEMBER 2014



Full duplex (FD) and self interference (SI)

- Although SI cannot be perfectly canceled, short-range systems (e.g., small-cell and Wi-Fi) are making the SI reduction problem much more manageable due to both their lower transmission powers and reduced path loss
- A lot of research is ongoing on SI (out of the scope of this tutorial). Recent results show that advanced SI canellation schemes can achieve 70-120 dB of cancellation in Wi-Fi systems. For example Huawei provides FD radios with 118 dB cancellation (static)
- A major concern is the time-varying nature of the SI channel, caused by the moving scatterers and reflectors in the surrounding environment and the mobility of the device itself
  - Preliminary experimental results presented in [1] for handheld FD mobile devices with single shared antennas are encouraging
  - Early results for high-Doppler scenarios are encouraging [2]

[1] D. Korpi et al., "Full-duplex mobile device: pushing the limits," Communications Magazine, IEEE, vol. 54, no. 9, pp. 80–87, 2016.
[2] F. Lehmann, A. Berthet, "A factor graph approach to digital self-interference mitigation in OFDM full-duplex systems," IEEE Signal Processing Letters, vol. 24, no. 3, pp. 344–348, 2017

FD challenges mitigated in cars

- No miniaturization issues like in small-form factor devices
  - Antennas can be separated on the vehicle rooftop at a distance that could make passive isolation remarkably efficient.
- Large processing and unlimited power capabilities
  – Vehicular OBUs are good candidates to host complex FD transceivers
- Less stringent cost contraints (that impact the analogue components quality)
  – High-quality analog components can create less signal distortions and imperfections
- Connected cars at an early deployment stage
  – New vehicles can be easily equipped with FD radios

Impact of FD on IEEE 802.11p/ITS G5 MAC

- Enable listening/sensing while talking: collision detection (CD) becomes possible!
- Simultaneous transmission and reception improves throughput
- Reduce delay in multi-hop communications
- Reduce feedback delay
  - An ACK can be sent by the FD receiver while the sender is transmitting
- Reduce hidden terminal problem
  - by letting a node transmitting while it is receiving, other nodes hidden to the transmitter, detect the channel as busy and refrain from transmitting

Some recent research results

- Address vehicular unicast transmissions
- Use the reverse link of FD only for an immediate feedback
  - sent at a very low data rate to reduce the probability that a corrupted transmission continues

Advantages:

- Reduced interference (due to low data rate)
- Performance improvement with respect to HD
- Minor modifications to the standard and compatible with legacy devices

Alessandro Bazzi, Barbara M. Masini, Alberto Zanella, "Immediate Feedback to Increase the Throughput of Full Duplex Networks Based on IEEE 802.11p, ?", IEEE International conference on Intelligent Transportation systems telecommunication (ITST), Warsaw, Polland, 2017 May 29-31. → related to unicast transmission

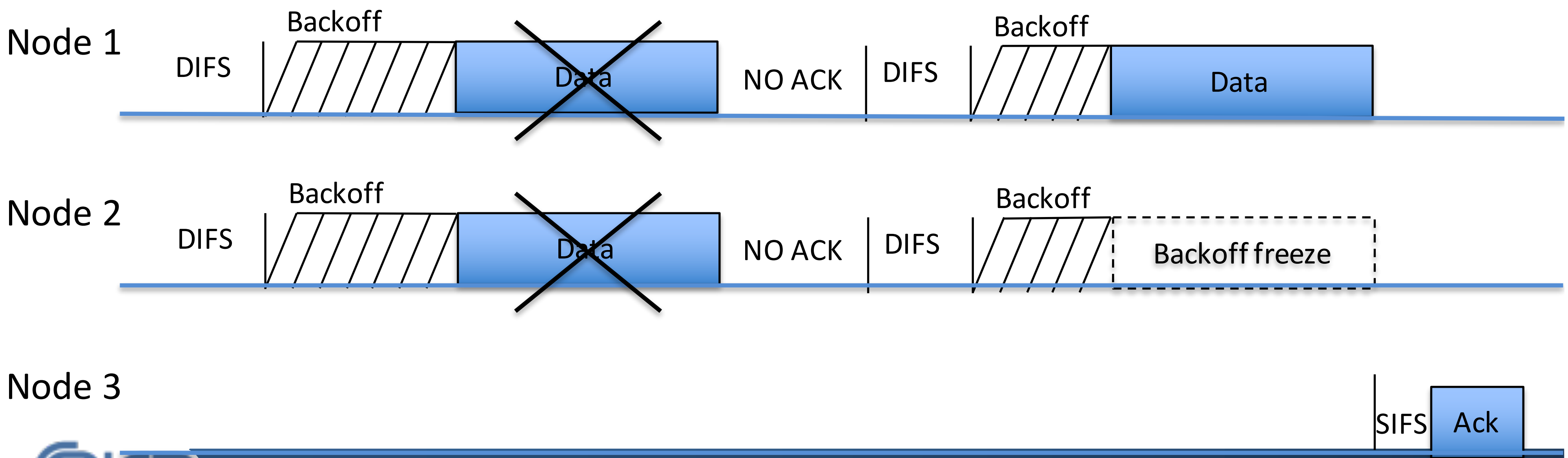
A. Bazzi, C. Campolo, B. M. Masini, A. Molinaro, A. Zanella, A. O. Berthet, On the Potential of Full-Duplex for Beaconing over IEEE 802.11 Vehicular Networks, submitted → related to broadcast transmission

IEEE 802.11p MAC

- MAC based on Carrier Sensing Multiple Access with Collision Avoidance CSMA/CA

  Each node senses the medium and transmits only if it is sensed as idle for an interval of variable duration called backoff.

  ACK sent by the RX at the end of transmission



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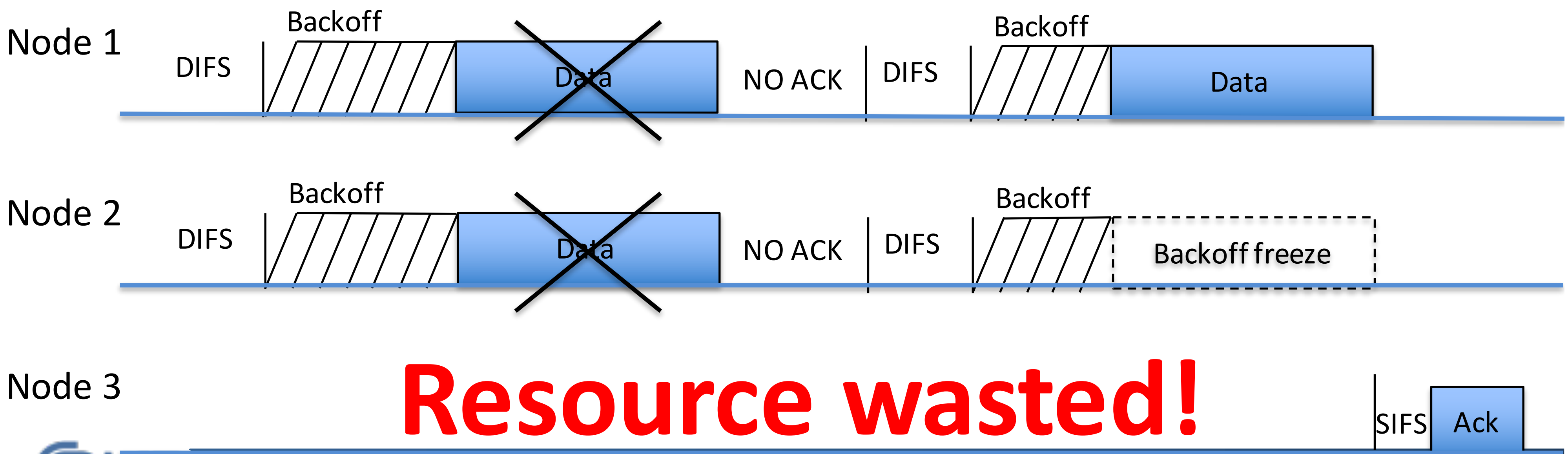
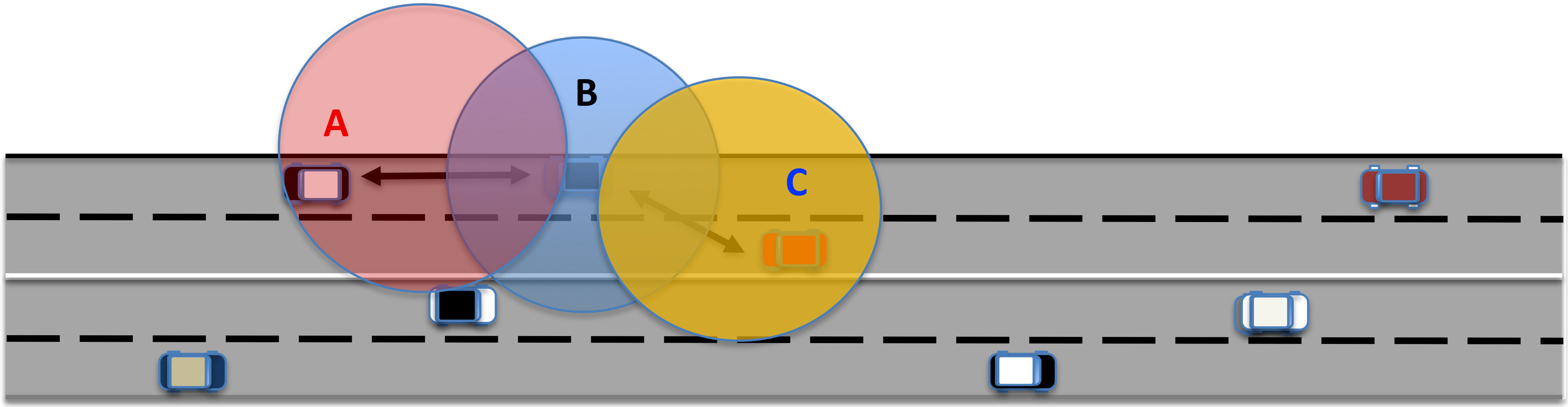
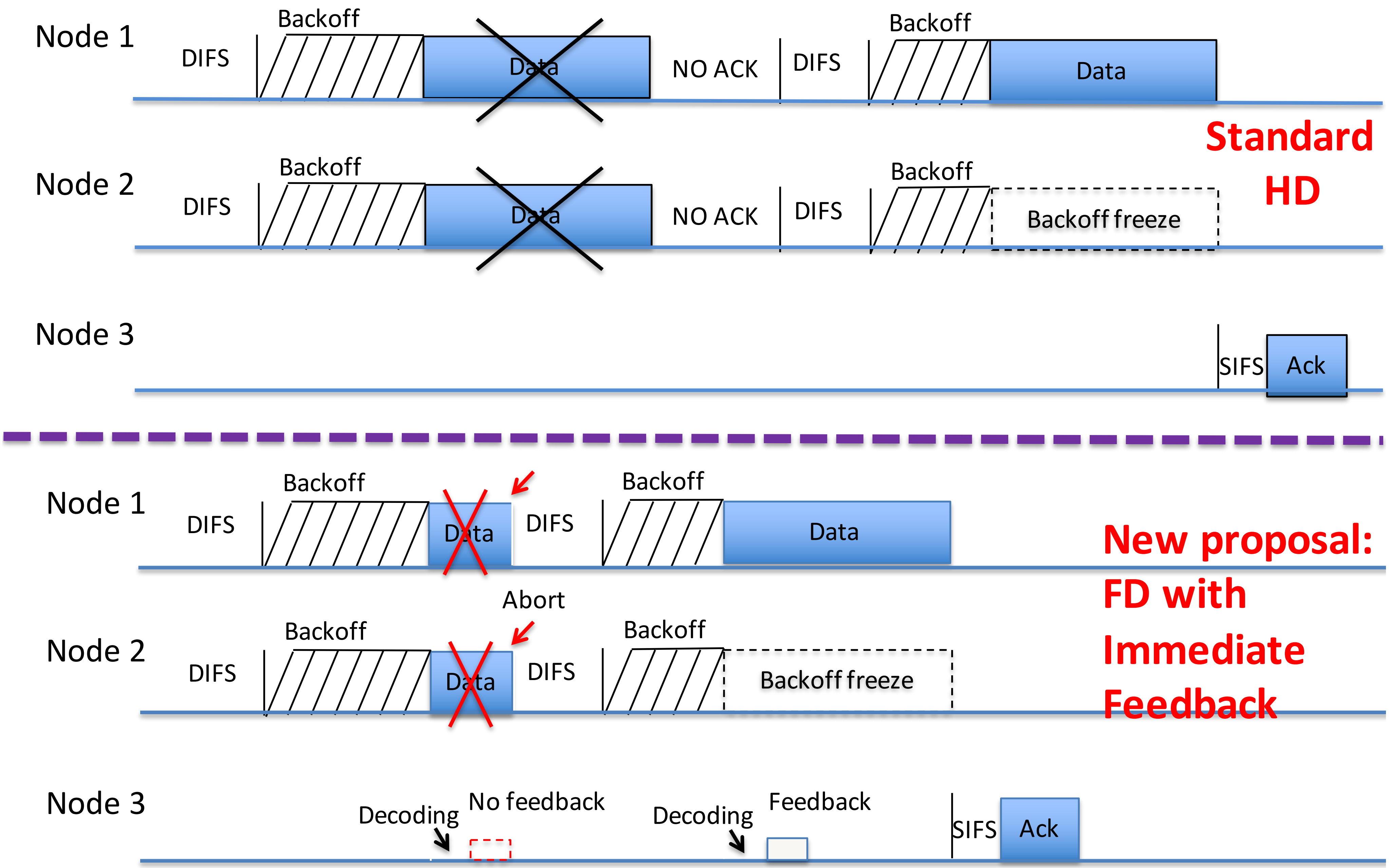


CSMA/CA resource wasted

1. Hidden terminal problem
2. A transmission needs to conclude before a collision is recognized (even if the RX cannot detect the signal from the beginning since the sensing mechanism is made by the transmitter, although the collision is at the receiver)

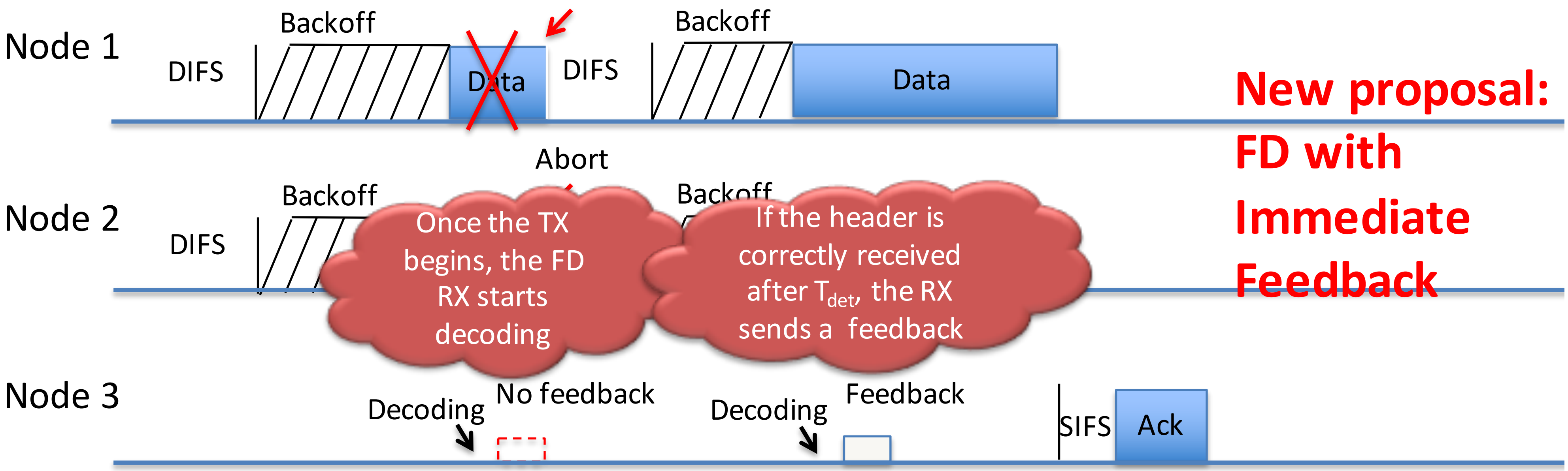


Our proposal to reduce resource wasting



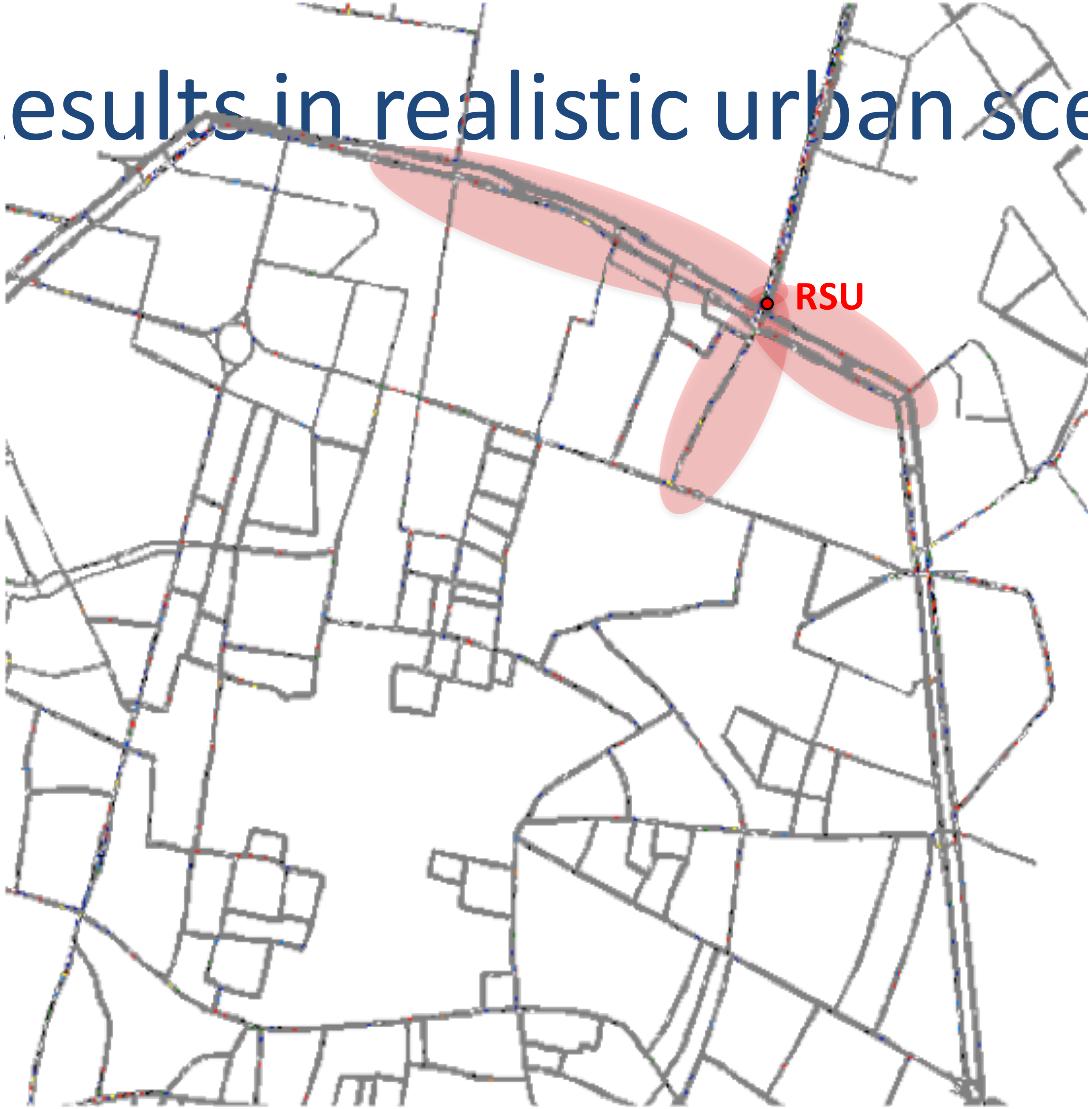
Considerations

- The detecting interval T_{det} must be long enough to receive the TX ID
- The detecting interval T_{det} should be short enough to improve the performance
- The feedback is sent at a very low data rate to not interfere with ongoing transmissions and contain only an hash of the ID
- If the TX does not receive the feedback or read a different TX ID, it immediately abort the transmission



New proposal: FD with Immediate Feedback

Results in realistic urban scenario



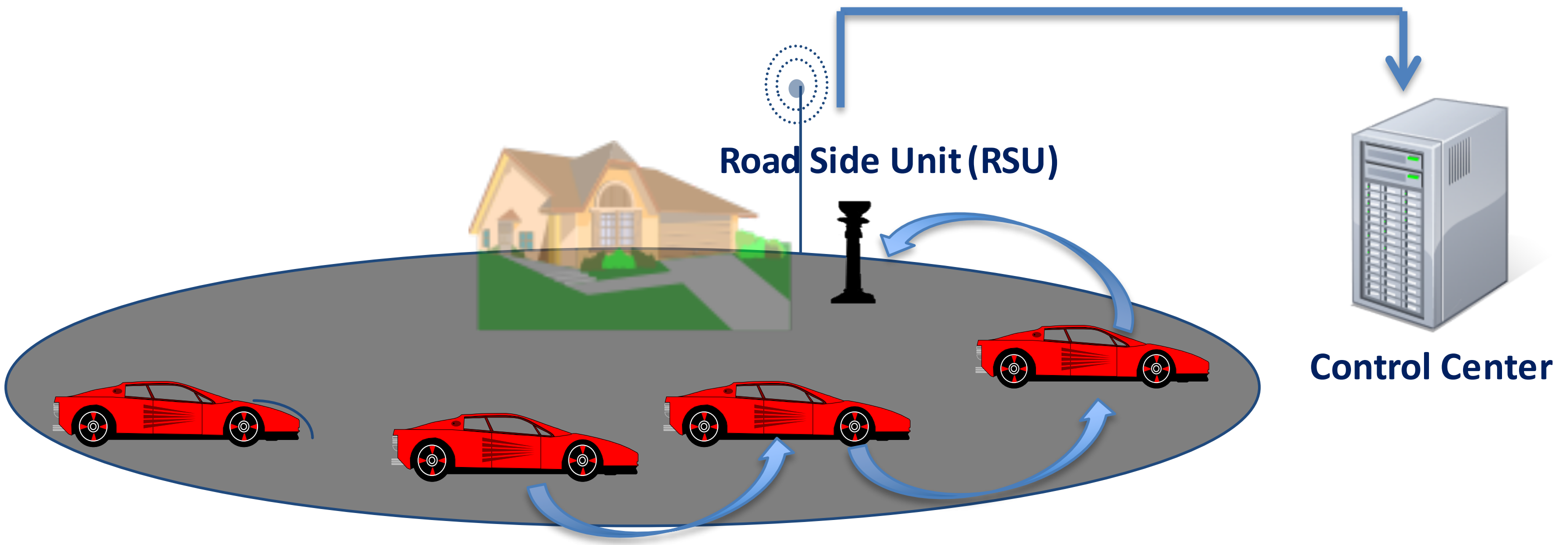
City of Bologna
Italy

The Application: crowd sensing

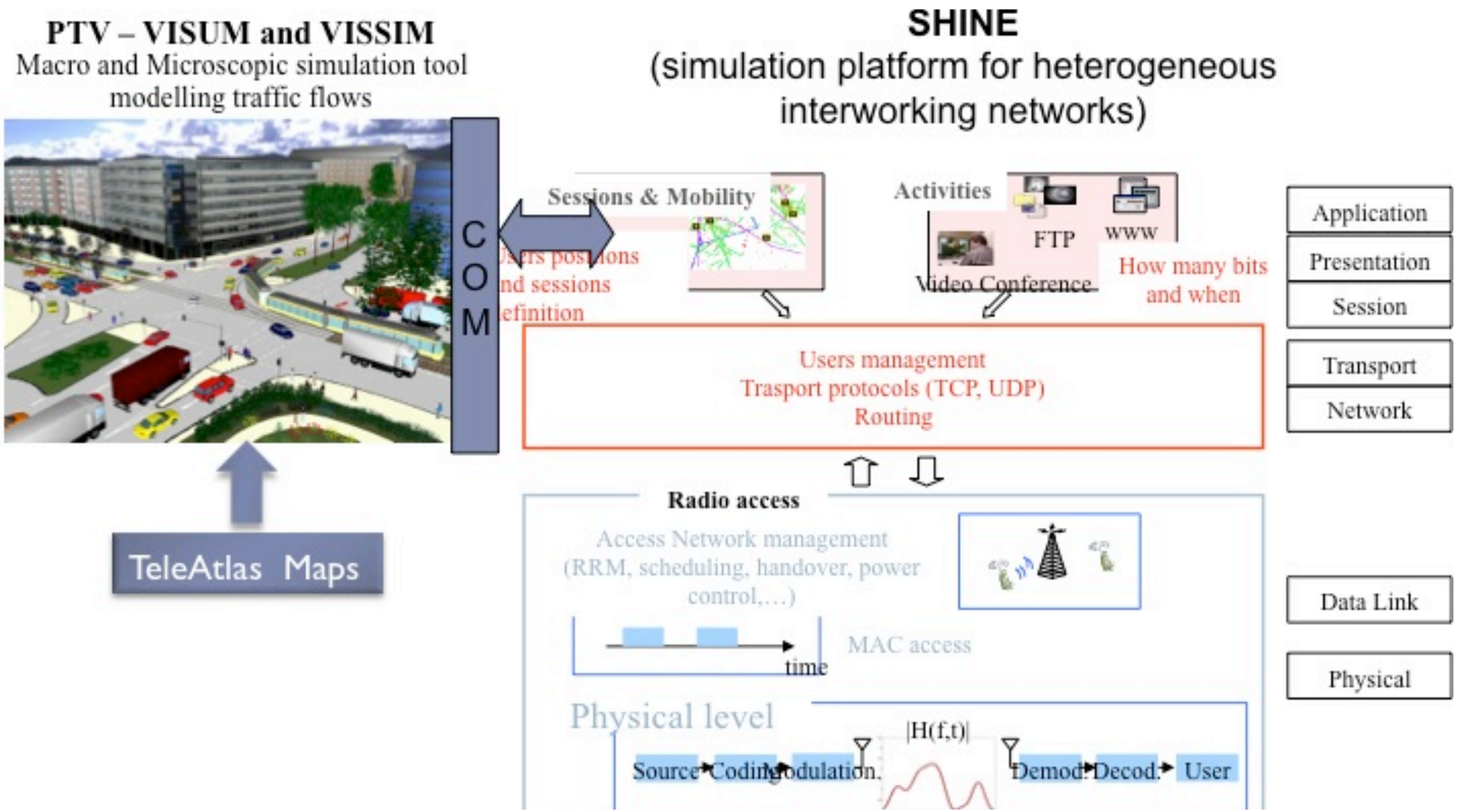
- An OBU transmits the measured data as far as it is within the coverage distance of a RSU

If not:

- Each vehicle identifies the neighbor nearest to a RSU (greedy forwarding), which receives the data, and transmittt them as far as it is within the coverage area of the RSU.

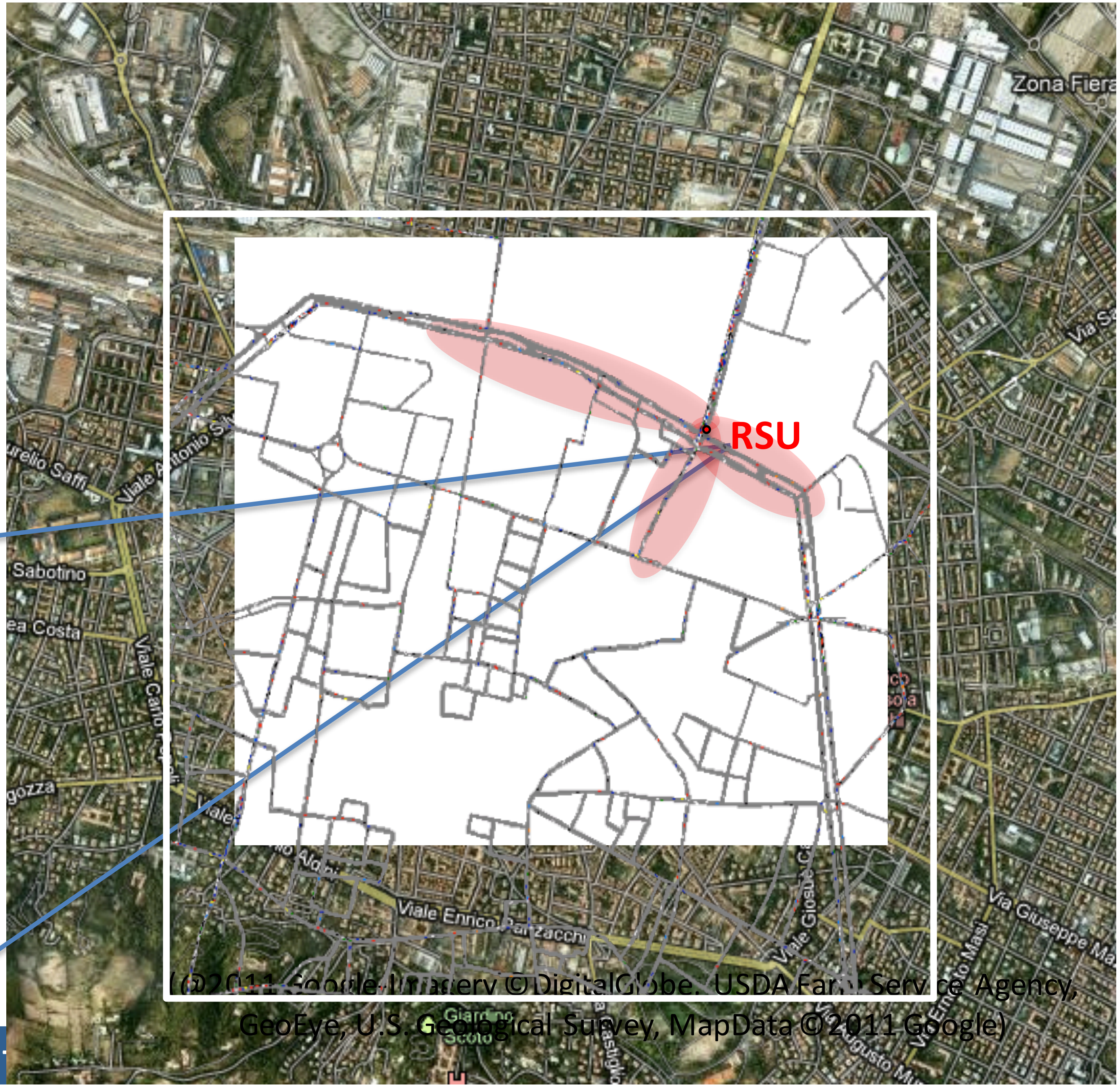


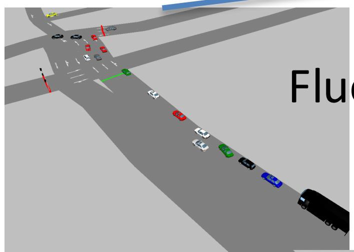
Simulation Tool: Network+Roadmap



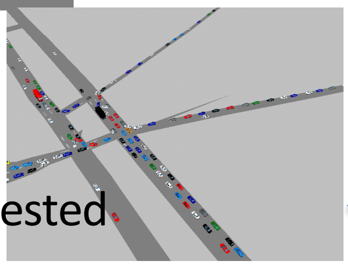
Simulation Settings

- 1.8 x 1.6 km^2 scenario
- 1 RSU at the main junction
- Traffic:
  - Fluent traffic with 455 vehicles on average
  - Congested traffic with 670 vehicles on average





Fluent



Congested

IEEE 802.11p System Setting

- Sensing procedure with random access, hidden terminals, exposed terminals and capture effect
- Mode 1: 3Mb/s

- Path loss model [Karedal, 2011]:
  - 2.2 exponent in LOS
  - 9 dB attenuation per each external wall of buildings
  - 0.4 dB/m loss inside buildings [Sommer 2011]

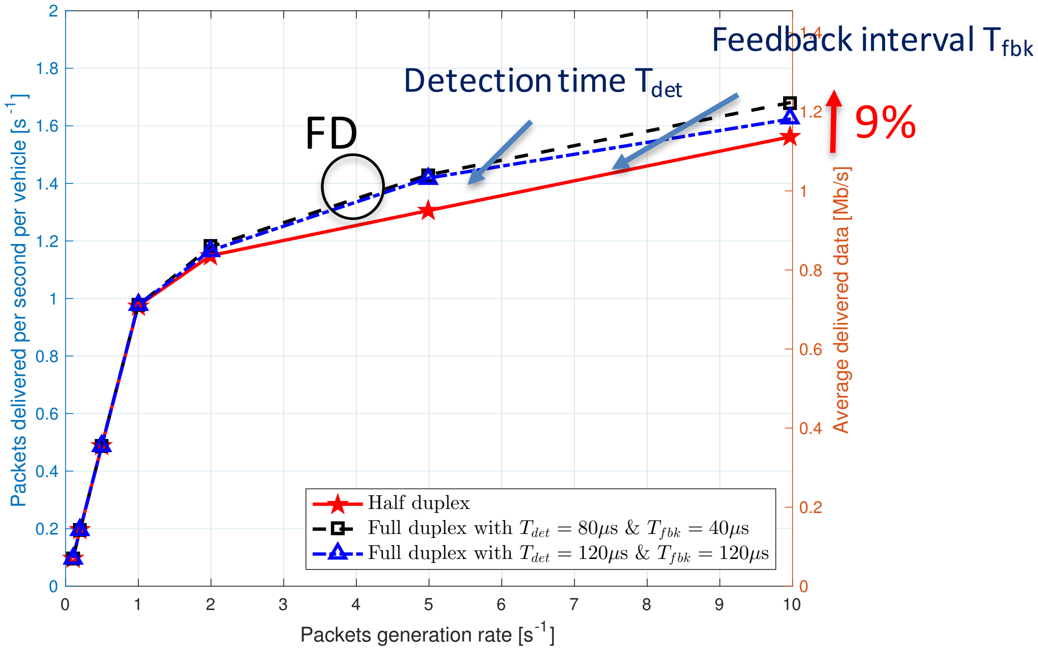
- Equivalent radiated power: 23 dBm
- RX Sensitivity: -85 dBm
- RX Antenna Gain: 3 dB

Average range: 740 m

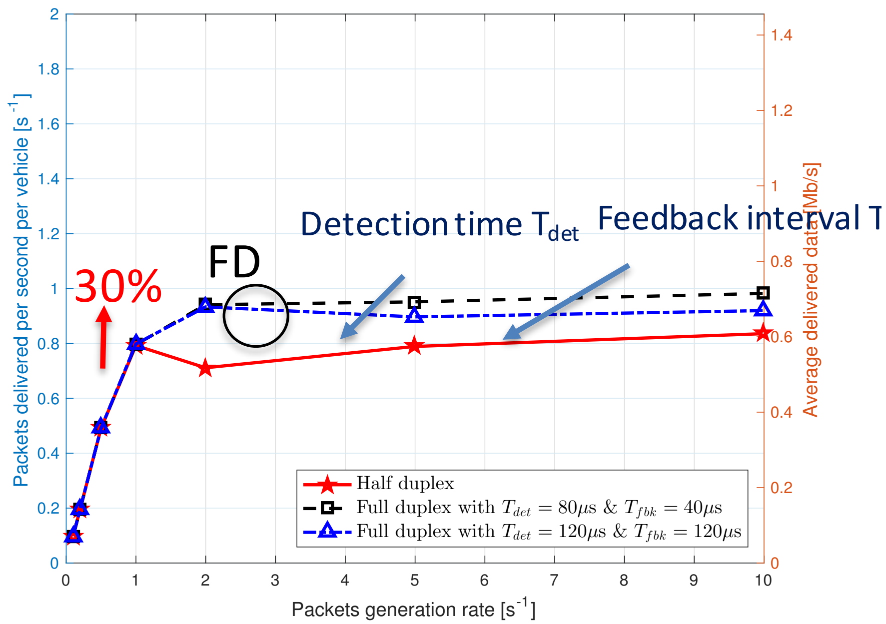
- A packet is correctly received if both the received power is higher then the RX sensitivity and the SINR is higher than a threshold of 10 dB.

Packets and data delivered to the RSU

Fluent traffic



Congested traffic

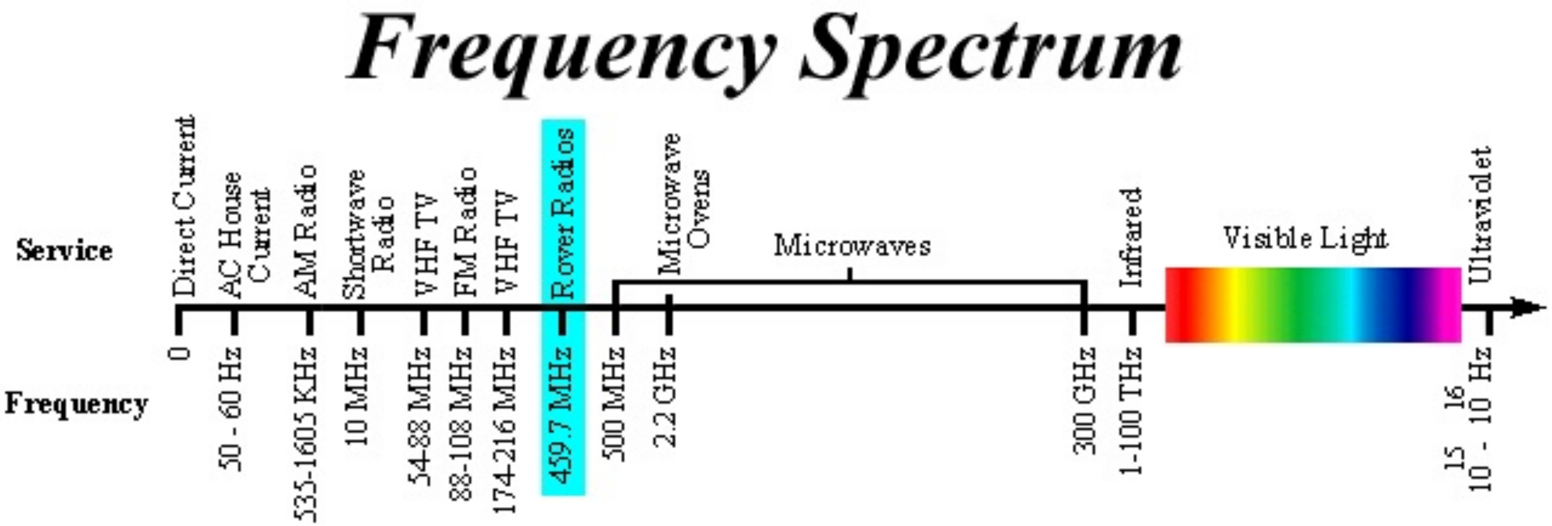


Advantage of FD evident for higher data and vehicular traffic

Complementary technologies for the Internet of vehicles: visible light communication

Complementary technologies

- Visible Light Communication (VLC)
- mmWave communications



Designation	Band	Designation	Band
Direct Current (DC)	0 Hertz	Very High Frequency (VHF)	30 - 300 MHz
Very Low Frequency (VLF)	3 - 30 KHz	Ultra High Frequency (UHF)	300 - 3000 MHz
Low Frequency (LF)	30 - 300 KHz	Super High Frequency (SHF)	3 - 30 GHz
Medium Frequency (MF)	300 - 3000 KHz	Extreme High Frequency (EHF)	30 - 300 GHz
High Frequency (HF)	3 - 30 MHz	Microwave Frequencies	500 MHz - 300 GHz

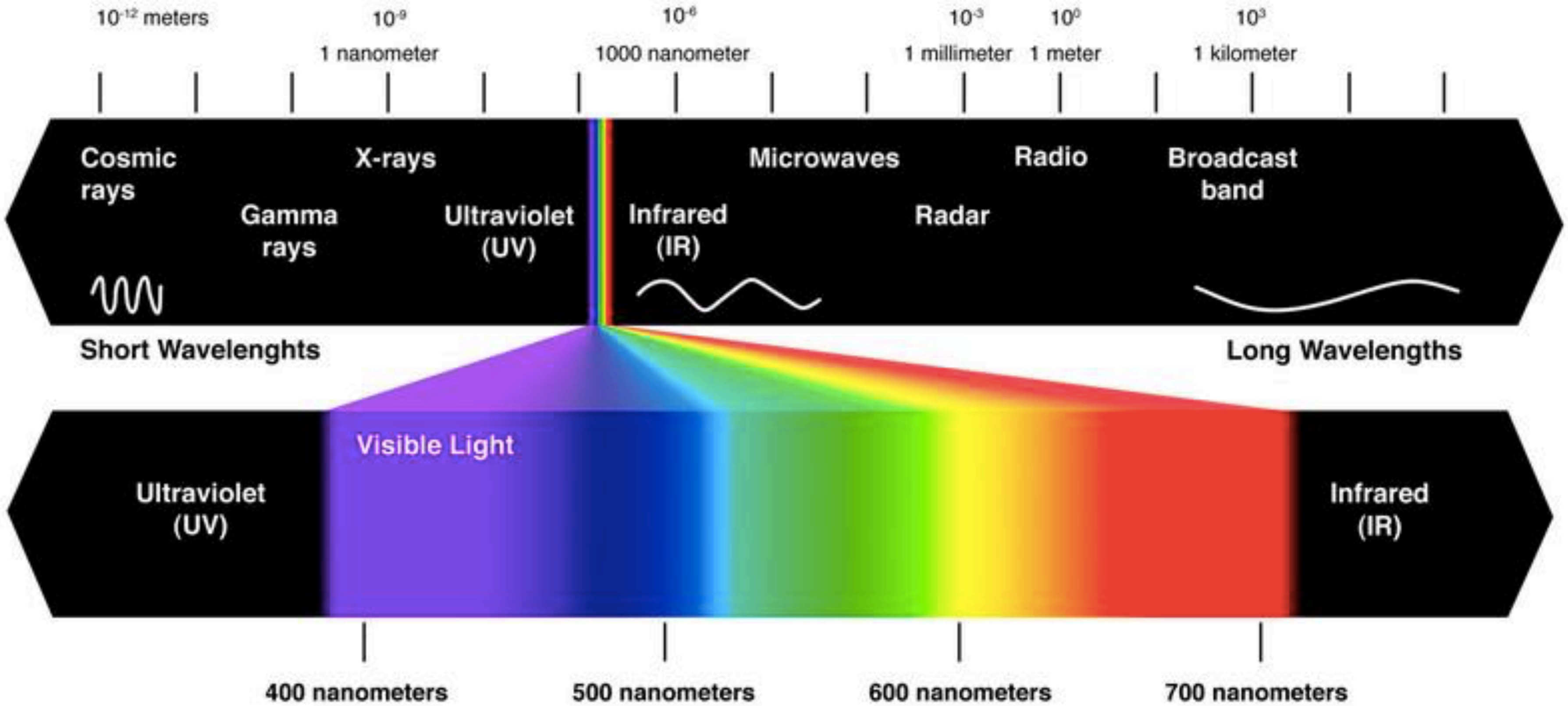
Visible Light Communication (VLC)

- **VLC = Illumination + Communication**

- LEDs light is switched on and off extremely quickly via a "computer" (the light appears constant)
- Light can be received by LEDs, photodiodes, cameras

VLC frequency

between 400 and 800 THz



VLC vs RF

VLC

- Communication in visibility (LOS):
  - High degree of spatial reuse
  - Low number of neighbours
  - Typical short range communication
- Wider bandwidth and low congestions
- No frequency licence (best things in life are free ☺)
- Usage: getting popularity
- Safe for human's body
- The data rate rapidly falls with increasing link distance
  - Power decreases with distance raised to the power of 4
- Light interference affects the performance and data rates are degraded by shot noise

RF

- See around the corner
  - Affected by interference
  - Cross walls
  - Higher number of neighbours
  - Longer range
- Congested bandwith
- Usage: everywhere
- Susceptible to biological damage
- The data rate falls (less rapidly) with increasing link distance
  - Power decreases with d raised to the power of 2

VLC based on IEEE 802.15.7

1. Communication based on IEEE 802.15.7 Standard
2. PHY

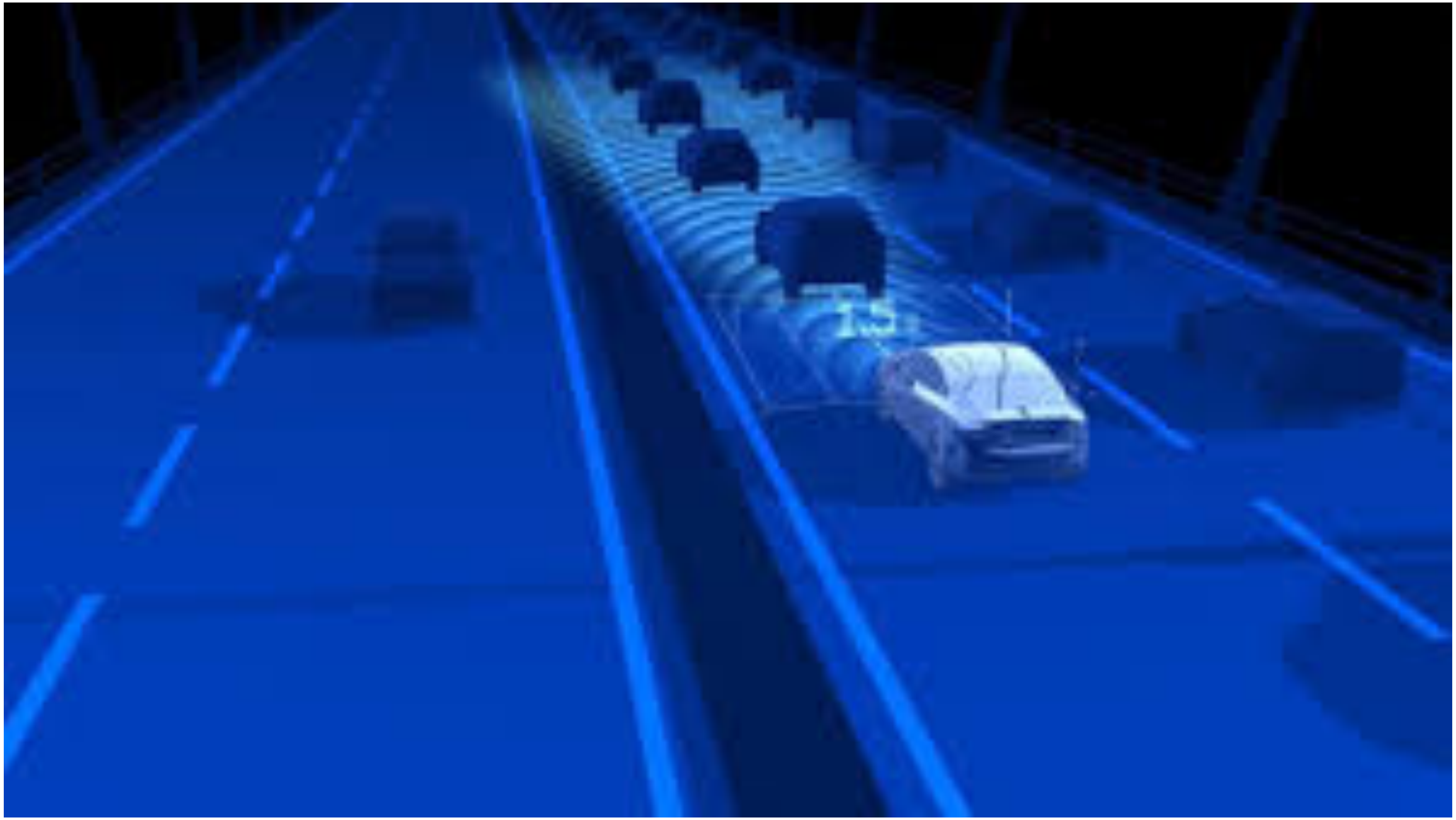
Operating Modes	Data Rate	Modulation
PHY I	11.67 – 266.6 kb/s	OOK / VPPM
PHY II	1.25 – 96 Mb/s	OOK / VPPM
PHY III	12 – 96 Mb/s	CSK

3. MAC based on Carrier Sensing Multiple Access with Collision Avoidance CSMA/CA

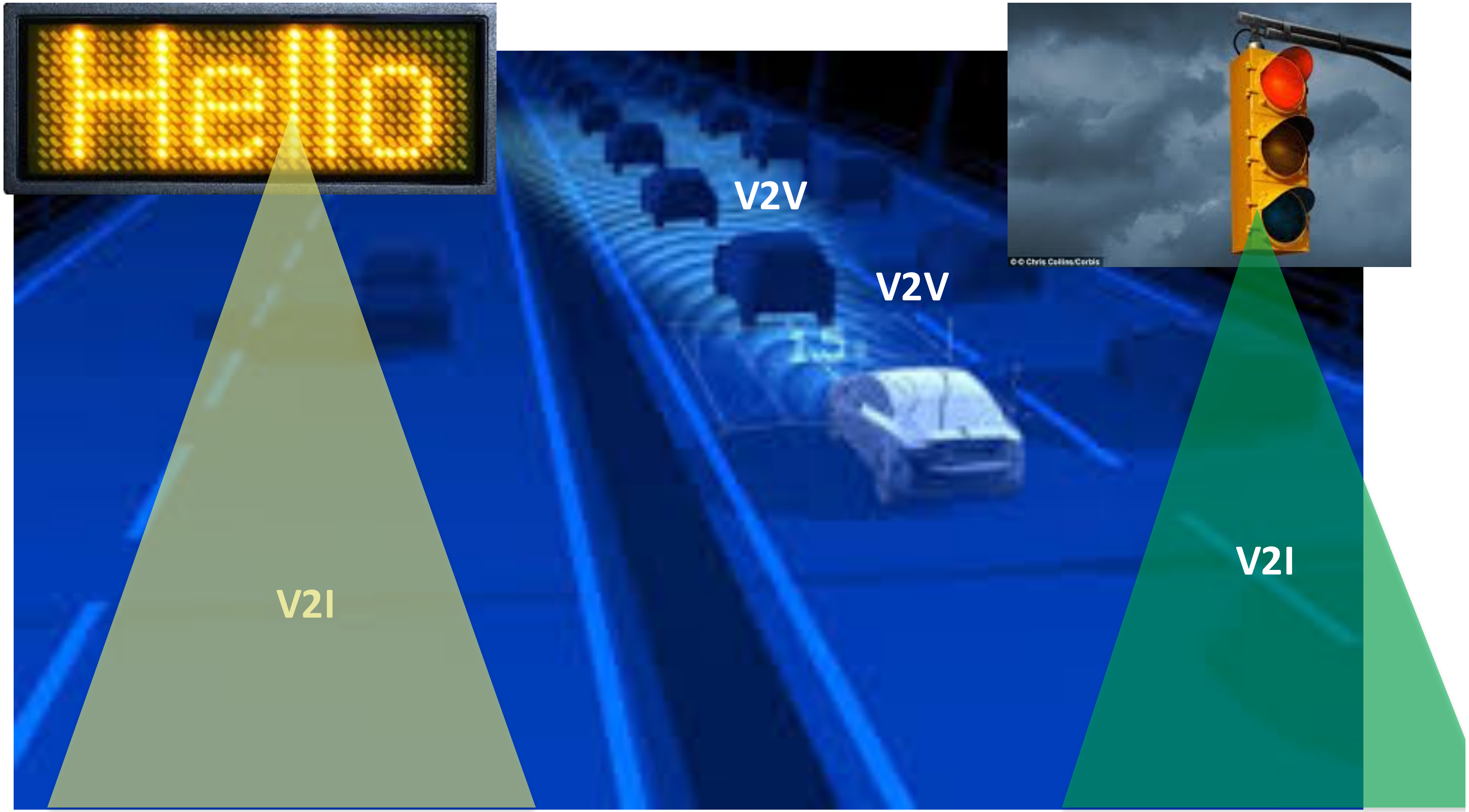
VLC vs IEEE 802.11p and LTE

Feature	Short range RF	Cellular networks	VLC
Today reference	WAVE/IEEE 802.11p	3GPP LTE	IEEE 802.15.7
Frequencies	5.9 GHz	400 MHz - 3.5 GHz	380-800 THz
Use of frequencies	Reserved for ITS	Licensed	Unlicensed
Communication range	Up to 1 km	Ubiquitous	Lower than 100 m
Directionality	Normally none	Normally none	High
Obstacles effect	High impact	Medium impact	Obstructing
Spatial reuse	Limited	Limited	High
Implementation costs	Requires ad hoc devices	Requires ad hoc devices	Uses the available LEDs
V2V support	Yes	Future: D2D mode	Yes
V2I support	RSUs to be deployed	Native	Traffic lights and other light sources

Vehicular Visible Light Networks



Vehicular Visible Light Networks



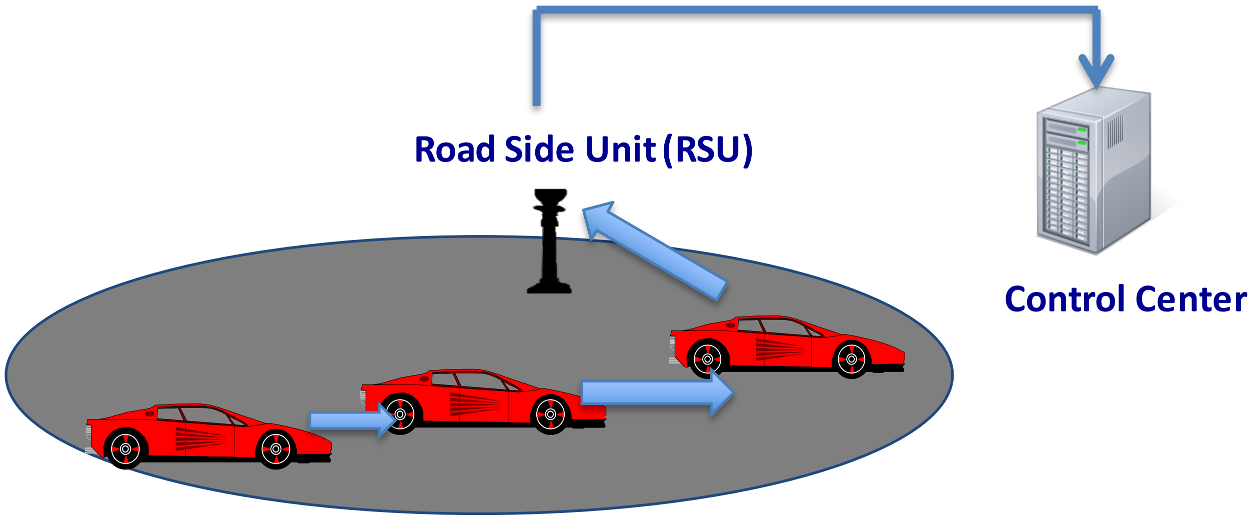
VLC as a complementary technology

- VLC works when transmitter and receiver are in visibility
  - Limitations in vehicular networks (such as intersections, limited visibiliy)
  - Useful for specific applications (such as platooning)
- VLC can complement other RF technologies

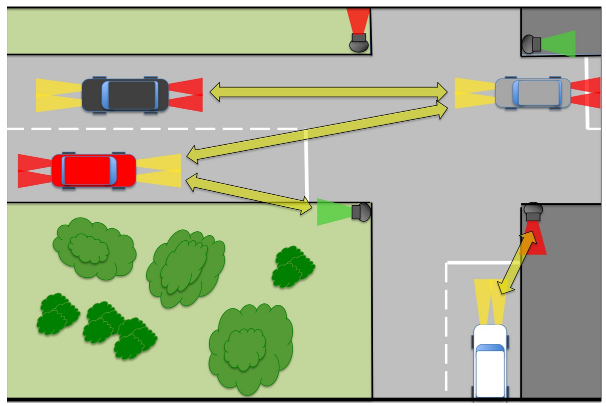
Alessandro Bazzi, Barbara M. Masini, Alberto Zanella, Alex Calisti, “Visible Light Communications as a Complementary Technology for the Internet of Vehicles”, Computer Communications, Available online 9 July 2016, ISSN 0140-3664

Example application: VLC+11p for crowd sensing

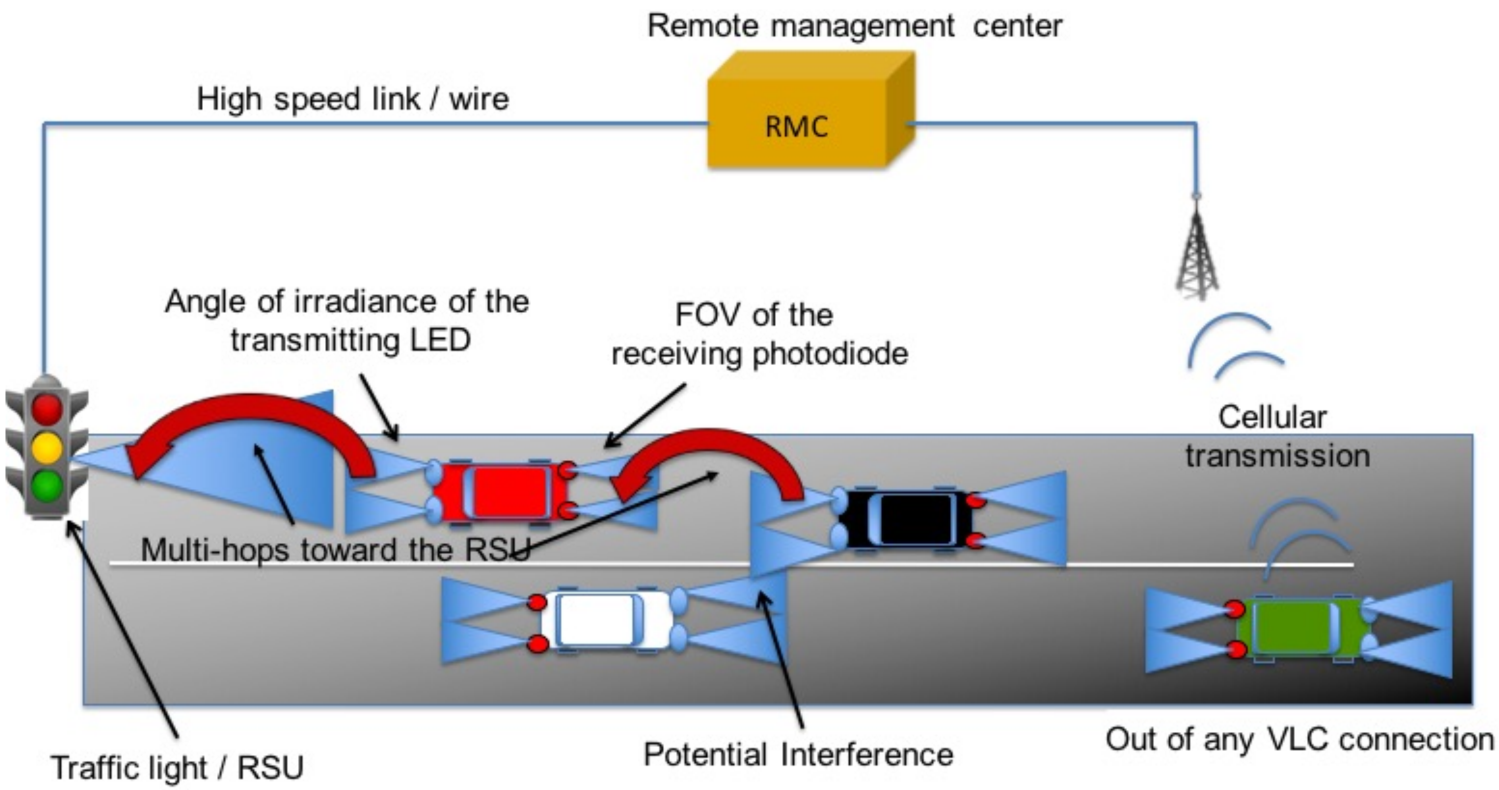
Data uploading from vehicles toward a remote control center



Use of VLC to V2V and V2R communications



Assumptions on VLC



- TX via LED
- RX via photodiode
- RSUs are integrated in traffic lights

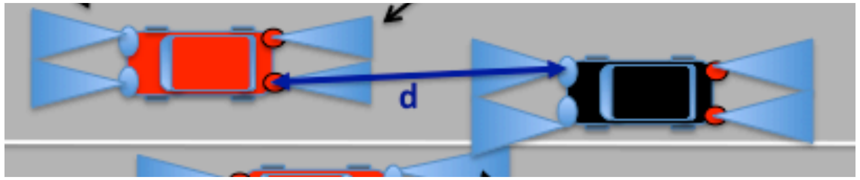
Transmission via cellular system only
- after a given time out or
- when a certain amount of data has been collected.

- Uplink transmission of data from vehicles to the remote control center (RMC)
- Each vehicle periodically transmit a message with position, speed, acceleration, ID, …
- Vehicles try to tx through the head or rear LED lights to the nearer road side unit (RSU)
  - If in visibility of the RSU: direct transmission
  - If not in visibility of the RSU, multi-hop toward the RSU with greedy forwarding (GF) algorithm
- If no neighbors in visibility:
  - When a max number of packets has been accumulated, tx through the cellular network

Assumptions on VLC

1. Communication based on **IEEE 802.15.7** Standard
2. **PHY:** PHY1 based on VPPM modulation with data rate 124.4 kb/s
3. **MAC:** non beacon enabled unslotted random access with CSMA/CA

VLC Channel Model



Channel Model: a transmission is possible only if

1. the virtual line connecting two vehicles is inside the transmitter angle of irradiance and the receiver FOV
2. they are in visibility, that is the virtual line connecting them does not cross any other vehicle or building
3. the received power Pr > receiver sensitivity Pr_{min}
4. the SINR is higher than a threshold γ_{min}

$$\mathrm{SINR} = \frac{\beta^2 P_\mathrm{r}^2}{I + \sigma_\mathrm{shot}^2 + \sigma_\mathrm{thermal}^2} \qquad P_\mathrm{r} = H(d,\theta,\psi) P_\mathrm{t}$$

$$H(d,\theta,\psi) = \begin{cases} \frac{(\mathrm{m}+1)A}{2\pi d^2} \cos^m(\theta)\cos(\psi) & \text{if } \psi < \Psi_\mathrm{C} \\ 0 & \text{otherwise} \end{cases} \qquad \mathrm{m} = -\frac{\ln 2}{\ln(\cos\phi_{\frac{1}{2}})}$$

$$I = \left(\sum_{i=1}^{N_\mathrm{int}} \beta P_{\mathrm{r}i}\right)^2 = \left(\sum_{i=1}^{N_\mathrm{int}} \beta H(d,\theta,\psi) P_{\mathrm{t}i}\right)^2$$

VLC+11p

- VLC is used only in those cases where DSRC is not possible (*DSRC first* approach)
- 2. VLC is used anytime it is possible in order to maximally offload the DSRC network (*VLC first* approach)
- Congestion-adaptive VLC-DSRC procedure (CA-VDS):
  - In every time interval of duration Tcm = 0.1 s, the DSRC channel congestion ξcc is measured by each vehicle;
  - VLC is preferred if ξcc>=ξD, where ξD is a given threshold (DSRC is considered congested).
  - If ξcc < ξD, DSRC is preferred.
    - using ξ = 0, VLC is always preferred to D (VLC first)
    - DSRC irrespective of the channel congestion level
    - when ξD = 1, DSRC is always preferred (DSRC first)

$$\xi_{\mathrm{cc}} = \frac{t_{\mathrm{busy}}}{t_{\mathrm{busy}} + t_{\mathrm{idle}}}$$

Simulation Settings

- 1.8×1.6 km^2 scenario
- Four VLC RSU at the main junction
- One 802.11p RSU
- Traffic:
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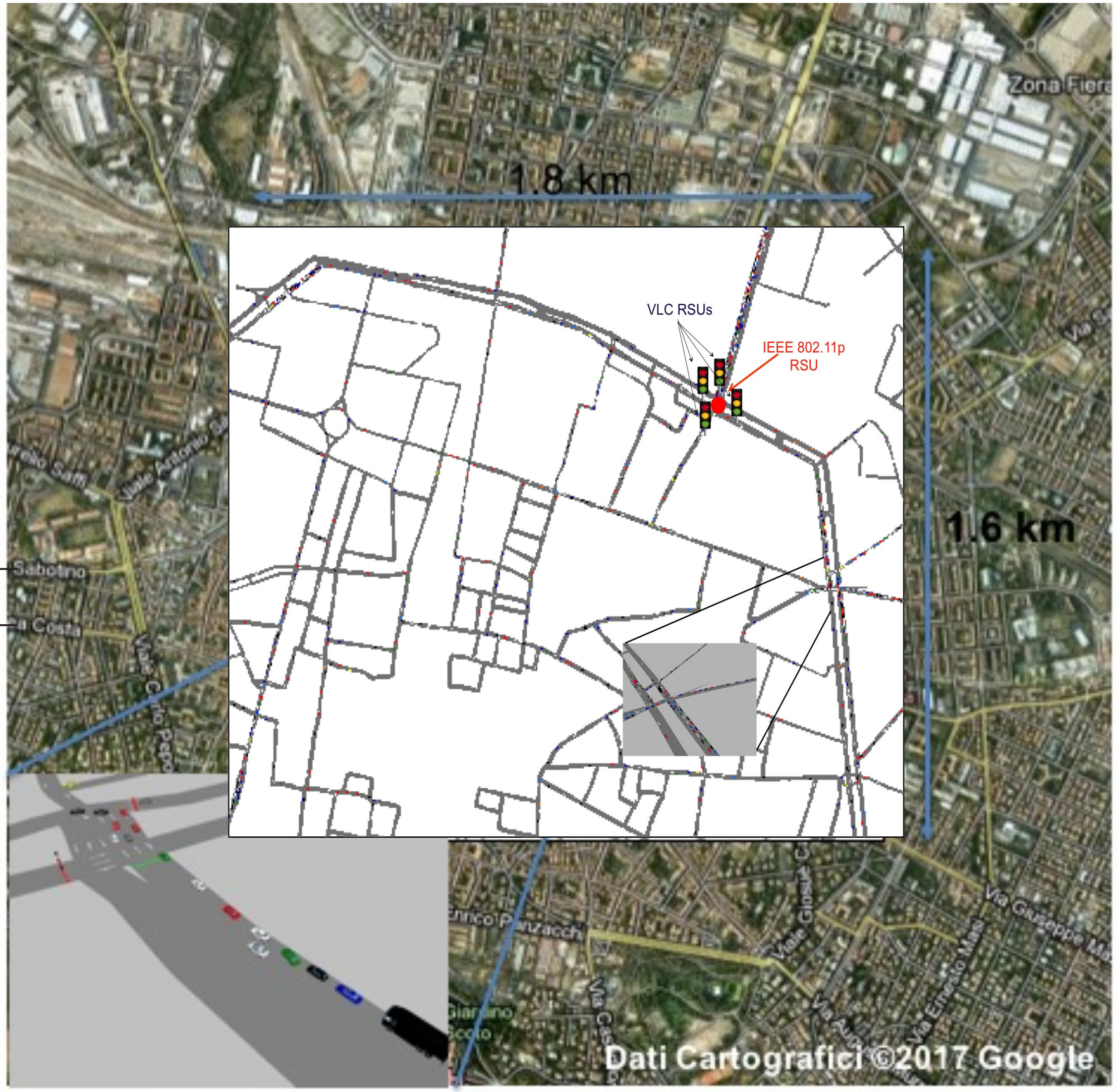
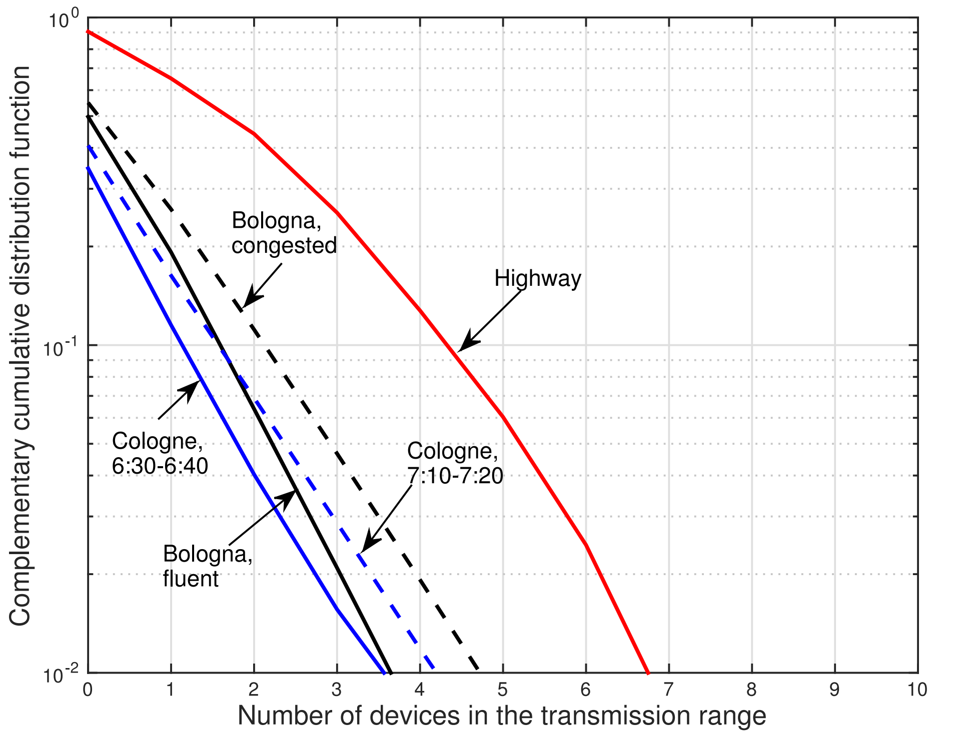
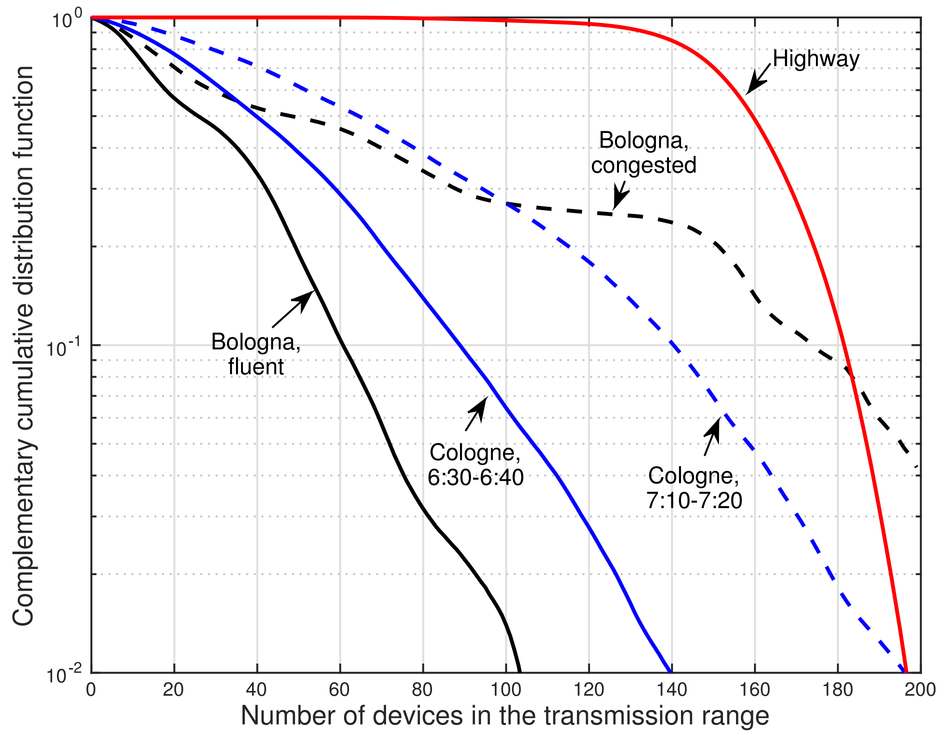


Param.	Definition	VLC	802.11p
P_t	Transmission power	30 W	0.2 W
β	Detector responsivity	0.54 A/W	–
A	Physical area of the photodiode	1 cm^2	–
ψ_c	FOV of the receiver	30°	–
m	Order of the generalized Lambertian radiant intensity	20	–
$\gamma_{\min}$	Minimum SNR	11.4 dB	10 dB
d_{max}	LOS range	50 m	$520 \div 1050$ m (96% prob.)
R	Nominal data rate	266.6 kb/s (∗)	3 Mb/s
B	Packet size	100 bytes	
λ	Packet generation rate	[0.1–10] packets/s	

CCDF of the number of devices in the tx range



(a) VLC.

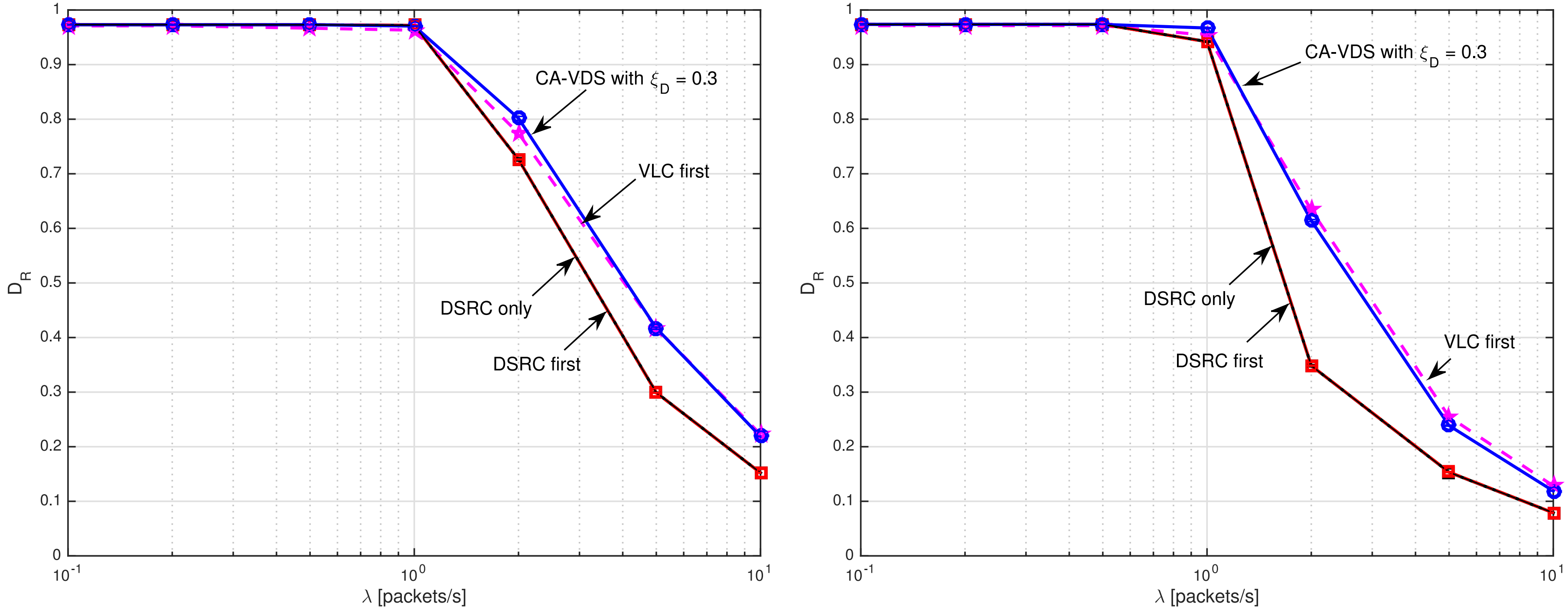


(b) DSRC.

the probability of having more than one neighbor with VLC is less than 0.5 in a highway busy scenario and less than 0.2 in all the others

number of neighbors between tens to hundreds

Delivery rate vs packet generation rate



(a) Bologna, fluent traffic. Delivery rate.

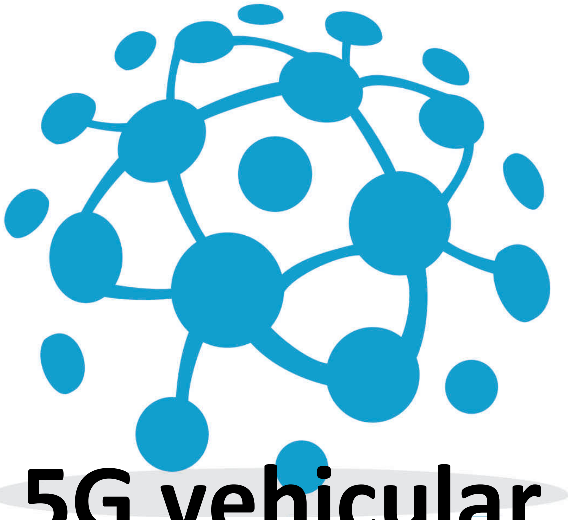
(b) Bologna, congested traffic. Delivery rate.

- The performance of DSRC first is similar to DSRC only
- When VLC is selected first, for values of λ greater than 1 packets/s DR is instead higher than both the DSRC

Conclusion

- In terms of availability, IEEE 802.11p/ITS G5 have the desirable features of not relying on network infrastructure and being fully distributed,
- On the other hand, the uncoordinated channel access strategy used by IEEE 802.11p is unable to fulfill the (deterministic) latency, reliability and capacity requirements of future V2X use cases toward autonomous vehicles
- Will LTE-V2X gain the momentum or should we wait for 5G?
- Cellular-V2X is the road to 5G vehicular networks, where the best of both the world will be combined together and with other technologies

Ready for connecting automotive car constructors , telco providers, infrastructure managers and build visionary perspective



Toward 5G vehicular networks

when vehicles will talk to each other

- **Barbara Mavì Masini**
- **Alessandro Bazzi**

- CNR-IEIIT, Italy
- Email: barbara.masini@ieiit.cnr.it, alessandro.bazzi@ieiit.cnr.it