The University for
world-class professionals

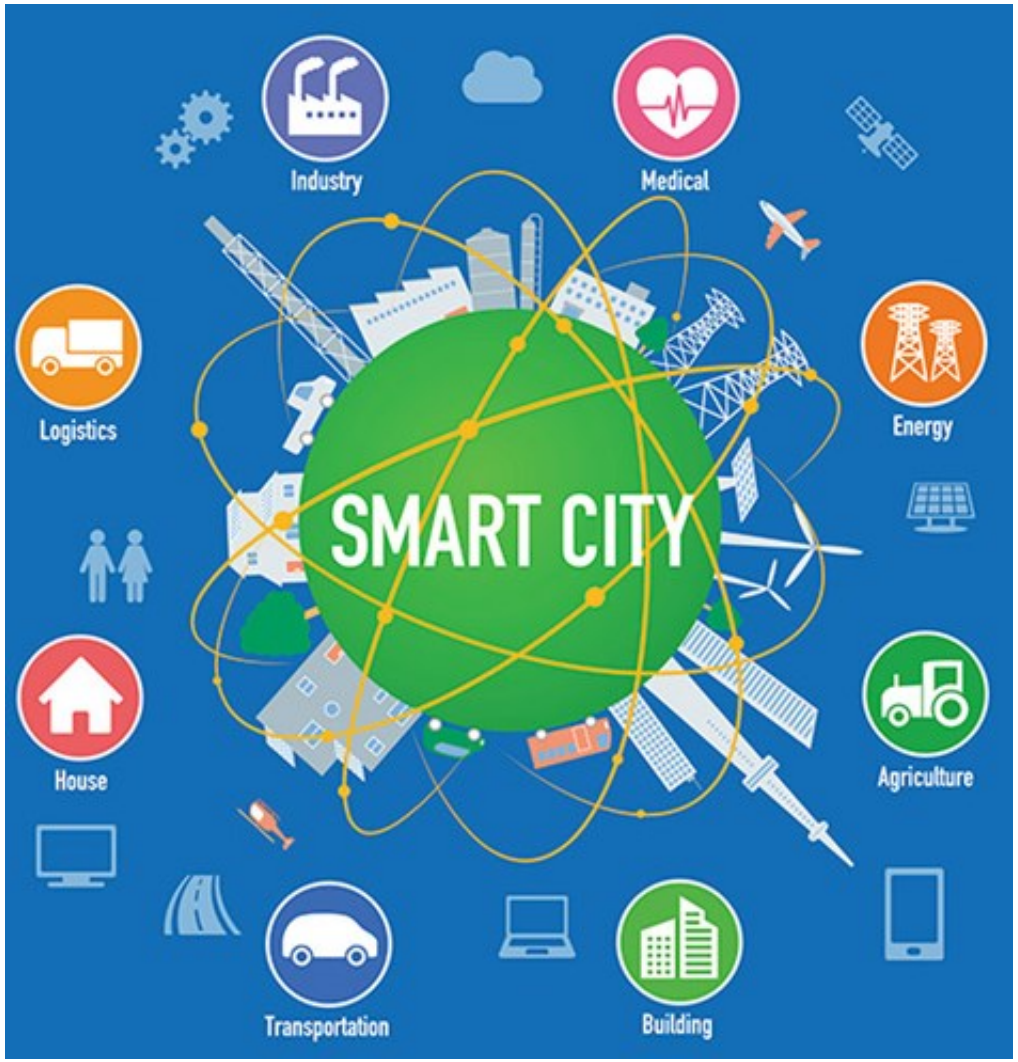
Manchester
Metropolitan
University

Towards Connected Vehicles for Smarter & Greener Transportation

Dr. Soufiene Djahel
Manchester Metropolitan University, UK
Centre for Advanced Computational Science (CfACS)
s.djahel@mmu.ac.uk

IEEE RTSI 2018, Sep. 10, 2018, Palermo, Italy

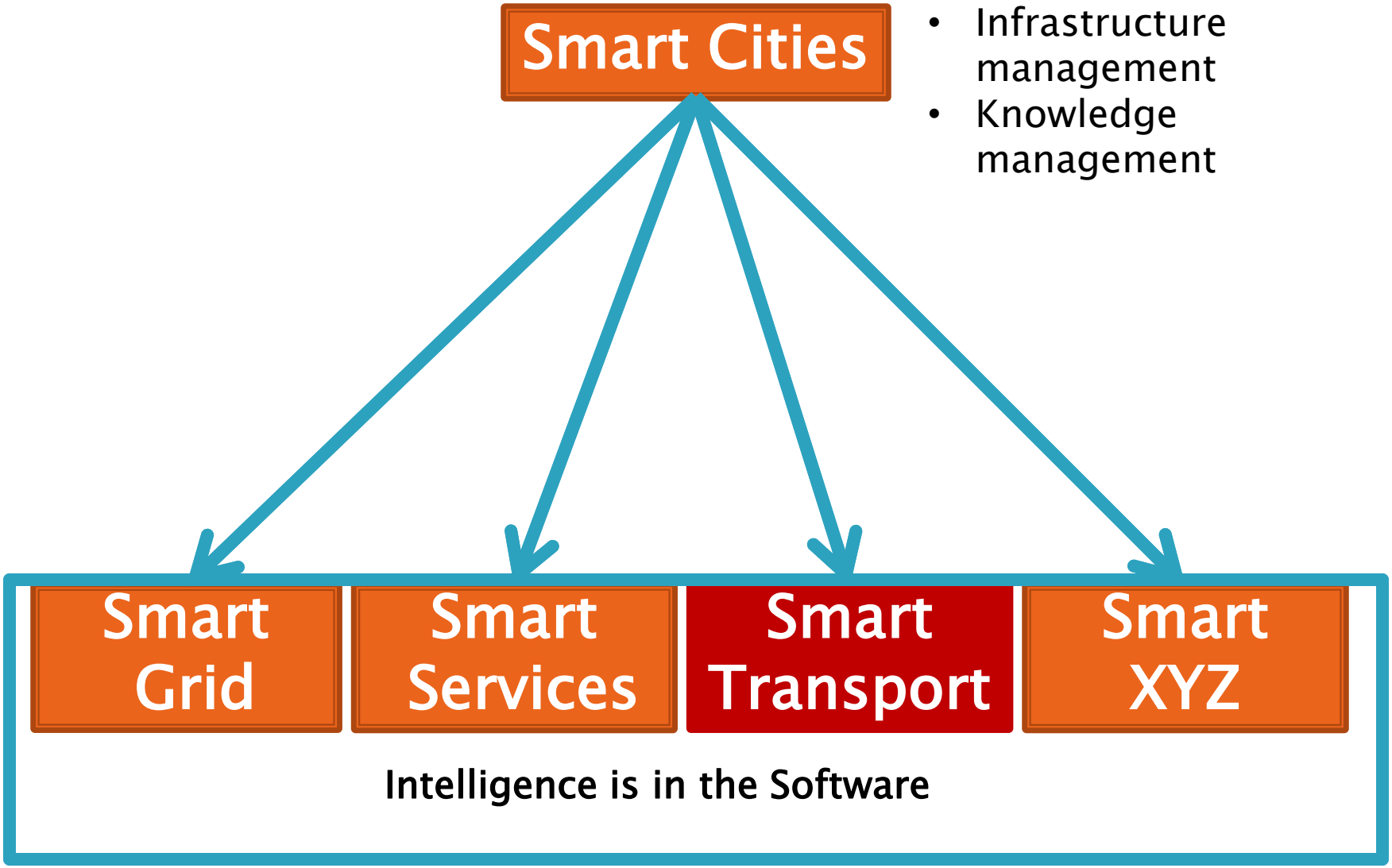
Smart Cities



Smart Cities

- Services offered by Smart Cities should be:
  - Smart
  - Cheap
  - Secure
  - Safe and reliable
  - <u>Aligned with societal trends</u>

Smart Cities



- Infrastructure management
- Knowledge management

Smart Transportation (1/3)

- Objective: leverage advanced technologies to develop multidisciplinary solutions to reduce traffic congestion and mitigate its undesirable impact
- Make the mobility of people and goods worldwide:
  - Faster
  - Cheaper
  - Eco-friendly
  - and safer

Smart Transportation (2/3)

- Evolution
  - Cities evolve
  - Traffic pattern, volumes, complexity and data sources evolve
    - 2.9 billion vehicles by 2050
  - Technology evolves, what to monitor evolves

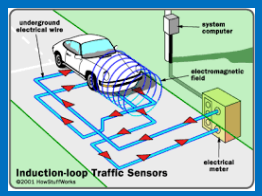
Smart Transportation (3/3)

- Critical impact
  - Congestion costs billions to world economy
  - According to a study conducted by INRIX, a leading traffic investigation service
    - 2013-2030: the economic loss due to traffic congestion in UK alone is expected to be a staggering £307 billion
      - => an increased congestion per-household cost from £1,426 in 2013 to £2,057 in 2030

Mobility as a Service (MaaS)

Efficient Data Collection

Wireless Sensing technologies, energy efficiency, efficient & secure multi-hop transmissions, VaaR



Traffic Congestion

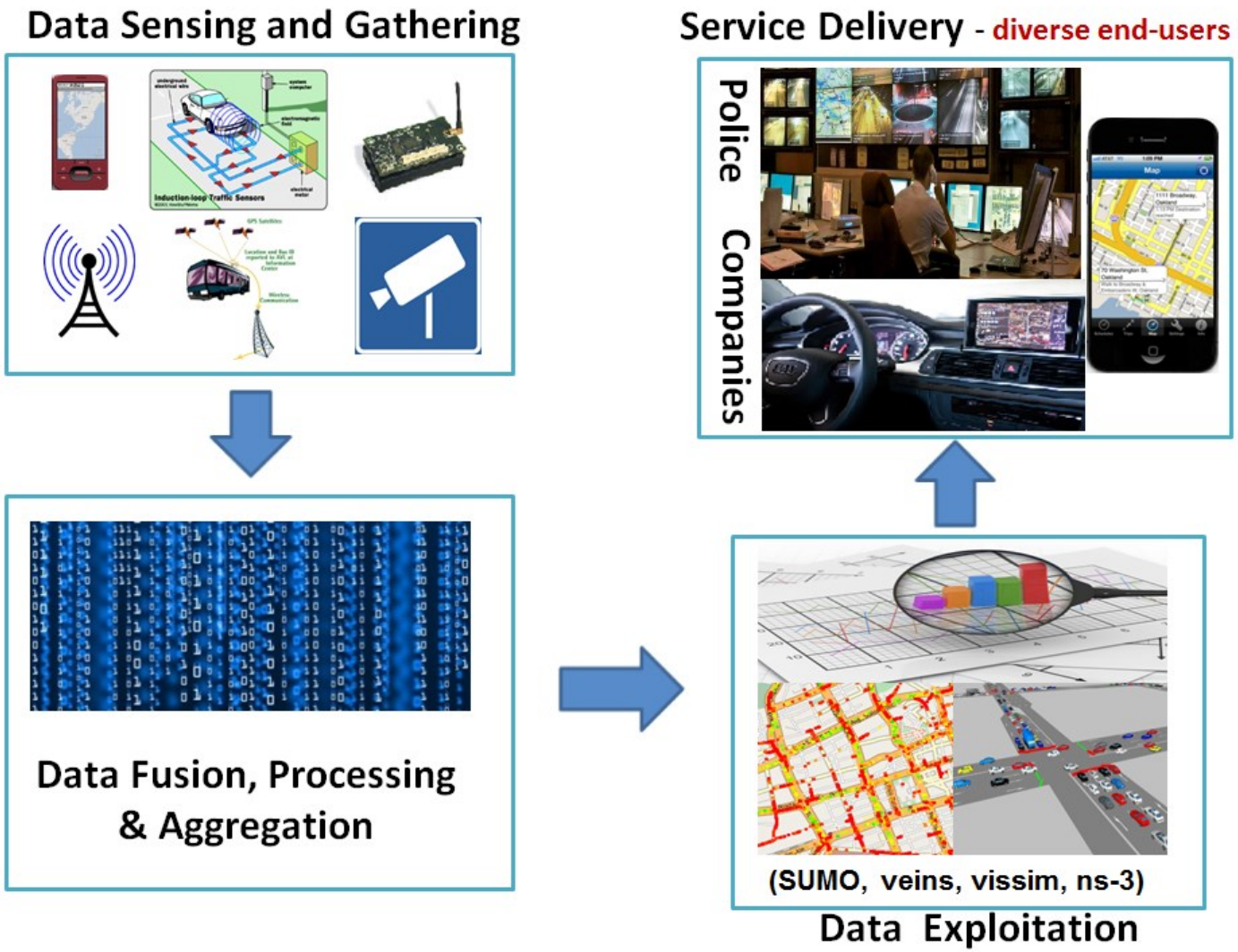
Prediction and mitigation techniques, Adaptive TMS, emergency services, etc.

Smart Cities Lab

CAVs

Secure and reliable communication protocols, Safety & traffic efficiency applications, bandwidth scarcity

Road traffic data life cycle



S. Djahel et al, "A Communications-oriented Perspective on Traffic Management Systems for Smart Cities: Challenges and Innovative Approaches", IEEE COMSAT, 2015

Some applications

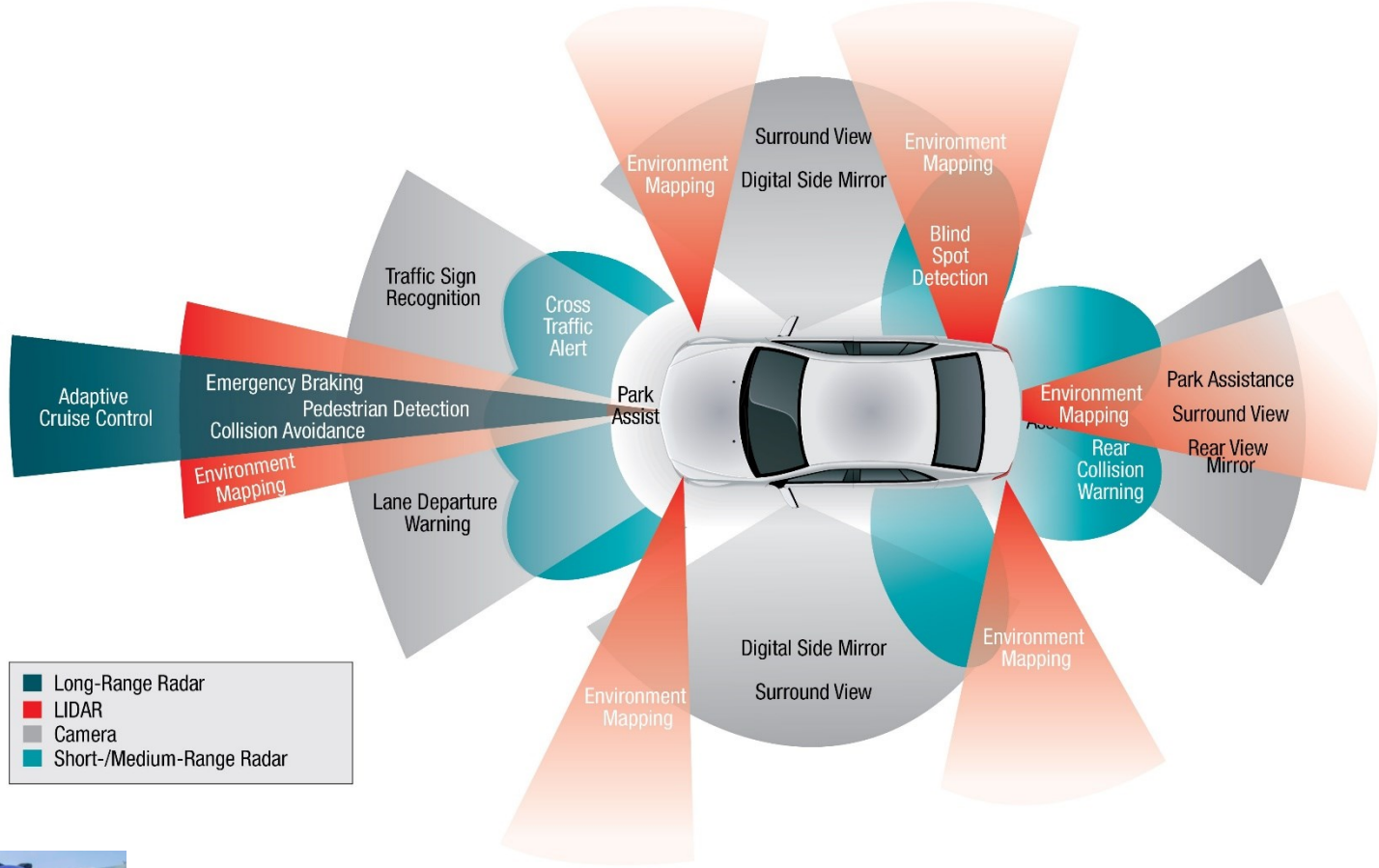
- Leveraging the wealth of traffic data gathered from road monitoring equipment or shared by road users
- Creating new business models for existing travel means
  - Waze
  - UBER
  - RESROBOT
  - …

Autonomous Vehicles

Autonomous (Self-driving) Vehicles (1/3)

- Localization: where am I?
- Sensing the surroundings: what's happening around me?
- Perception (fusion of sensor data)
- Reasoning and decision making
- Motion control

Autonomous (Self-driving) Vehicles (2/3)



Autonomous vehcile demonstration by
CATAPULT Transport System, UK

Autonomous (Self-driving) Vehicles (3/3)

GPS

DSRC (760 MHz, 5.9 GHz)

Cellular technology (LTE, 5G, etc.)

Electronic Toll Collection

Radar

Bluetooth

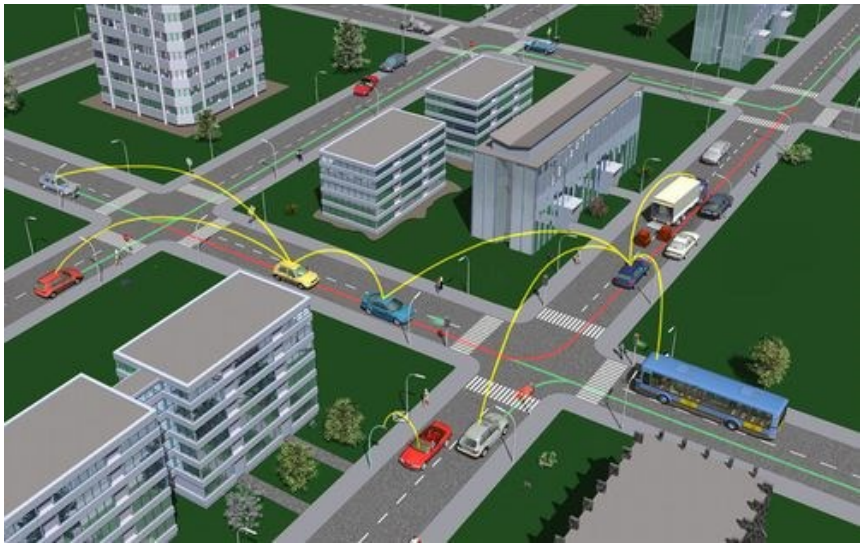
Wi-Fi

Wireless Battery Charging

Visible Light Communications (VLC)

Connected & Autonomous Vehicles (CAVs)

Vehicular Networks

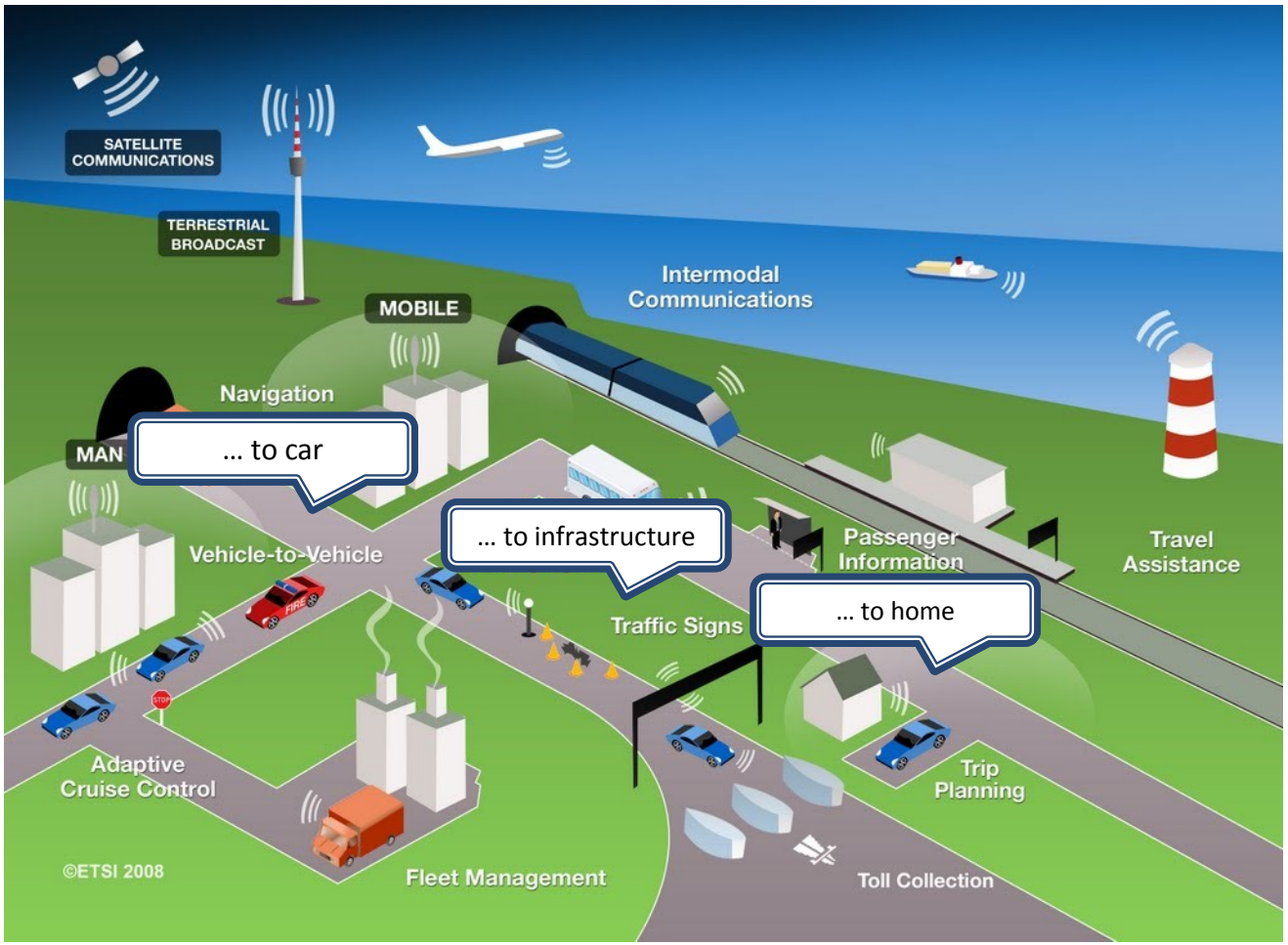


- Wireless communication between
  - Vehicles (V2V)
  - Vehicles and the road infrastructure (V2I)
  - Vehicles and X?

- Promise to solve many of today's road traffic problems by
  - Improving road users' safety
  - Shortening their trip times
  - Enhancing their travel experience
  - Reducing air pollution

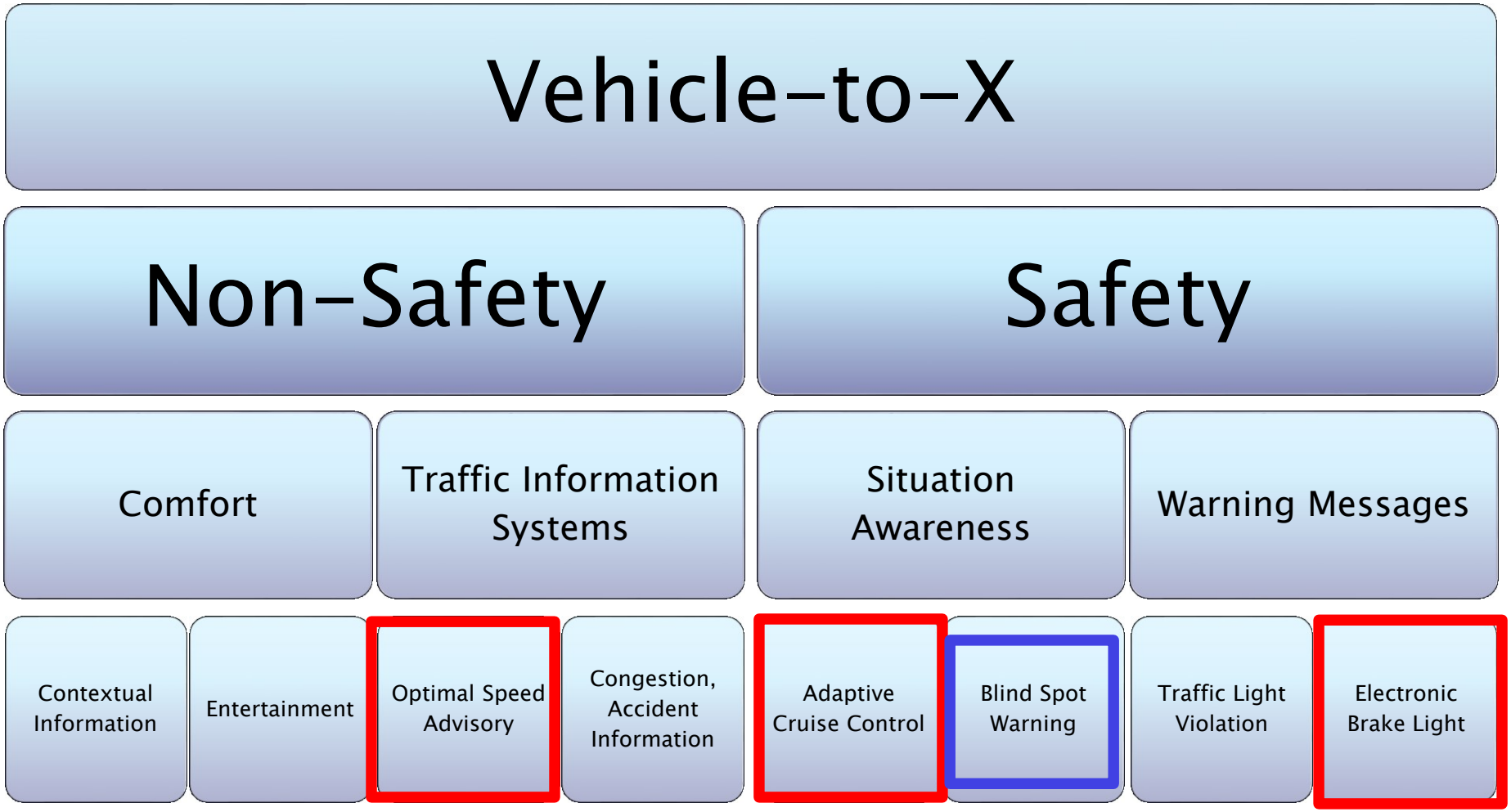
Vehicle to X communication patterns

- Vehicle-to-X (V2X)
  - X: pedestrian, RSU, IoT device etc.
- Inter-Vehicle Communication (IVC),
- Vehicular ad-hoc network (VANET),
- …



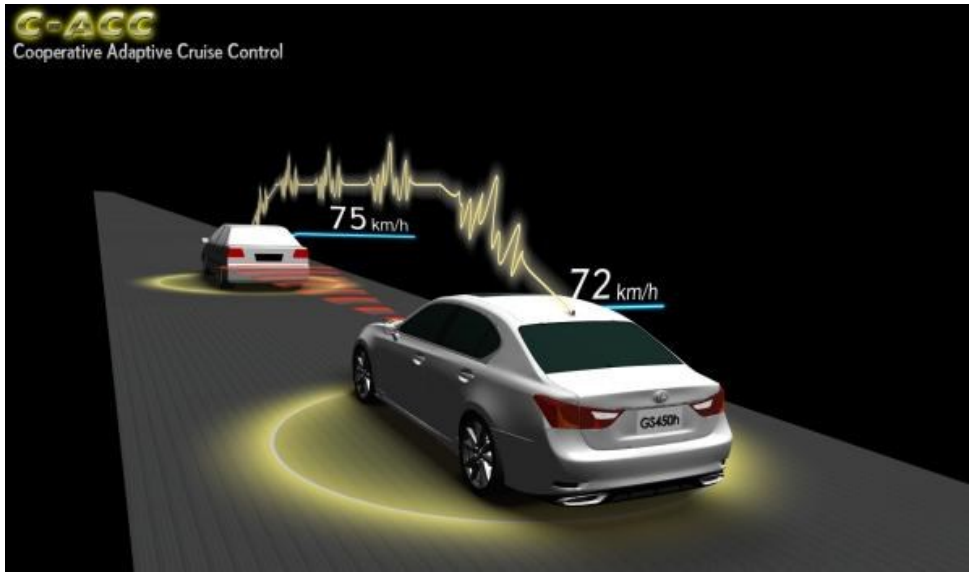
C. Sommer and F. Dressler, Vehicular Networking, Cambridge University Press, 2014

Taxonomy of use cases



C. Sommer and F. Dressler, Vehicular Networking, Cambridge University Press, 2014

Cooperative Adaptive Cruise Control



- Cars share info on speed changes in real-time
  - More efficient Adaptive cruise control system
  - Reduced carbon emissions

Taxonomy of use cases

Vehicle-to-X

Non-Safety	Safety
Many messages	Few messages
High data rate	Small packet size
Low latency demands	High latency demands
Low reliability demands	High reliability demands

C. Sommer and F. Dressler, Vehicular Networking, Cambridge University Press, 2014

IEEE802.11p WAVE/DSRC

- IEEE 802.11p
  - PHY layer mostly identical to IEEE 802.11a
  - Variant with OFDM and 16 QAM
  - Channel bandwidth down to 10 MHz (from 20 MHz)
  - Throughput down to 3 ... 27 Mbit/s (from 6 ... 54 Mbit/s)
  - Range up to 1000 m (theoretically), speed up to 200 km/h

IEEE802.11p WAVE/DSRC

- MAC layer of IEEE 802.11a plus extensions
  - QoS (EDCA priority access, cf. IEEE 802.11e, ...)
  - Multi-Frequency and Multi-Radio capabilities
  - New Ad Hoc mode
  - …

IEEE802.11p WAVE/DSRC

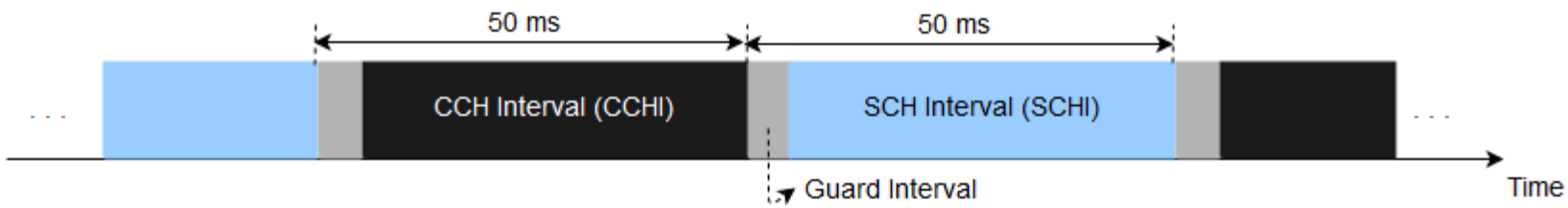
- Channel management
  - Dedicated frequency band at 5.9 GHz allocated to WAVE
  - Exclusive for V2V and V2I communication
  - 1999: FCC reserves 7 channels of 10 MHz ("U.S. DSRC")
    - 2 reserved channels, 1+4 channels for applications
  - ETSI Europe reserves 5 channels of 10 MHz

U.S. Allocation	...	Critical safety of Life	SCH	SCH	Control Channel (CCH)	SCH	SCH	Hi-Power Public Safety	...
European Allocation		SCH	SCH	SCH	SCH	CCH	SCH	SCH	
IEEE Channel		172	174	176	178	180	182	184	
Center Frequency (GHZ)		5.860	5.870	5.880	5.890	5.900	5.910	5.920	

ETSI ES 202 663 V1.1.0 (2010-01) : Intelligent Transport Systems (ITS); European profile standard for the physical and medium access control layer of Intelligent Transport Systems operating in the 5 GHz frequency band

IEEE802.11p WAVE/DSRC

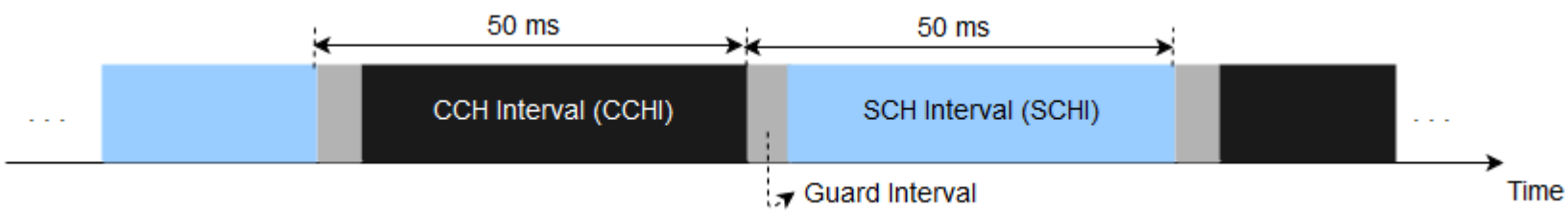
- Channel management
  - WAVE allows for both single radio devices & multi radio devices
  - Dedicated Control Channel (CCH) for mgmt and safety messages
    - single radio devices need to periodically listen to CCH



IEEE Vehicular Technology Society, "IEEE 1609.4 (Multi-channel Operation)," IEEE Std, November, 2006

IEEE802.11p WAVE/DSRC

- Time slots
  - Synchronization envisioned via GPS receiver clock
  - Standard value: 100ms sync interval (with 50ms on CCH)
  - Short Guard Interval (GI) at start of time slot (radio switching delay)
  - During GI, the medium is considered busy



Congestion control in Urban Vehicular Networks

Research problem: Introduction

- Cities generate an enormous amount of data
  - 4 million terabytes of traffic in 2022
  - 630K terabytes from connected cars
- A large portion to be carried by vehicular networks

➔ **Wireless congestion problem**

Ph.D. thesis "Enhanced Wireless Congestion Control in Urban Vehicular Environments", Sofiane Zemouri, University College Dublin, Ireland , July 2016

Research problem: Scope

- Safety and critical information. (periodically broadcasted)
- Urban scenarios
- Two types of messages
  - Safety and event driven warning messages
  - Control messages (beacons, CAMs, etc)

Congestion control for safety information

- Critical information, multi hop transmission, high periodicity, limited timeframe, short to medium length messages
- Goal, limit the amount of data inserted in the network
  - Get rid of unnecessary retransmissions after failures
  - Channel conditions (Shadowing, Doppler Effect,…)

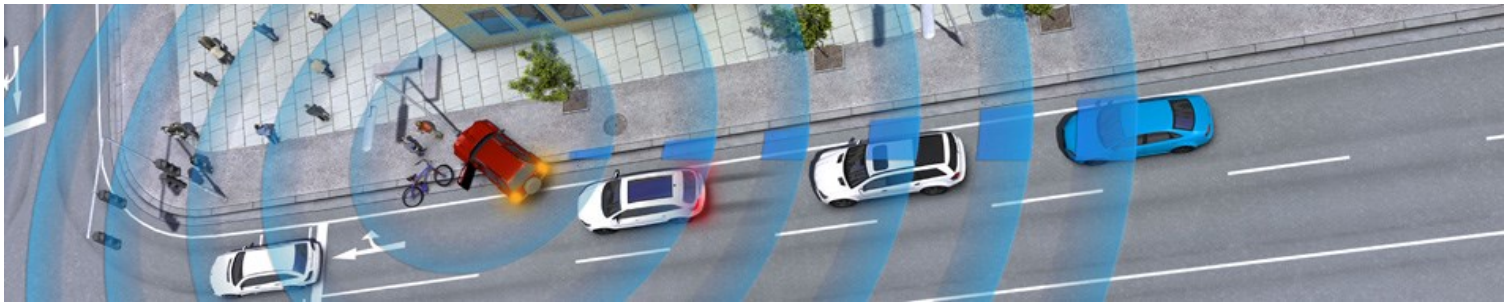
S. Zemouri, **S. Djahel**, and J. Murphy. A Fast, Reliable and Lightweight Distributed Dissemination Protocol for Safety Messages in Urban Vehicular Networks. Ad Hoc Networks Elsevier, Vol. 27, pp. 26-43, 2015

Congestion control for safety information

Road-Casting Protocol (RCP)

- Distance factor (D)
  - a function of the distance between the sender & the potential next forwarder, the next junction and the potential next forwarder, and the next junction to the transmission range of the sender

- Link Quality factor (LQ)
  - is a function of the signal quality (SQ), the channel quality (CQ) and the collision probability (CP)
    - CQ is intended to estimate the state of the channel around the receiver before and at the time of the reception of the emergency message



Congestion control for safety information

Road-Casting Protocol (RCP)

- Retransmission Probability

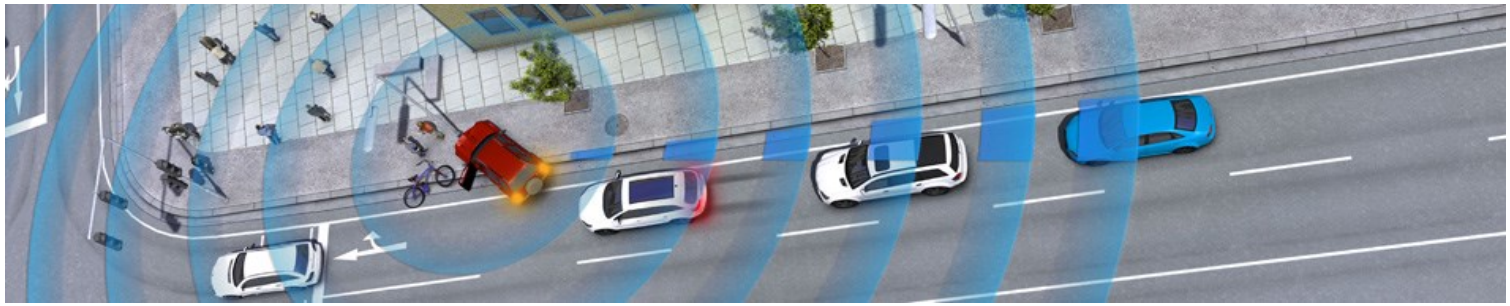
$$P = (1 - \omega_P)D + \omega_P LQ$$

$0.5 \leq \omega_P \leq 1$
D: Distance Factor
LQ: Link Quality Factor

- Retransmission Waiting Time (Backoff)

$$WT = CW \times (1 - P) + \delta$$

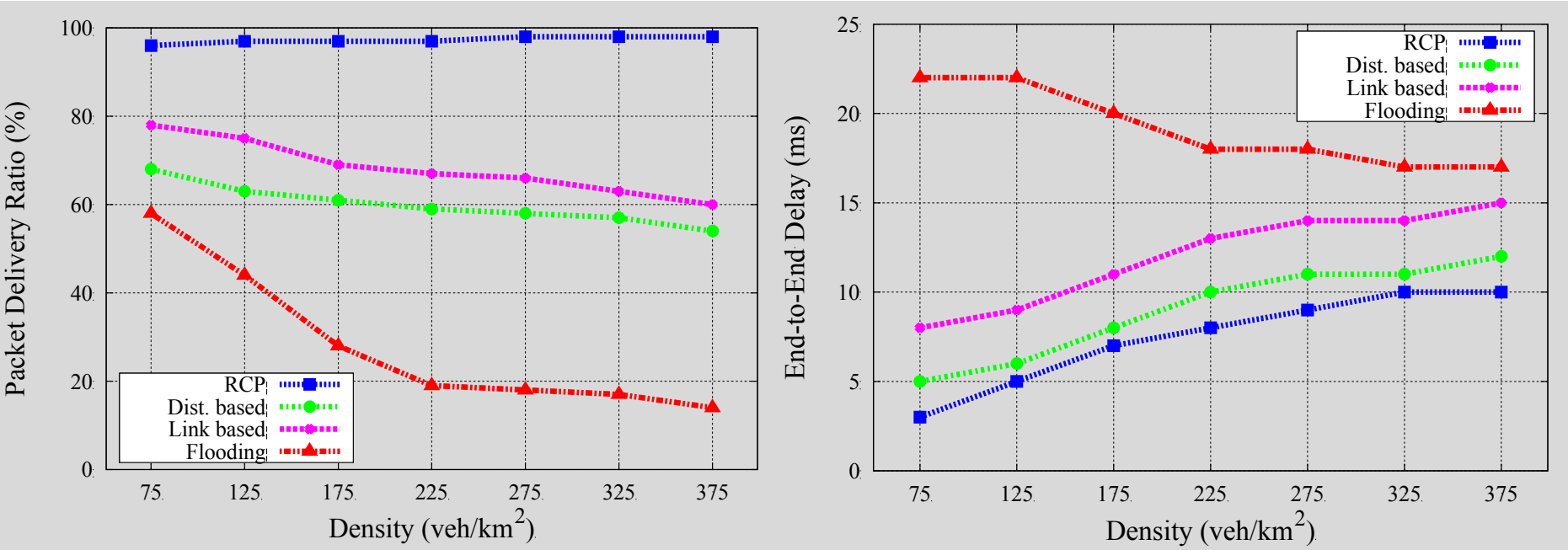
δ: Random value in μs
so that 2μs < δ < 9μs
CW: Contention Window



Congestion control for safety information

Bit rate: 6Mb/s
CW: [15,1023]

Data message size: 100 bytes
Broadcast frequency: 1hz



Impact of vehicles density on Packet Delivery Ratio and End-to-End Delay: RCP vs. distance based forwarding, link based forwarding and flooding

Congestion control for safety information

- Microscopic congestion control ✓
  - Amount of data inserted in the network on a point-to-point level
- Macroscopic congestion control
  - The extent of data inserted in the network (end-to-end)
- Determine the Region of Interest (RoI) for multi-hop safety messages
- Keep the amount of data inserted in the network minimal

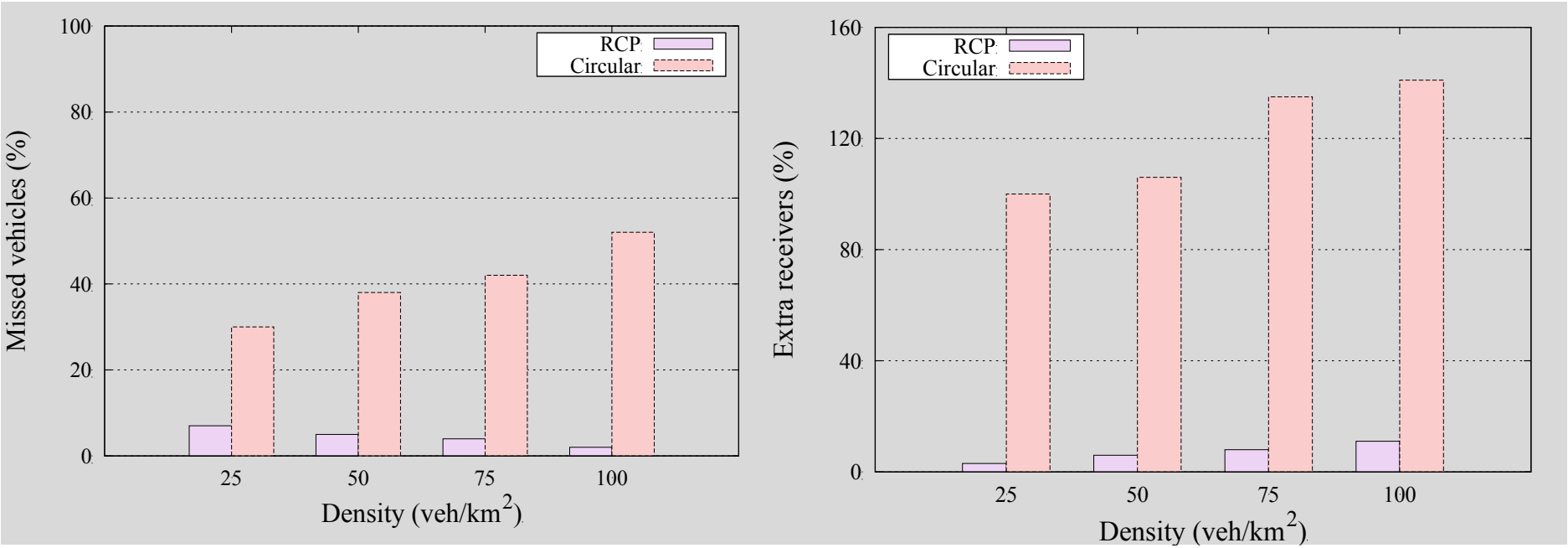
Congestion control for safety information

The set of critical junctions (red ticks) delimitating the zone where vehicles are already blocked due to an incident

Congestion control for safety information

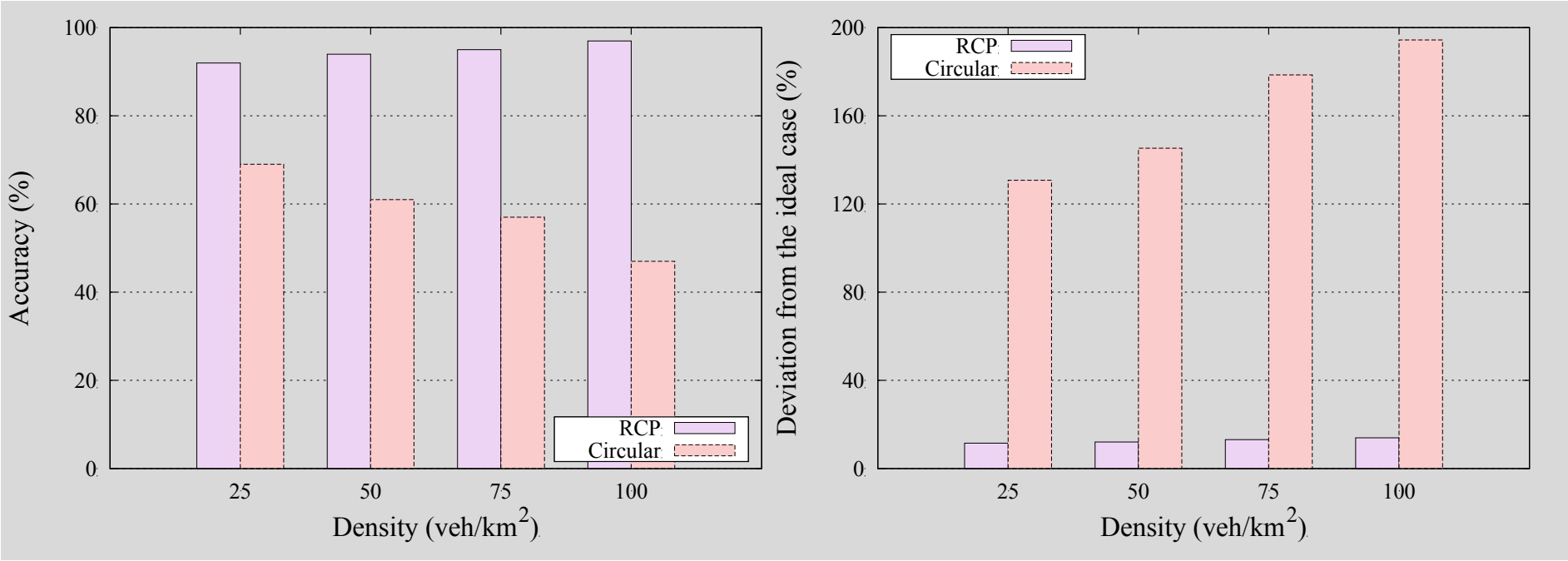
Road map connectivity check performed by each receiver of an emergency message: using simplified A* algorithm

Congestion control for safety information



The ratio, under different vehicle densities, of vehicles located inside and outside the RoI which did not receive the emergency message (Algiers map)

Congestion control for safety information



Impact of vehicles density on the accuracy of the RoI definition:
RCP scheme RoI vs. circular RoI
(Algiers map)

Congestion control for periodic beacons

Congestion control for periodic beacons

- Critical information, single hop transmission, high periodicity, continuously transmitted, short length messages
- Goal, limit beacons collisions to negligible levels in all channel conditions
- Channel capacity
  - 10 Hz / 48 ms / 60% ➔ 28.8 ms
  - 1 ms/beacon ➔ 28 beacons per CCHI ➔ 28 vehicles

C, Sommer, et al. How shadowing hurts vehicular communications and how dynamic beaconing can help". Mobile Computing, IEEE Transactions on, 14(7):1411-1421, 2015

Congestion control for periodic beacons

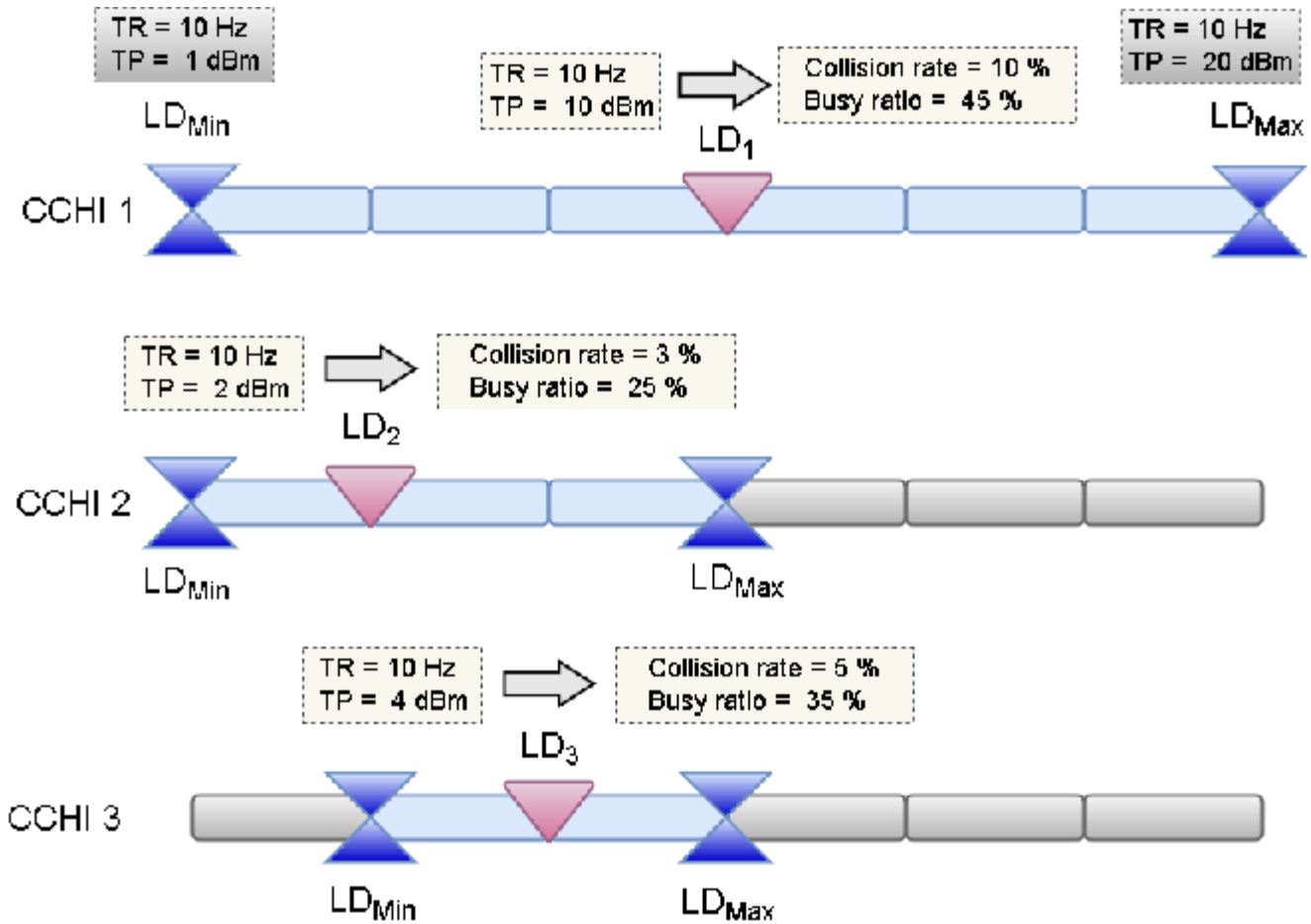
Adaptation mechanism:
Successive Rate and Power Adaptation (SuRPA)

- Successively adapt transmit Rate, then Power according to the observed local density
- Binary search
  - Fastest way to locate a value in a sorted set
  - The optimal channel load that produces marginal collision rate (lower than 5%)

Congestion control for periodic beacons

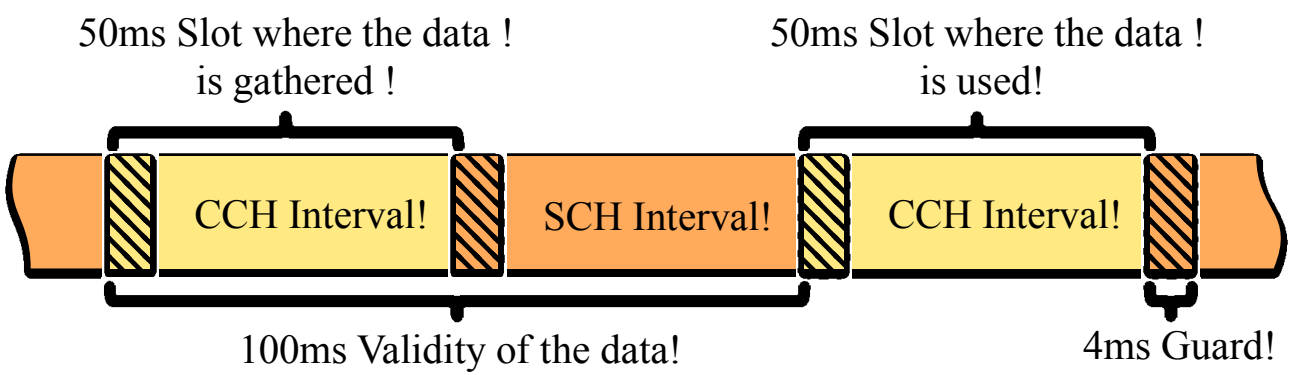
Adaptation mechanism:

LD: local density



Congestion control for periodic beacons

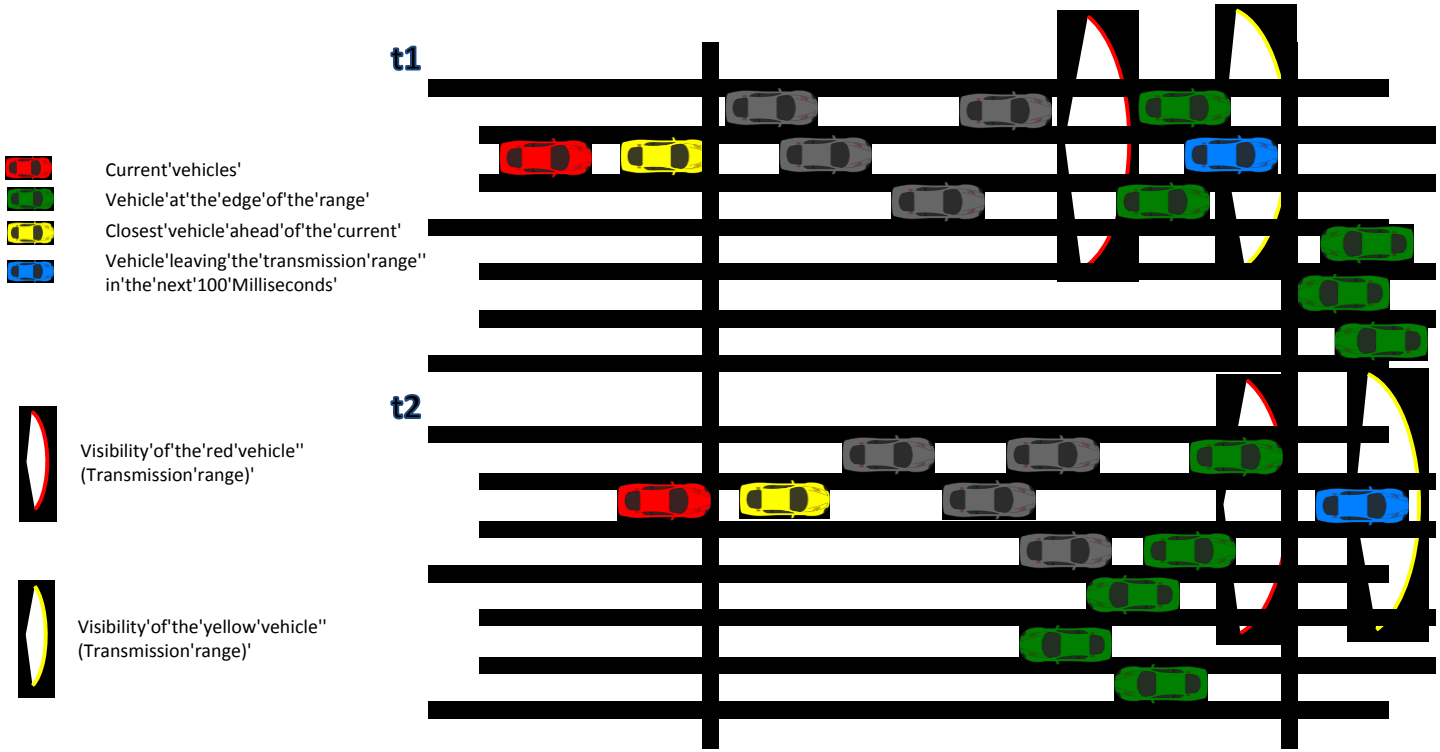
- Adaptation mechanisms:
  - Spatial and temporal adaptation of transmission parameters
- Further enhance this adaptation
  - Anticipate channel load peaks
- Predict near-future channel fluctuations
- Apply the transmit parameters adaptation to the predicted local density



Congestion control for periodic beacons

Altruistic prediction mechanism

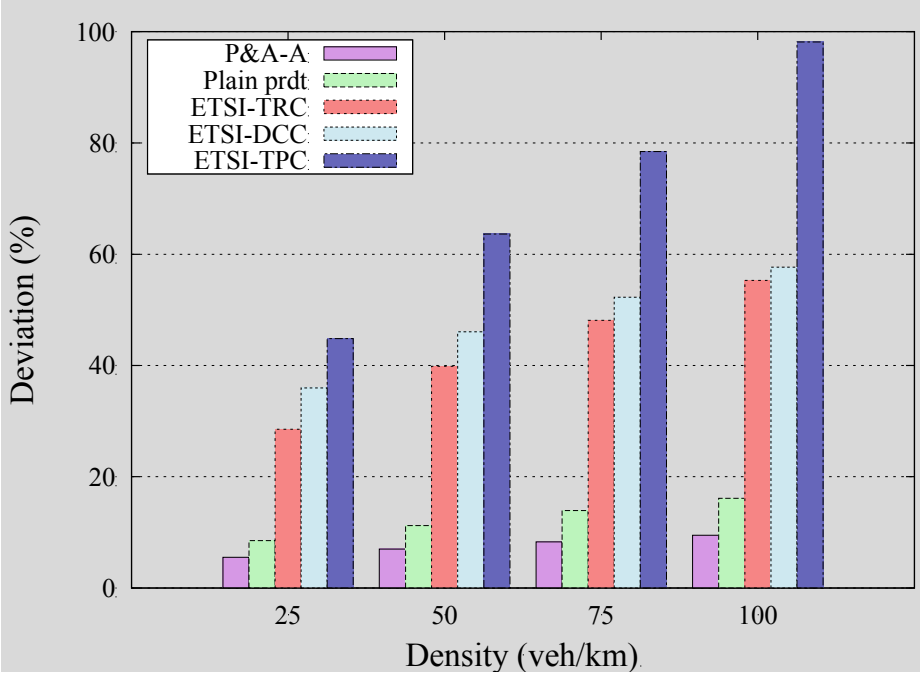
Prediction & Adaptation – Algorithms (P&A-A)



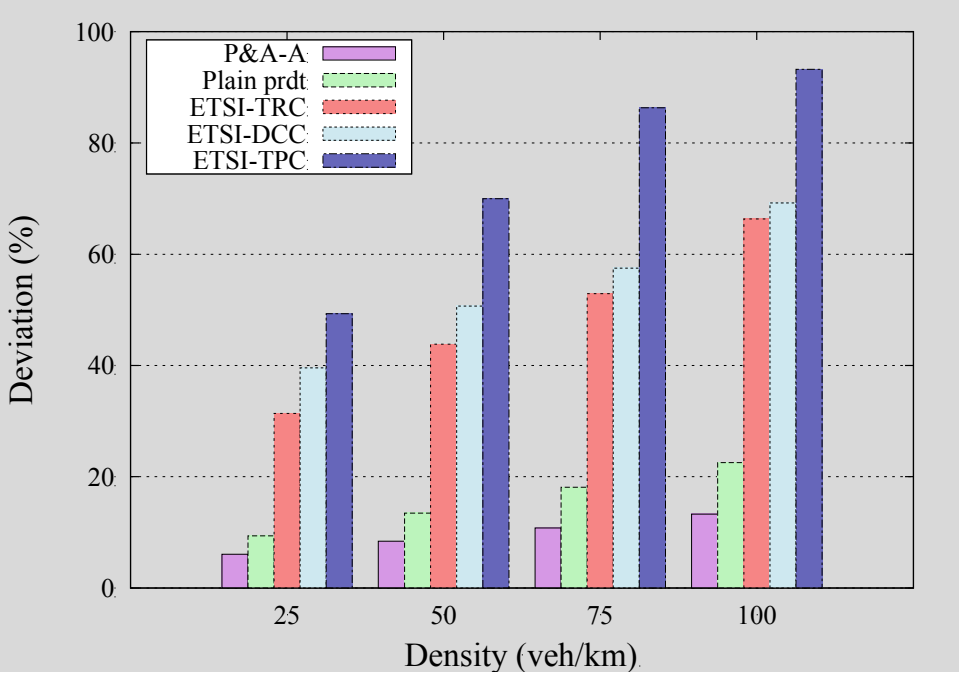
S. Zemouri, **S. Djahel**, J. Murphy. An Altruistic Prediction-Based Congestion Control for Strict Beaconing Requirements in Urban VANET. in IEEE Transactions on Systems, Man, and Cybernetics: Systems, 2018

Congestion control for periodic beacons

Manhattan

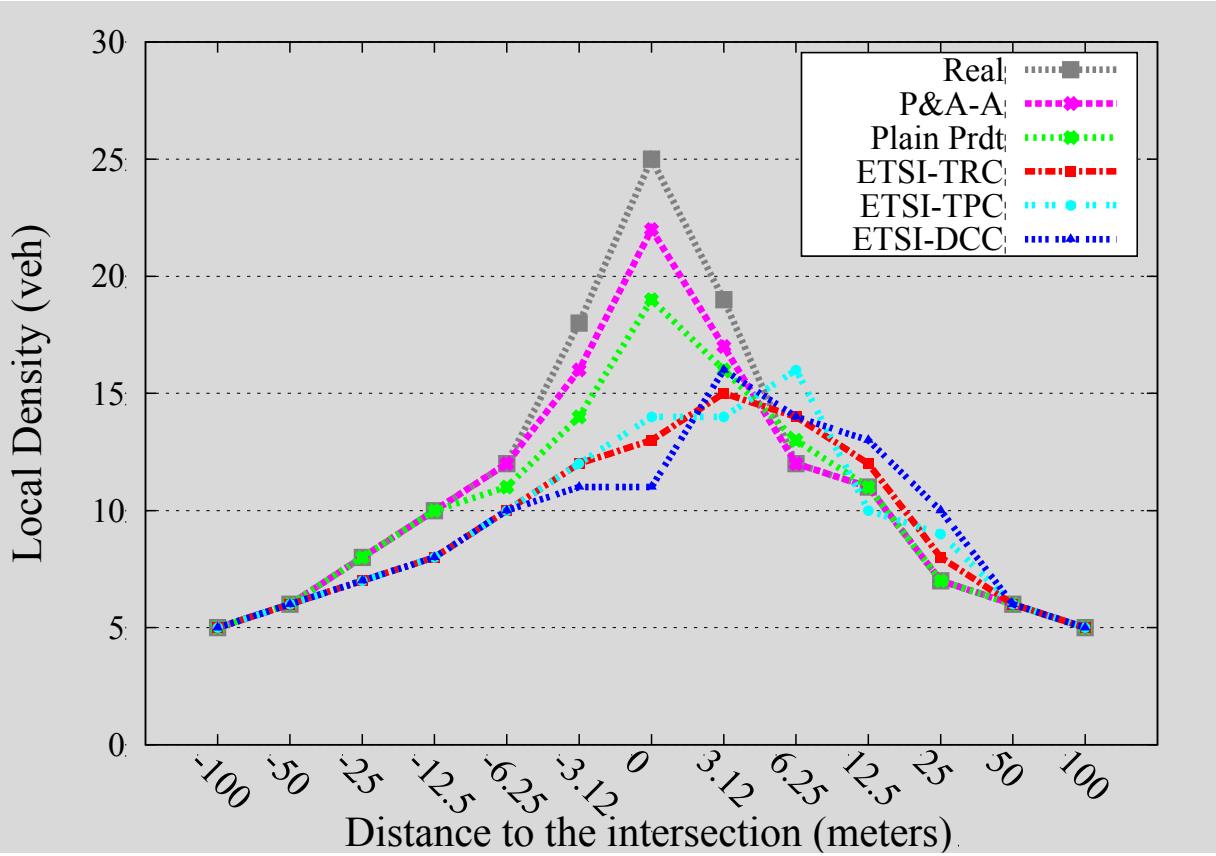


Kirchberg



The percentage of deviation from the effective (real) case under different vehicle densities: P&A-A vs. plain prediction and ETSI schemes

Congestion control for periodic beacons



Impact of the distance to the intersection on the observed density: P&A-A vs. plain prediction and ETSI schemes

Summary

- Road-Casting Protocol (RCP)
  - Next forwarder selection (microscopic congestion control)
  - Region of Interest definition (macroscopic congestion control)
- Prediction & Adaptation – Algorithms (P&A-A)
  - Altruistic prediction mechanism
  - Successive transmission Rate and Power adaptation

Next Road Re-routing

Ph.D. thesis Reducing Non-Recurrent Urban Traffic Congestion using Vehicle Re-routing, Shen Wang, Dublin City University, Ireland, July 2016

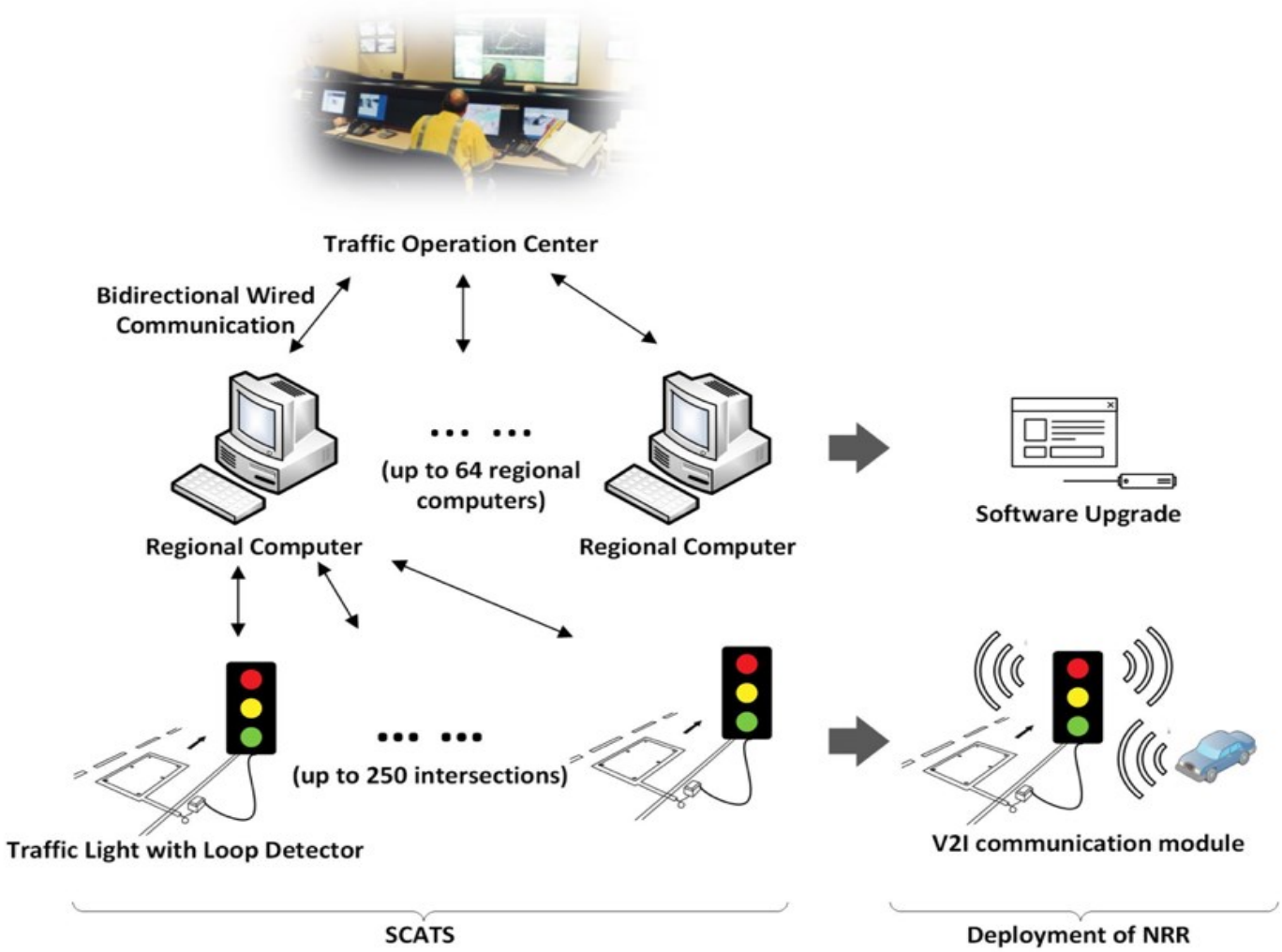
Next Road Re-routing (NRR)

- Main ideas: **Two-Step Re-routing**
  - First, in order to avoid the blocked road, vehicles are diverted to their optimal turns according to **the local traffic conditions**
  - Then, vehicles leverage the **on-board navigation system** to complete the remaining of their journeys.
- Objective
  - Reducing the **average trip time** of all the vehicles in the road network

Next Road Re-routing (NRR)

- Consider three factors on all the next turn choices
  - Geographic Closeness, Travel Time (**selfish** routing/individual benefit)
  - Traffic Load (**altruism** routing / global benefit)
  - The lane which has the **least cost value** will be suggested

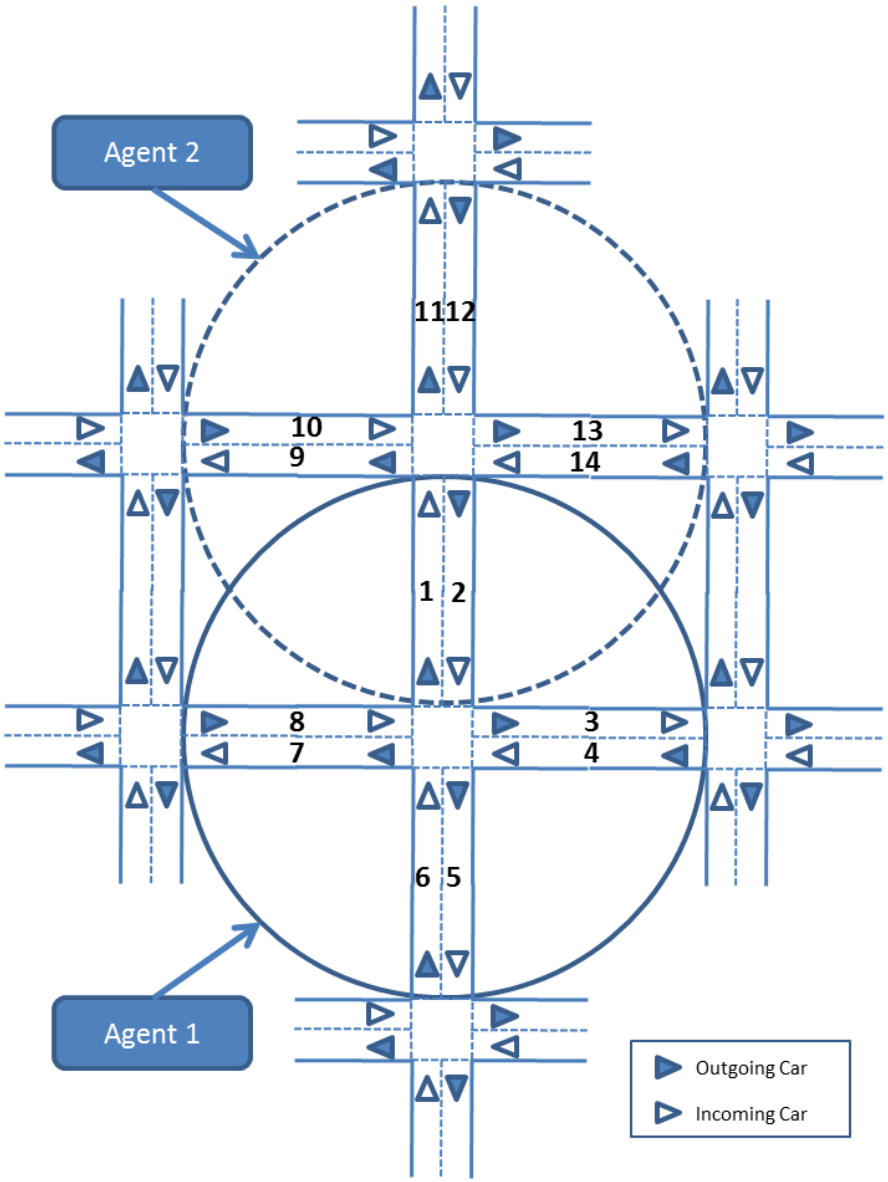
Next Road Re-routing (NRR): deployment



SCATS: Sydney Coordinated Adaptive Traffic System

MAS Architecture

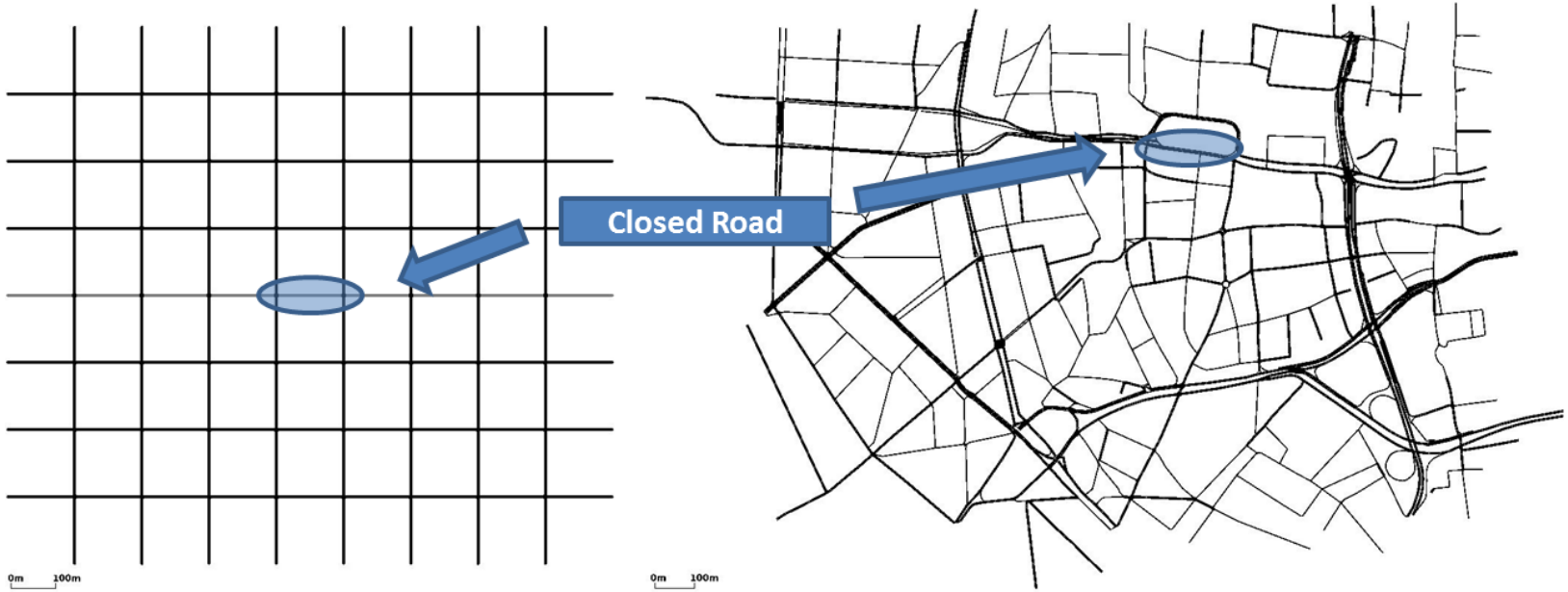
- **Agent**
  - The traffic light and the set of outgoing lanes that it controls.
  - Easier and more efficient than vehicle-based MAS
- **Coordination**
  - Global traffic load balancing can be done through "Lane 1"



Simulation Setting

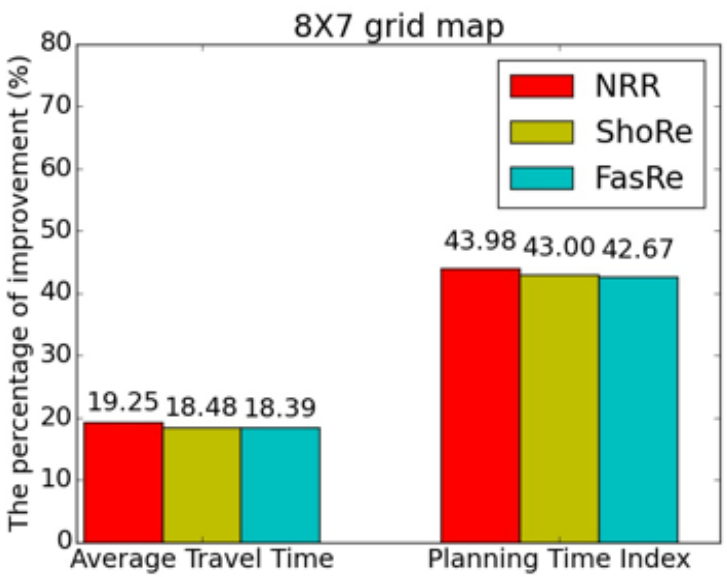
- Trip generation time : **30min**
  - Close one lane of the road in the center area for 20min (**5th min – 25th min**)
  - Simulation runs until all the trips are finished
- All **the vehicles are identical**
  - same length, same minimum gap etc.
- **Grid maps**:
  - 3X2, 4X3, 5X4, 6X5, 7X6, 8X7, 9X8
  - Road type: two bidirectional lanes; Length: 150 m
- **Realistic map** (TAPAS Cologne):
  - City center (18.15 km2)
  - Traffic demand: 6:00am – 6:30am

Blocked Road

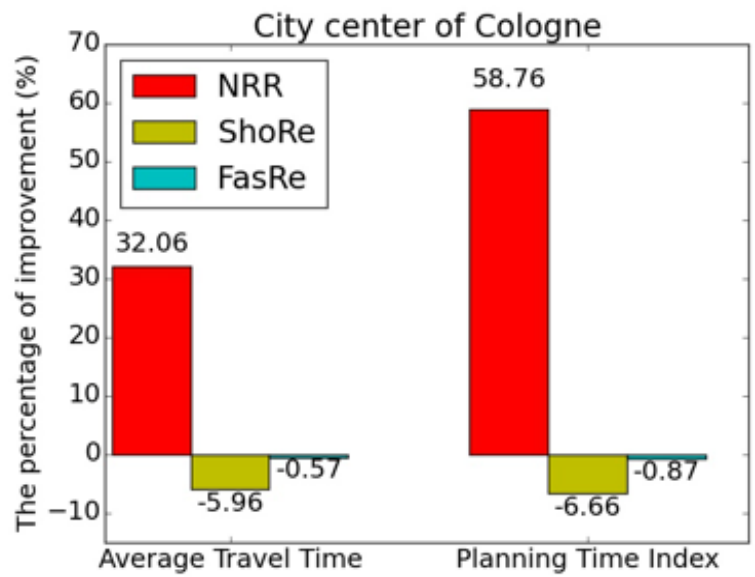


Performance Improvement

- NRR wins in both scenarios



(a)



(b)

Summary

- Novelties of NRR
  - Two steps re-routing
    - Optimal next-turn
    - Current navigation system
  - Make full use of the existing infrastructures
    - Traffic lights + Induction loops
    - Current navigation system
- Benefits of NRR
  - Substantial average trip time reduction
  - Keep the global traffic load balanced

Emerging Challenges

Emerging challenges in Smart Transportation

- Bandwidth scarcity of DSRC spectrum
- Congestion and awareness control
- Electric and hybrid vehicles
  - Route planning and re-routing
- Security, privacy, liability, and dependability
- …

Bandwidth scarcity of DSRC spectrum

- Cognitive radio technology
  - Opportunistic usage of spectrum holes in other bands
  - Software Defined Radio (SDR)
- Using LTE/5G networks to carry specific types of vehicular traffic
- Internet of Vehicles (IoV)
- …

Electric vehicles

- Efficient route planning and re-routing
- How to efficiently overcome their specific constraints?
  - Limited battery capacity
  - Limited number of charging stations
  - Long waiting time at stations
  - Significantly long battery recharge time
  - Range anxiety

Security, privacy and liability

- Cyber attacks
  - Severe consequences in case of a successful attack
- Privacy
  - Location, interests, social networks
- Liability
  - In case of a car crash
    - The car manufacturer or the driver?

Conclusion

- Smart transportation is an emerging research field facing many challenges and offering many opportunities
- Successfully overcoming these challenges promises a significant societal and economic impact
- Most experts foresee that vehicular networks will be a key enabler of smart & green transportation, thus addressing its major technical challenges is essential

Example of a recent research contribution

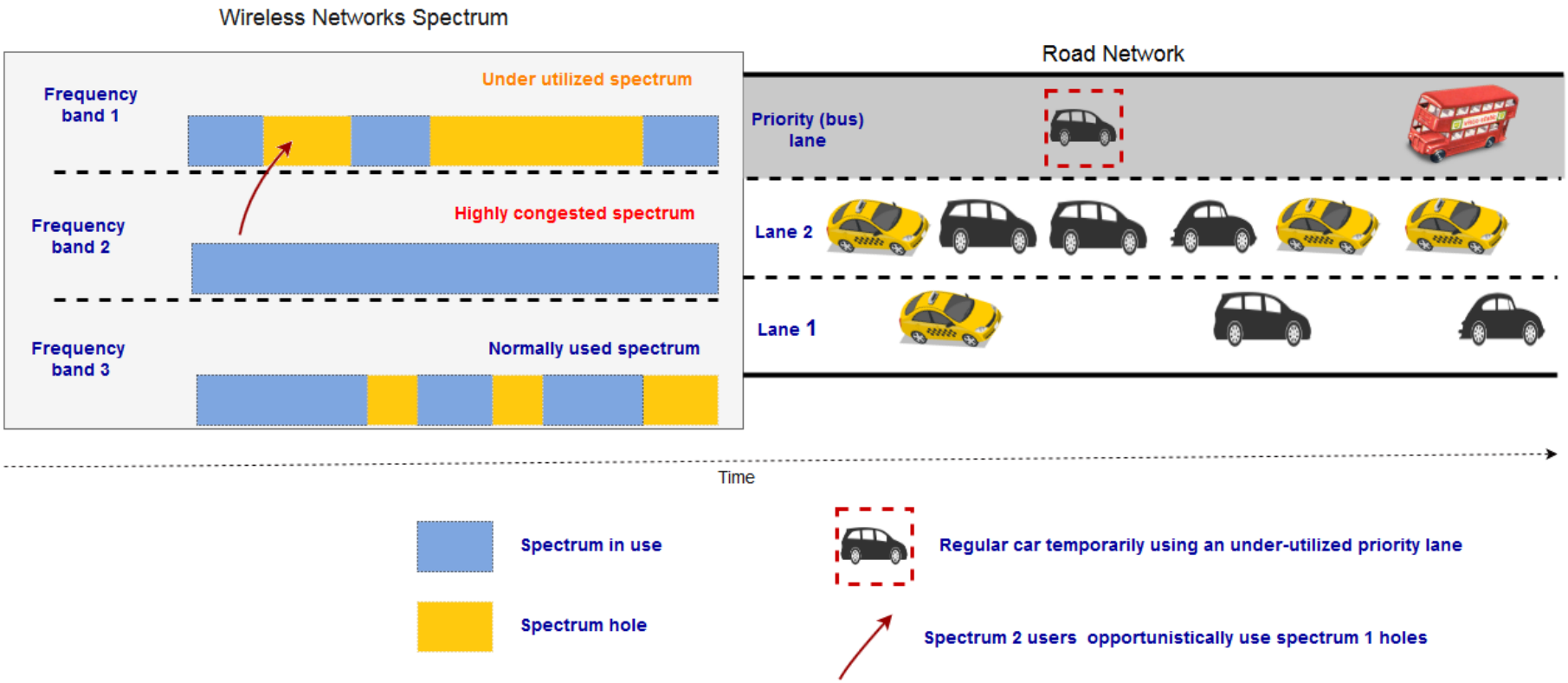
- CRITIC : A Cognitive Radio Inspired Road Traffic Congestion Reduction Solution, Wireless Days conference 2018, April 3-5, 2018, Dubai, UAE.

CRITIC : Main idea

Apply Cognitive Radio principle used in wireless networks in road networks

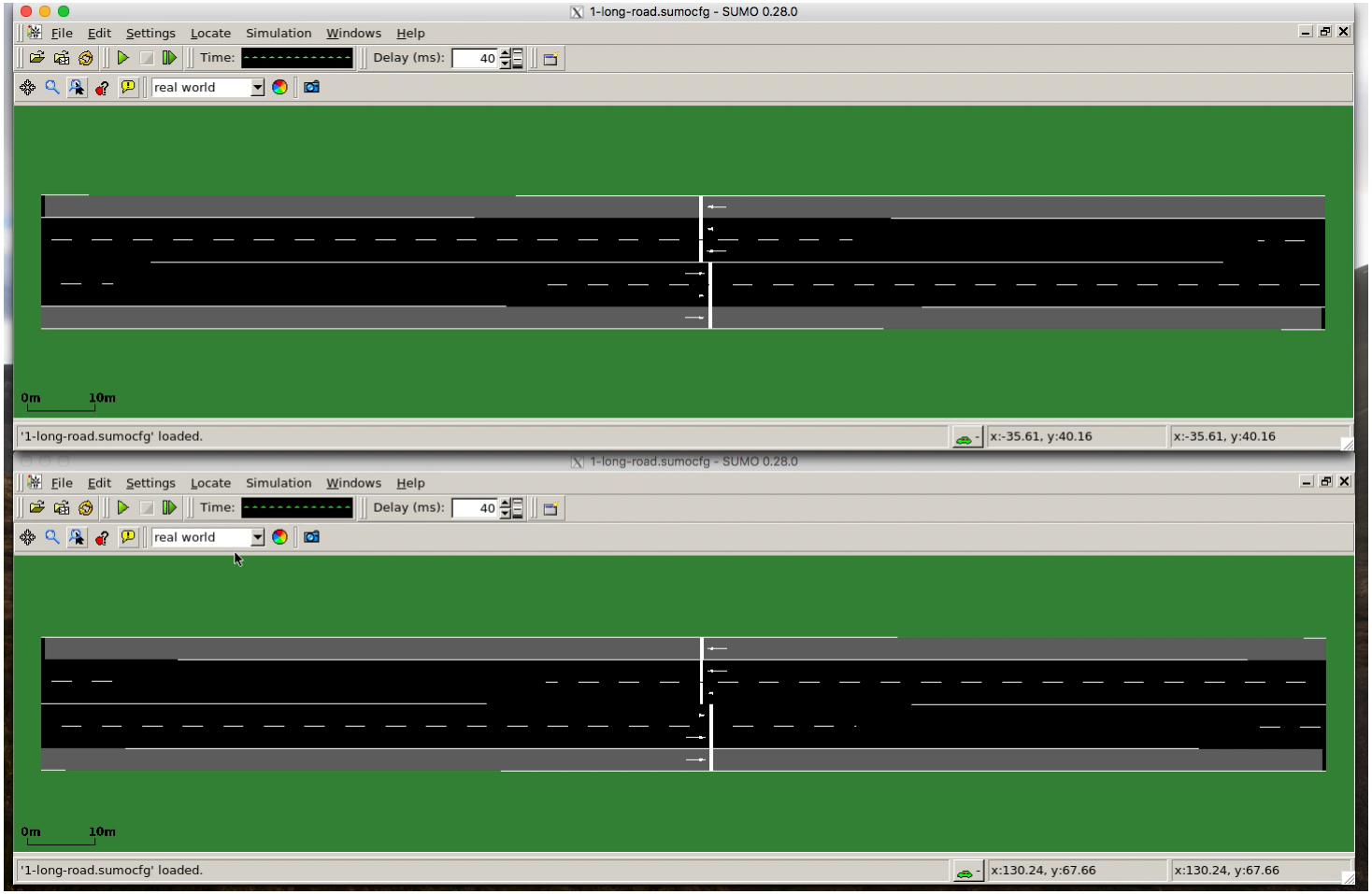
The reserved lanes policy
&&
Connected Vehicles system

CRITIC: Illustration



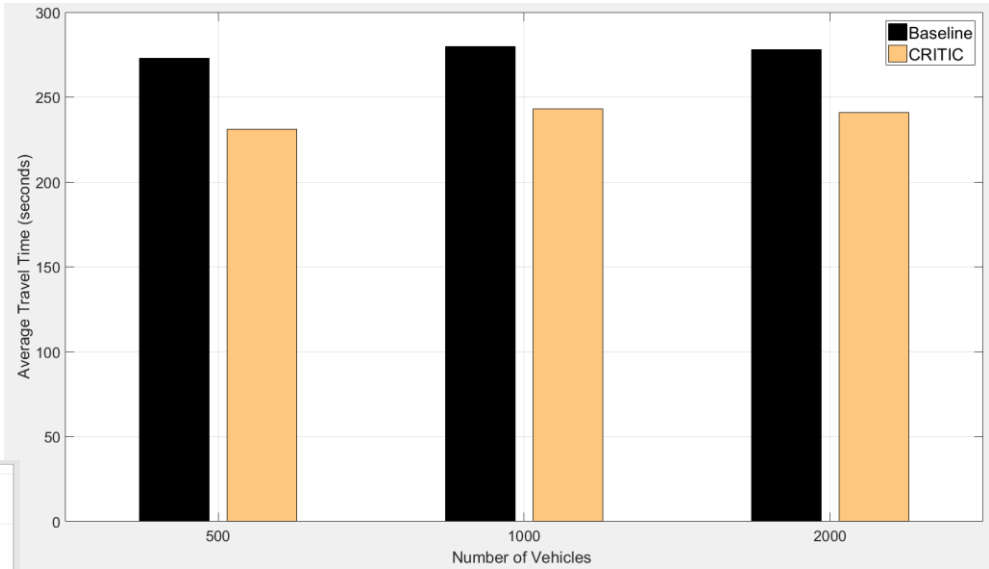
CRITIC: A Cognitive Radio Inspired Road Traffic Congestion Reduction Solution

CRITIC: Demo



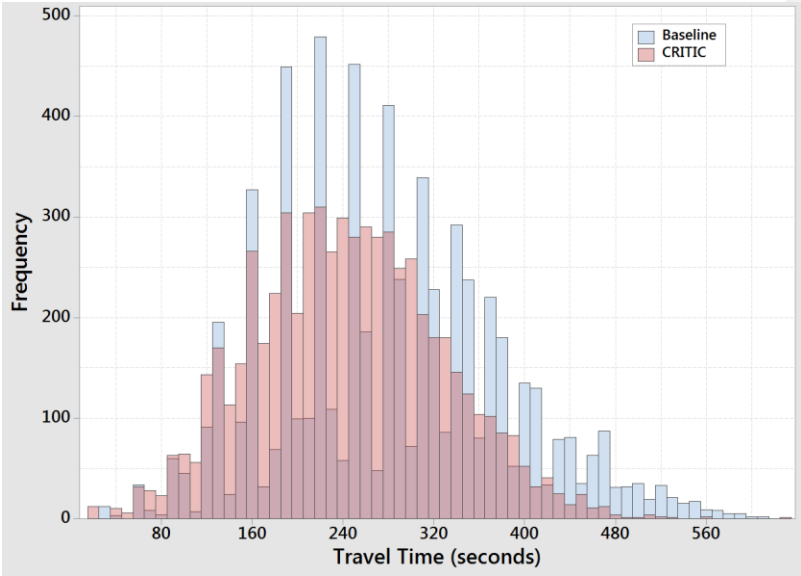
Link on Youtube:
https://www.youtube.com/watch?v=7ap-Nk1uoKo

CRITIC : Performance evaluation results



10x10 Grid network

10x10 Grid network



References

- S. Zemouri, **S. Djahel**, J. Murphy. An Altruistic Prediction-Based Congestion Control for Strict Beaconing Requirements in Urban VANET. in IEEE Transactions on Systems, Man, and Cybernetics: Systems, 2018
- S. Wang, S. Djahel, Z. Zhang, and J. McManis. Next Road Rerouting: A Multi-Agent System for Mitigating Unexpected Urban Traffic Congestion. IEEE Transactions on Intelligent Transportation Systems, Vol, 17, No, 10, 2016
- S. Zemouri, S. Djahel, and J. Murphy. A Fast, Reliable and Lightweight Distributed Dissemination Protocol for Safety Messages in Urban Vehicular Networks. Ad Hoc Networks Elsevier, Vol. 27, pp. 26-43, 2015
- S. Djahel, et al., A Communications-oriented Perspective on Traffic Management Systems for Smart Cities: Challenges and Innovative Approaches, IEEE Communications Surveys and Tutorials, Vol. 17, No. 1, 2015

References

- S. Wang, S. Djahel and J. McManis. An Adaptive and VANETs-based Next Road Re-routing System for Unexpected Urban Traffic Congestion Avoidance. **IEEE VNC 2015,** Dec. 16 – 18, 2015, Kyoto, Japan
- S. Djahel, N. smith, Shen Wang and J. Murphy. Reducing Emergency Services Response Time in Smart Cities: An Advanced Adaptive and Fuzzy Approach. **IEEE ISC2 2015**, Oct. 25 – 28, 2015, Guadalajara, Mexico
- S. Zemouri, S. Djahel, and J. Murphy. A short-term vehicular density prediction scheme for enhanced beaconing control. **IEEE Globecom** 2015, 6-10 December 2015, San Diego, CA, USA
- C. Sommer and F. Dressler, **Vehicular Networking**, Cambridge University Press, 2014

References

- ETSI EN 302 663 V 1.2.1 Intelligent Transport Systems (ITS). Intelligent transport systems (its); access layer specification for intelligent transport systems operating in the 5 ghz frequency band, 2013
- Dar, K. and Bakhouya, M. and Gaber, J. and Wack, M. and Lorenz, P., "Wireless Communication Technologies for ITS Applications," IEEE Communications Magazine, vol. 48 (5), pp. 156-162, May 2010
- **1609.4-2016** -IEEE Standard for Wireless Access in Vehicular Environments (WAVE)— Multi-Channel Operation, IEEE Vehicular Technology Society, Revision of IEEE Std 1609.4-2010
- R. A. Uzcategui and G. A. Marum. WAVE: A Tutorial, IEEE Communications Magazine, May 2009

References

- Simulators
- SUMO
  - http://www.dlr.de/ts/en/desktopdefault.aspx/tabid-9883/16931_read-41000/
  - https://sourceforge.net/projects/sumo/
  - http://sumo.dlr.de/wiki/SUMO_User_Documentation
- ns-3
  - https://www.nsnam.org/
- Vissim
  - http://vision-traffic.ptvgroup.com/en-us/products/ptv-vissim/