Cellular-V2X and Integrated Moving Networks

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CHALMERS

Outline

- Why Cellular-Assisted Vehicle-to-everything (V2X)?
- Designing the 5G Cellular-V2X Radio Interface
- Integrated Moving Networks
- Conclusions

V2X Basics

- Vehicle-to-everything (V2X) communication: Passing of information from a vehicle to any entity that may affect the vehicle, and vice versa.
- A vehicular communication system incorporating specific types of communication
  - V2I (Vehicle-to-Infrastructure)
  - V2V (Vehicle-to-vehicle)
  - V2P (Vehicle-to-Pedestrian)
  - V2D (Vehicle-to-device)
  - V2G (Vehicle-to-grid).
- The main motivations for V2X are safety and energy savings.
- V2X communication was originally based on WLAN technology forming a vehicular ad-hoc network as two V2X senders come within each other's range.
- "Hence it does not require any infrastructure for vehicles to communicate, which is key to assure safety in remote or little developed areas."
- "WLAN is particularly well-suited for V2X communication, due to its low latency. It transmits messages known as Common Awareness Messages (CAM) and Decentralised Notification Messages (DENM) or Basic Safety Message (BSM). The data volume of these messages is very low. The radio technology is part of the WLAN IEEE 802.11 family of standards and known in the US as Wireless Access in Vehicular Environments (WAVE) and in Europe as ITS-G5."

Source: Wikipedia

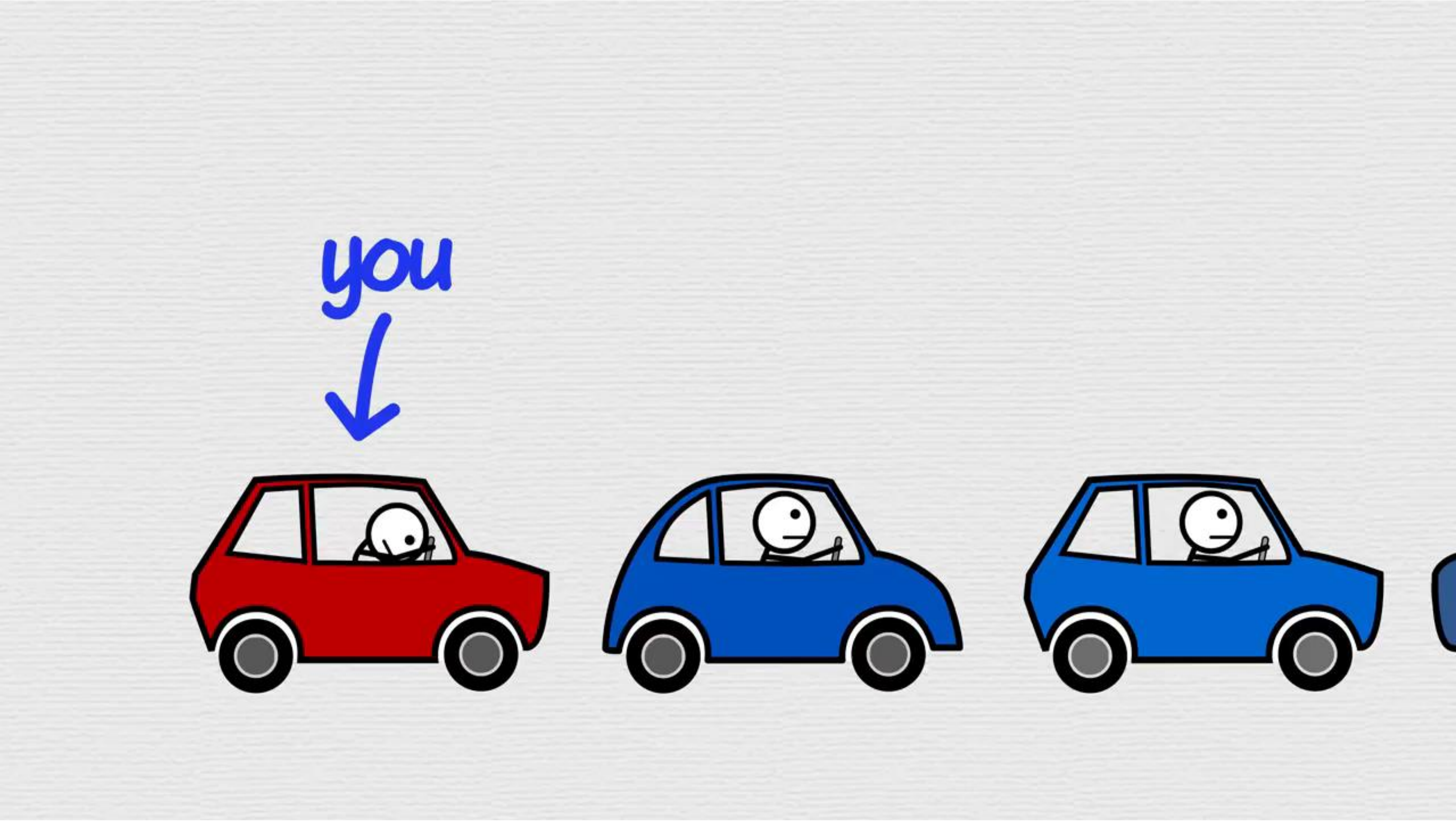
Functions in Intelligent Transportation Systems (ITS)

- Forward collision warning
- Lane change warning/blind spot warning
- Emergency Electric Brake Light Warning
- Intersection Movement Assist
- Emergency Vehicle Approaching
- Road Works Warning
- Platooning
- …

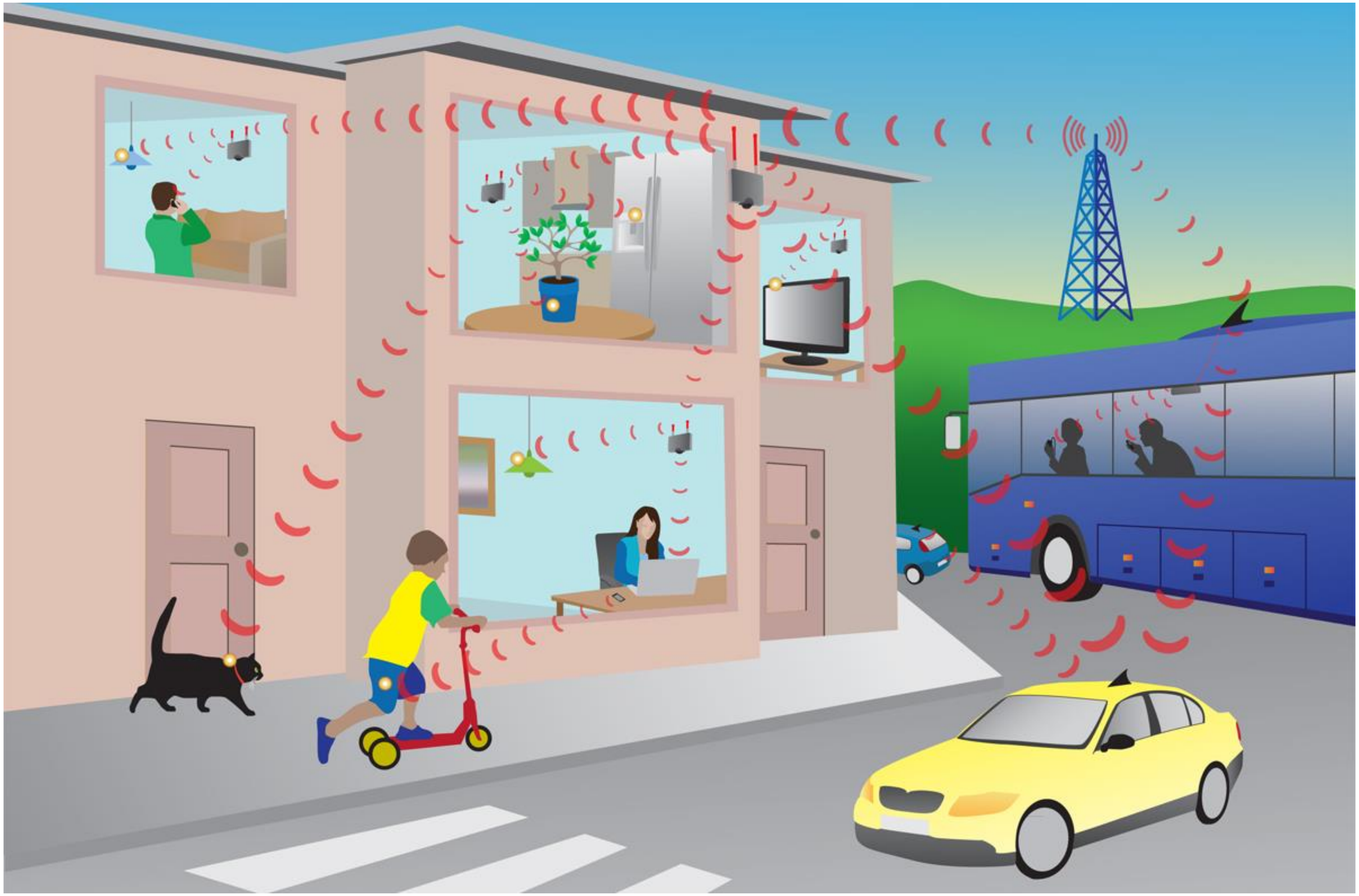
Source: Wikipedia

Intelligent Transportation Systems (ITS) – Why Long Information Horizon Matters

https://www.youtube.com/watch?v=iHzzSao6ypE&feature=youtu.be



Wireless Communications Everywhere and with "Everything"



Increasing Need for <u>Mobile</u> Broadband

Original Motivation cont.

- A larger number of mobile users will be vehicular

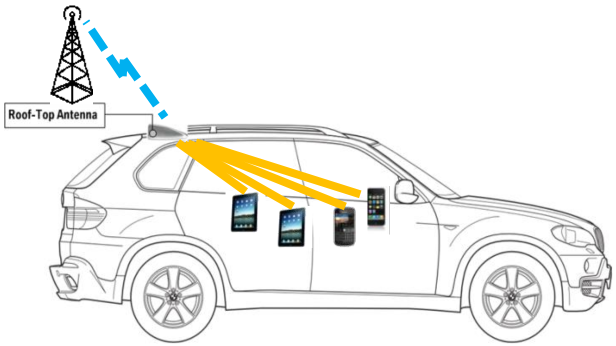
	Home access Internet	Office access Internet	On-road access Internet
USA	37.8%	19.6%	42.6%
UK	45.6%	17.8%	36.6%
Germany	43.4%	15.3%	41.3%
France	33.1%	21.7%	45.2%
Italy	39.6%	21.4%	39.0%
South Africa	48.6%	21.4%	30.0%
Mexico	28.2%	27.6%	44.2%
Brazil	36.7%	24.7%	38.6%
Korea	33.7%	31.7%	34.6%
India	45.9%	30.4%	23.7%
China	30.1%	32.7%	37.2%

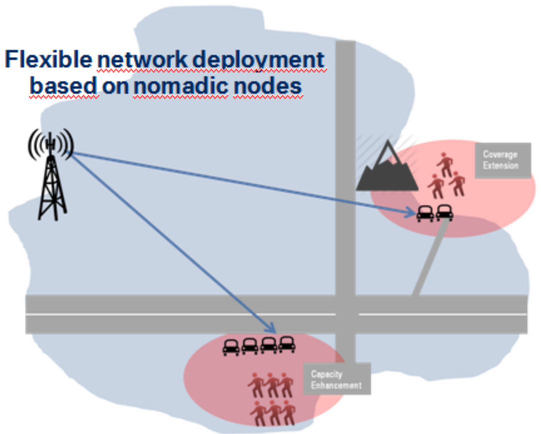
Source: Cisco VNI Mobile, 2011

Moving Networks in the METIS project

"Moving Networks" refers to novel concepts that focus on moving and/or nomadic network nodes & terminals.

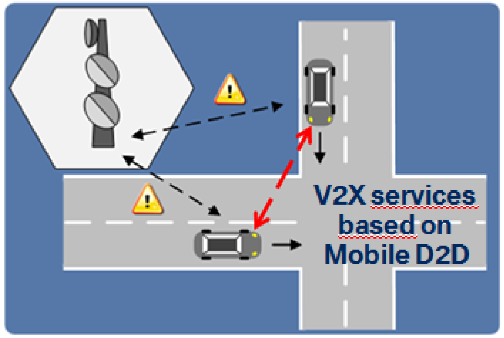
- **Cluster #1: Mobility-robust high-data rate comm. links**
  - Requirement: High-data Rate, Low Latency
  - Relaying inside vehicles is not the only focus





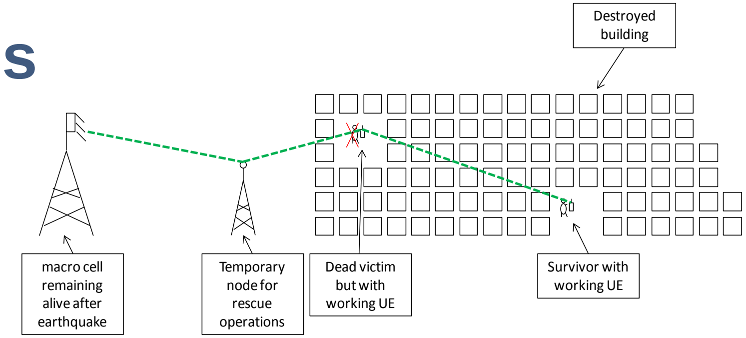
- **Cluster #2: Flexible network deployment based on nomadic network nodes**
  - Requirement: High Data Rate
  - Relaying inside vehicles is not considered here!

- **Cluster #3: V2X communications**
  - Requirement: Low-Medium Data-Rate, Low Latency, High Reliability



Test Cases related to Moving Networks

TC10: Emergency communications



Basic communications in a place where little mobile or wireless network infrastructure exists, e.g. due to a natural disaster.

- **Battery lifetime:** 1 week (with today's battery technology)
- **Availability**: 99.9% victim discovery rate
- **Destroyed or unreliable NW infrastructure**

TC6: Traffic jam

Provision of public cloud services inside vehicles during traffic jams due to the sudden increase in the capacity demand 12

- **Traffic volume**: 480 Gbps/km^2
- **User data rate:** 100/20 Mbps in DL /UL with 95% availability

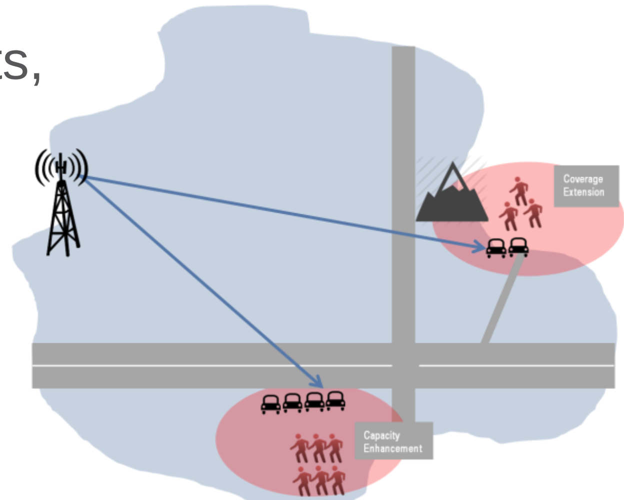
Test Cases related to Moving Networks

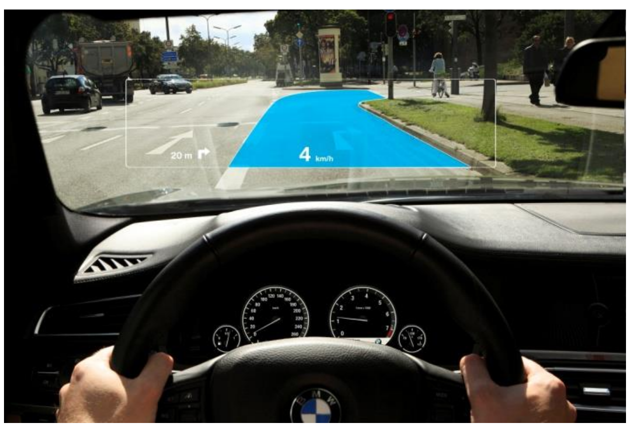
TC7: Blind spots

The ubiquitous capacity demands in blind spots, such as rural areas with sparse NW infra-structure or in deeply shadowed urban areas.

– **User data rate:** 100/20 Mbps in DL/UL

– **Energy efficiency**: 50% / 30% reduction for UE / infrastructure





TC8: Real-time remote computing for mobile terminals

Remote computing services, e.g., augmented reality service, on-the-go at higher speeds.

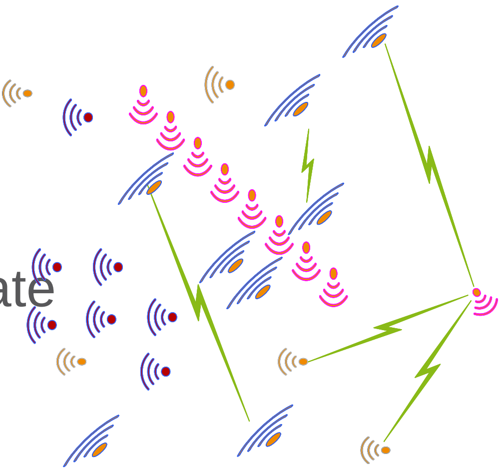
– **User data rate:** 100/20 Mbps in DL /UL

– **Latency**: Less than 10 [ms] with 95% reliability

– **Mobility:** Up to 350 km/h

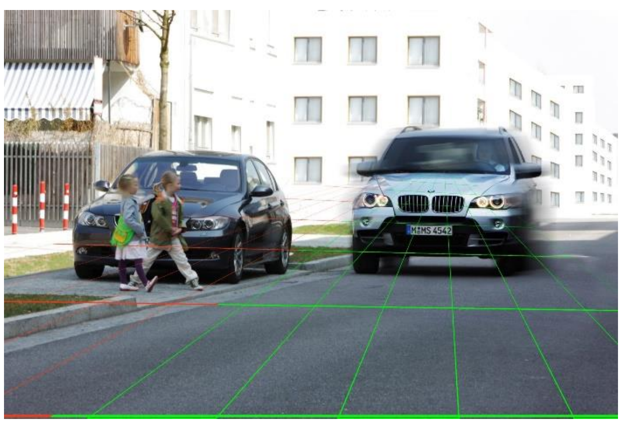
Test Cases related to Moving Networks

TC11: Massive deployment of sensors and actuators



Small sensors and actuators that are mounted to stationary or movable objects and enable a wide range of applications

- **Energy efficiency:** 0.015 µJ/bit for 1 kbps data rate
- **Protocol efficiency**: 80% at 300,000 devices per access node
- **Availability**: 99.9%



TC12: Traffic efficiency and safety

Cooperative intelligent traffic systems (C-ITS) for road safety and traffic efficiency

- **Latency:** Less than 5 [ms] for 99.999%
- **Detection range**: up to 1 km
- **Availability:** ~100%

Cellular V2X — General Motors' EN-V

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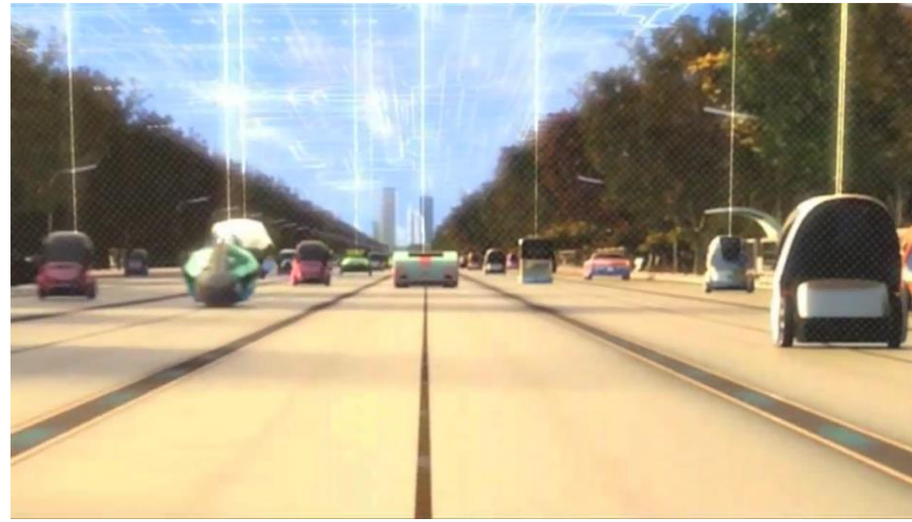

https://www.youtube.com/watch?v=0tiHwzGsotA

What is Cellular-V2X ?

C-V2X is a comprehensive road safety and traffic efficiency solution that allows **vehicles** to communicate with

- **Other vehicles (V2V),**
- **Pedestrians and Cyclists smartphones (V2P),**
- **Road Infrastructure (V2I),**

supported by the

- **Mobile network (V2N)**

to guarantee coverage and continuity of services

Fifth Generation Communication Automotive Research and innovation

5G-PPP: Phase 2

5GCAR

Project Manager:
Dr. Mikael Fallgren, Ericsson

Facts

5G PPP Phase 2 Project
June 2017 – May 2019
30 Full time researchers
8 M€ budget

5GCAR contact

Webpage

https://5g-ppp.eu/5gcar/
https://5gcar.eu/

Email

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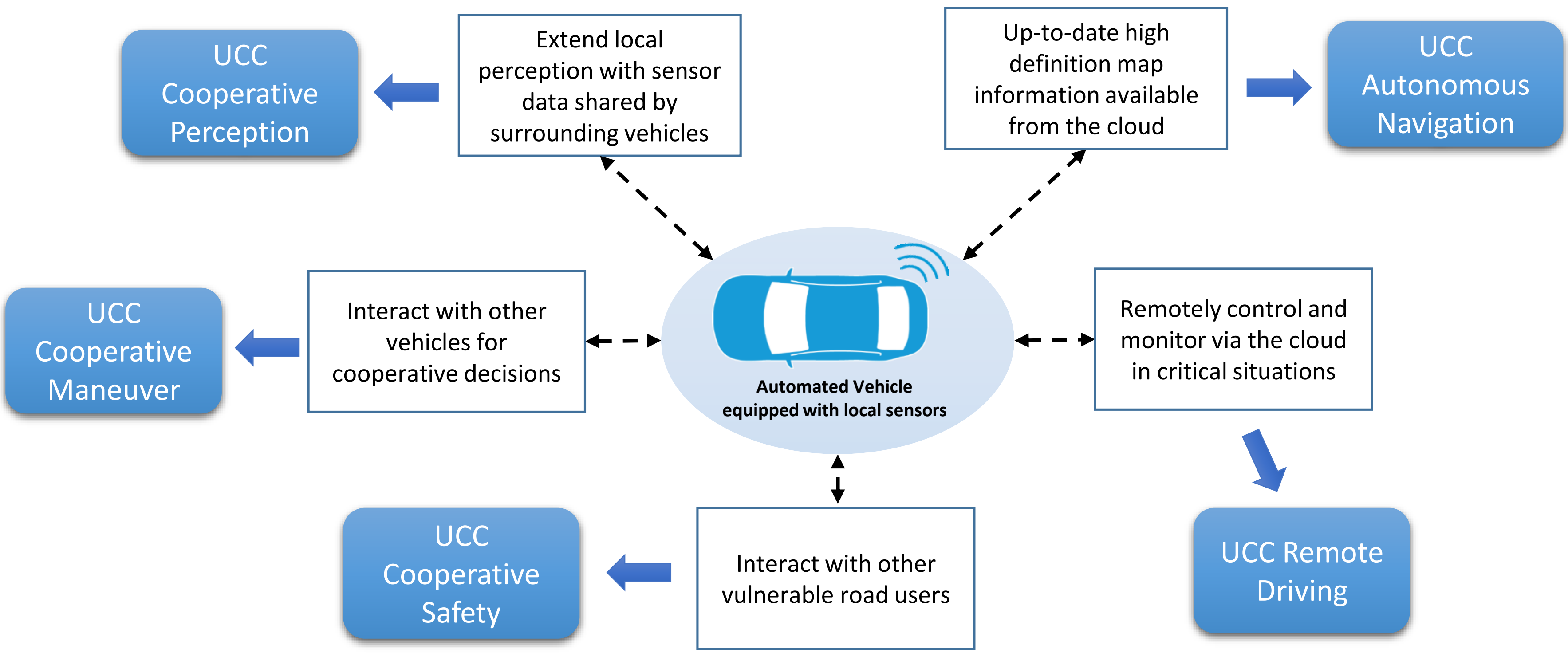
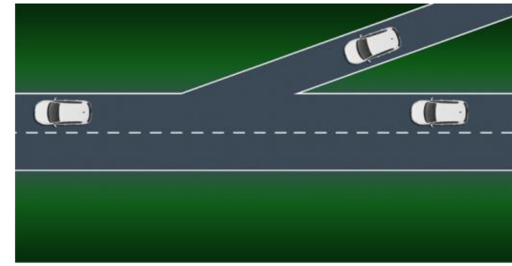
5GCAR Use Case Classes

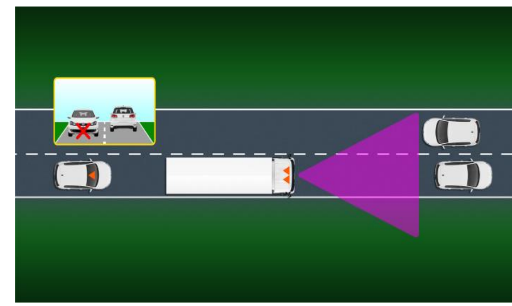


On the 5GCAR Use Cases

12 - **Cooperative maneuver**: sharing local awareness and driving intentions and negotiating the planned trajectories
  - Lane merge



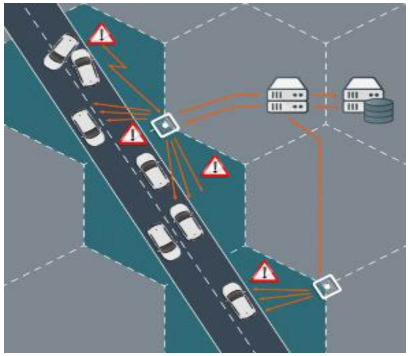
- **Cooperative perception**: perception extension is built on the basis of exchanging data from different sources, e.g., radars, laser sensors, stereo-vision sensors from on-board cameras
  - See-through



- **Cooperative safety**: achieved by exchanging the information about detection of the presence of road users
  - Network assisted vulnerable pedestrian protection

On the 5GCAR Use Cases

- **Autonomous navigation**: construction and distribution of real-time intelligent HD map
  - High definition local map acquisition

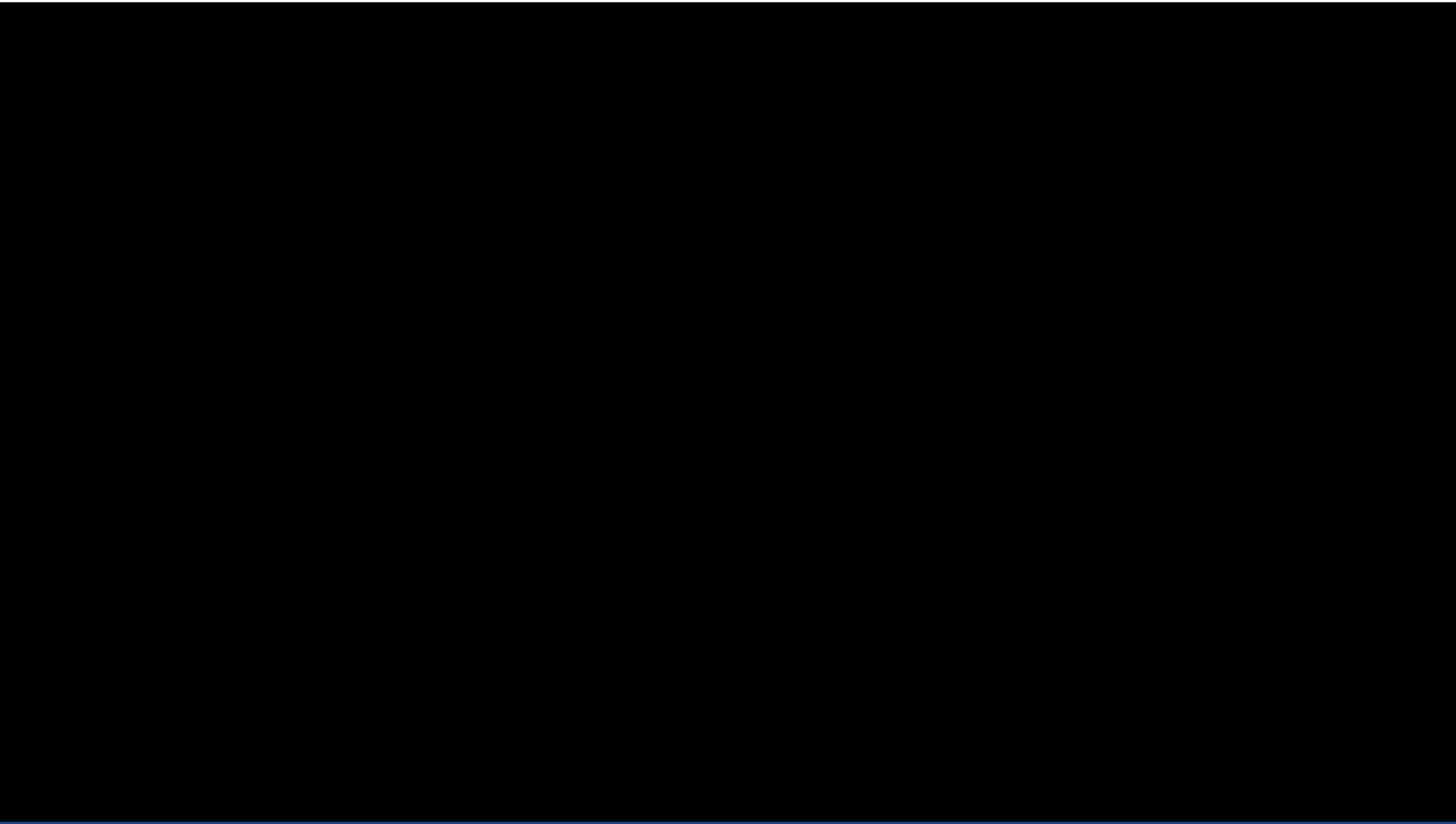


- **Remote driving**: control the different actuators of the car (steering wheel, brake and throttle) from outside the vehicle through wireless communication
  - Remote driving for automated parking

Further information: https://5gcar.eu/.

Phantom Auto's Remote Driving

https://www.youtube.com/watch?v=HlGqYFclKqU



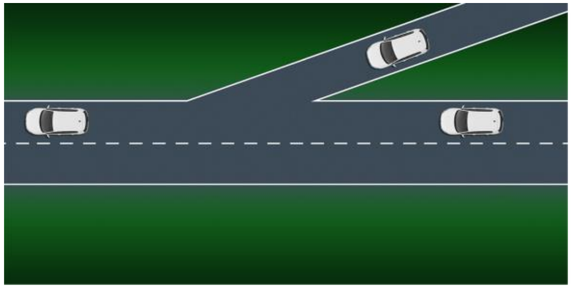
On 5GCAR Requirements

Requirement label

Automotive	Network	Qualitative
Intersection crossing time	Avilability	Cost
Localization	Communication range	Power consumption
Maneuver completion time	Date rate	Security
Minimum car distance	Latency	
Mobility	Reliability	
Relevance area	Data unit size	
Sw updates		
Takeover time		

- Lane merge: **Localization, Latency**
- See-through: **Data rate**
- Network assisted vulnerable pedestrian protection: **Reliability, Localization**
- High definition local map acquisition: **Localization, Density, Security**
- Remote driving for automated parking: **Availability, Reliability, Latency**

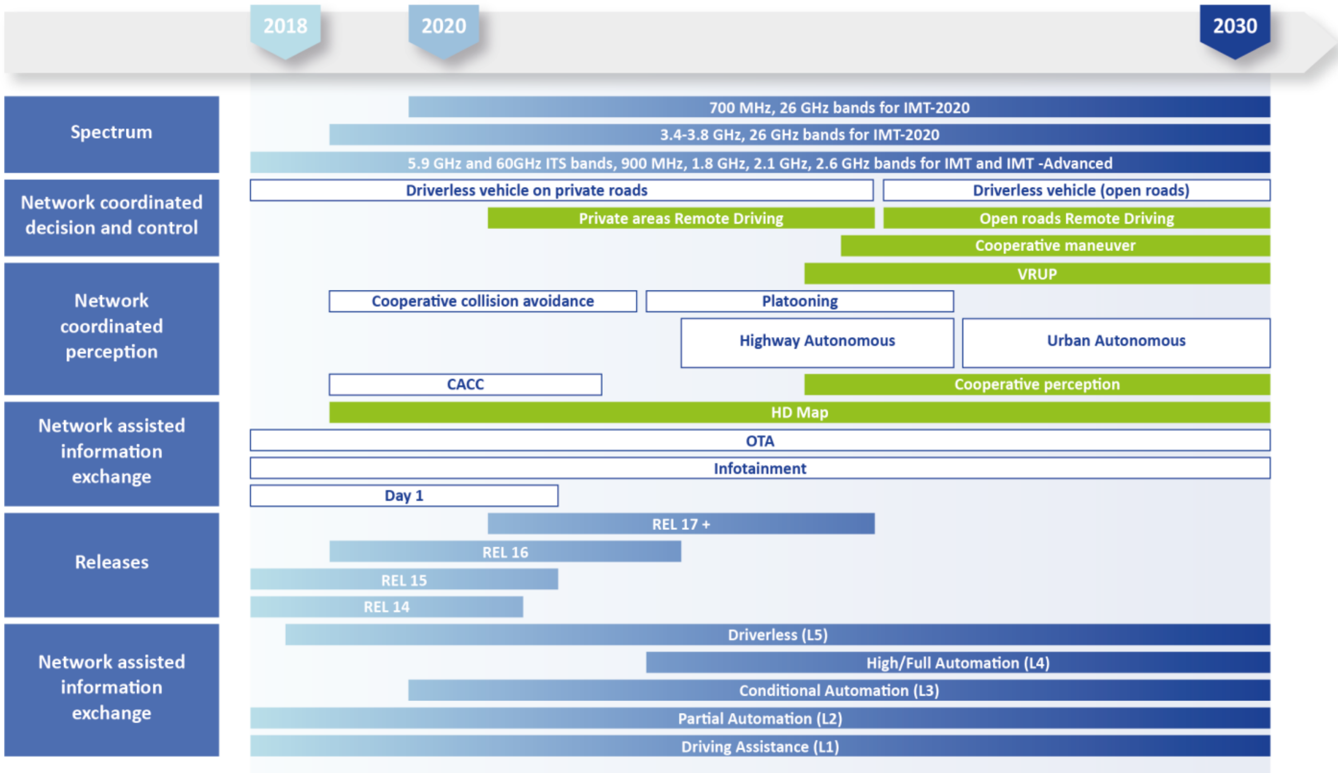
Illustrative 5GCAR Cellular-V2X Requirements



Lane merge

Use Case 1: Lane merge	
Requirement Label	**Requirement Value and Requirement Unit**
Automotive requirements	
Intersection crossing time	Not applicable
Localization	1 to 4 meters
Maneuver completion time	4 seconds
Minimum car distance	0.9 to 2 seconds
Mobility	0 to 150 km/h
Relevance area	250 to 350 meters
Take over time	10 seconds
Network requirements	
Availability	V2I/V2N 99% and for V2V 99.9%
Communication range	> 350 meters
Data rate	1.28 Mbps
Latency	< 30 ms
Reliability	99.9%
Service data unit size	800 bytes/message without trajectories 16000 bytes/message with trajectories
Qualitative requirements	
Cost	Medium
Power consumption	Low
Security	Privacy: High Confidentiality: Low Integrity: High Authentication: High

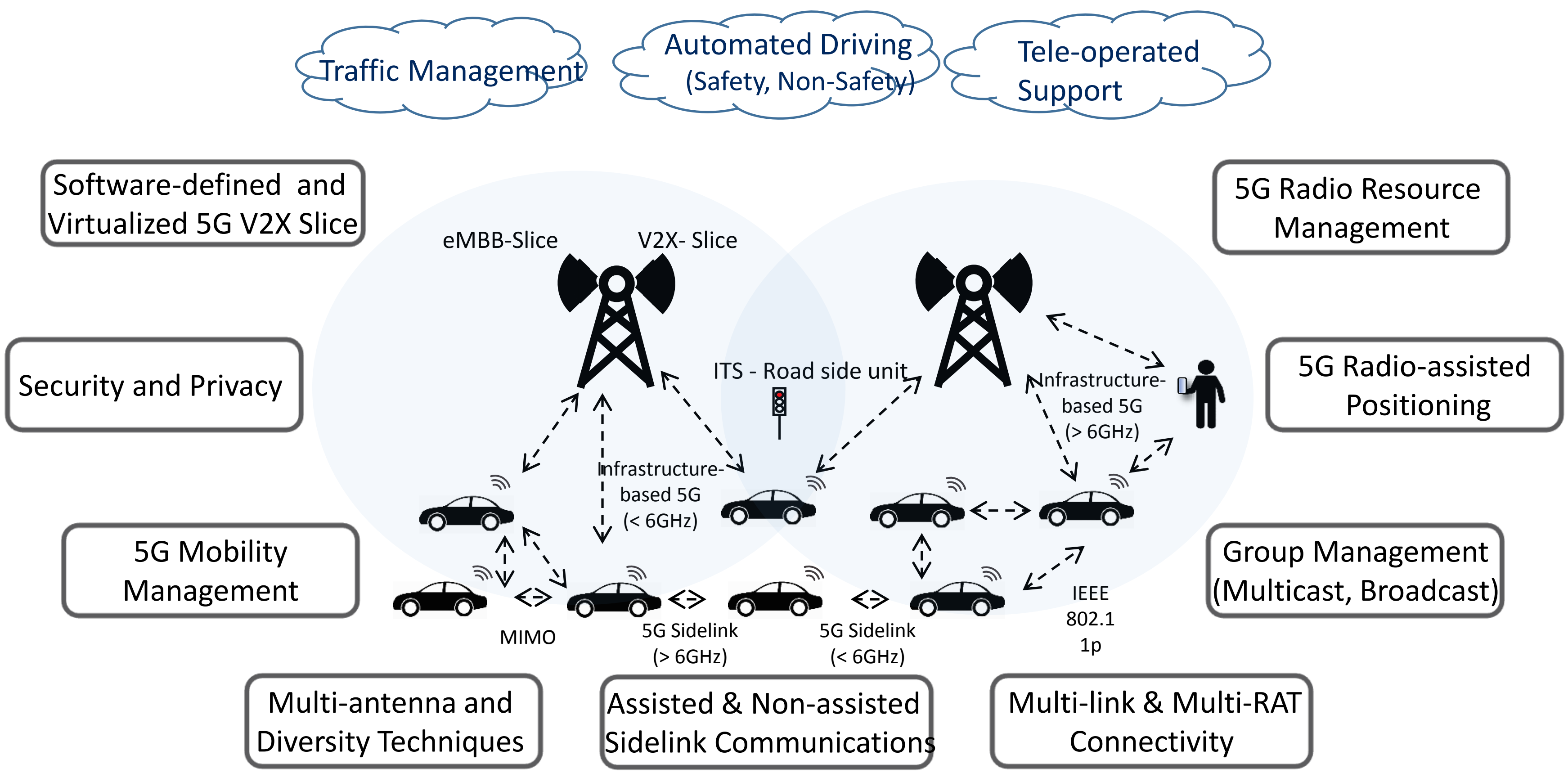
Use Case Roadmap 5GCAR Perspective



- *The European regulation (Delegated ACT and CAFÉ) will modulate this roadmap*

- Automotive industry considers level 4 as the first one where connectivity may become a must
- Level 4 should arrive to the market in the first half of the next decade.
- The real level 5, i.e. on open roads is expected in the second half of the decade.
- Level 5 is already now available in private road or campus (shuttles).
- In 2025, 5G mobile phone subscription will be around 30% in Europe

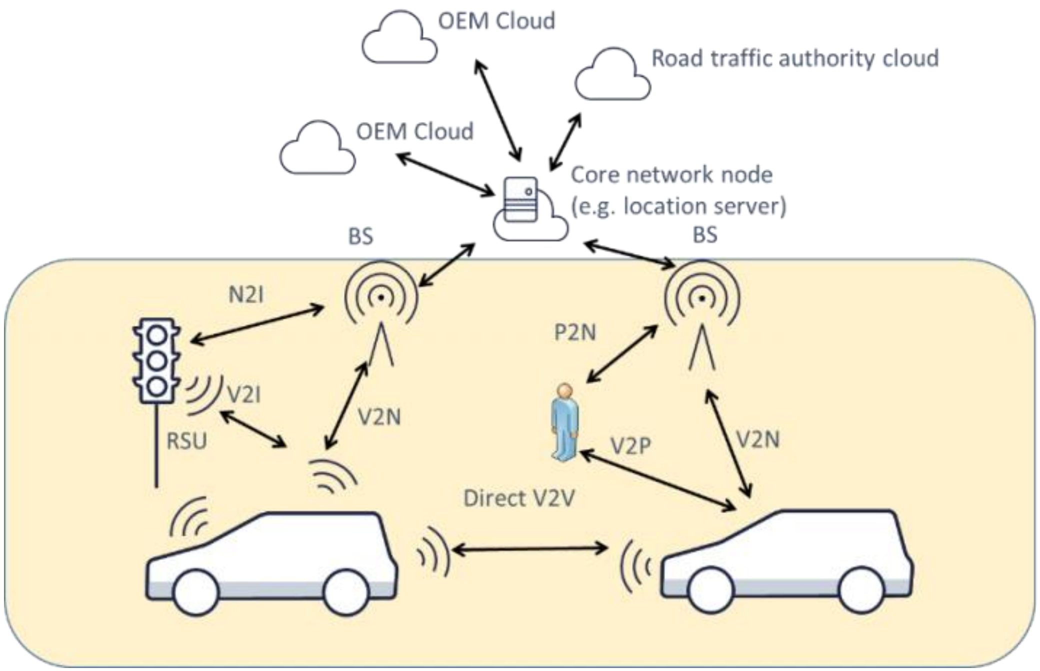
Concept and key technical components



5G V2X Radio Interface

Scope

- **Efficient** and scalable 5G air interface to enable **low-latency**, **high-reliability** V2X communications
- **Infrastructure-based** communication (between vehicles and network)
- **Sidelink** communication (direct data exchange among vehicles without routing data traffic through the network infrastructure)
- Support 5G radio-assisted **positioning** techniques for both VRU and vehicles.



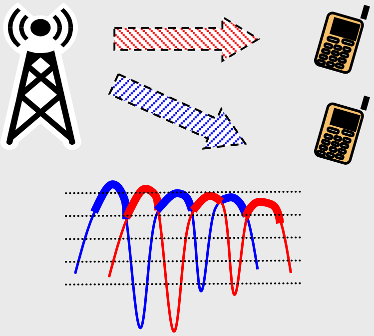
Designing the 5G V2X Radio Interface
– Towards a Reliable High Capacity Infrastructure Interface

- Robust
- High capacity
- Low latency
- Support multicast/broadcast
- Efficient also for small packets

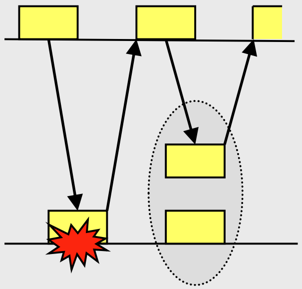
Ultra-Reliable Low-Latency Communication (URLLC).

Recap: Adaptive Transmission

Link adaptation



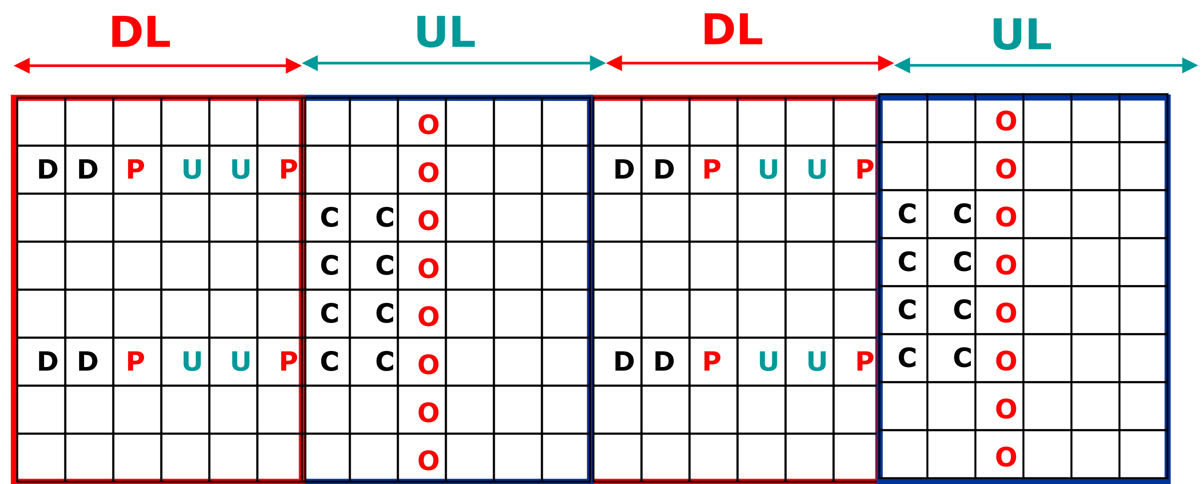
Fast scheduling



Fast retransmissions with soft combining

- Frequency-channel-dependent scheduling & fast link adaptation
  - Spectrally efficient transmission
  - Adapt per spatial chunk (resource block) layer to small-scale fading
- Non-frequency adaptive transmission (for fast terminals, multicast, ...)
  - Robust transmission
  - Adapt per frame to shadow fading and path loss

Acquire Channel State Information at the Transmitter (CSIT) for Mobile Users (FDD)



Dl prediction horizon: 2.5 x 0.3372ms=**0.843ms**

UL prediction horizon: 2.5 x 0.3372ms=**0.843ms**

1. DL control symbols:
Report which present chunks belong to which flows

2. DL pilot symbols:
Used for channel prediction
Used for channel estimation

3. UL control symbols:
Report which next UL chunks appointed to which uplink flows

4. Pilot symbols:
Used for coherent detection
And updating predictor states

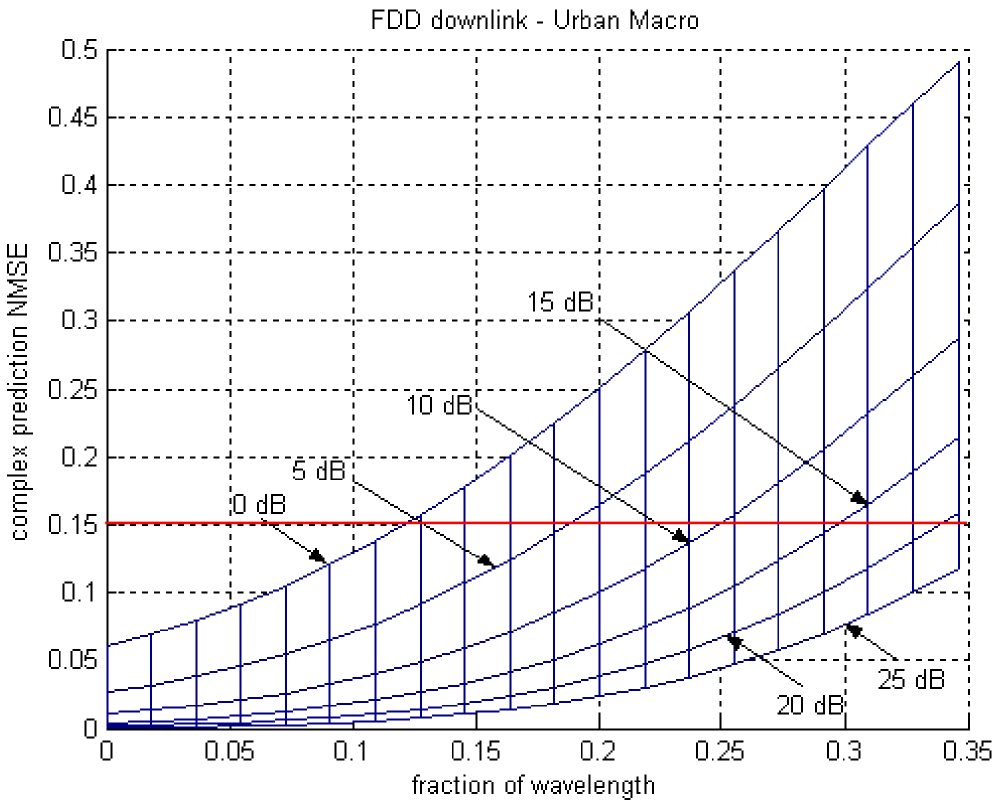
5. DL control feedback symbols:
Carry DL channel prediction report

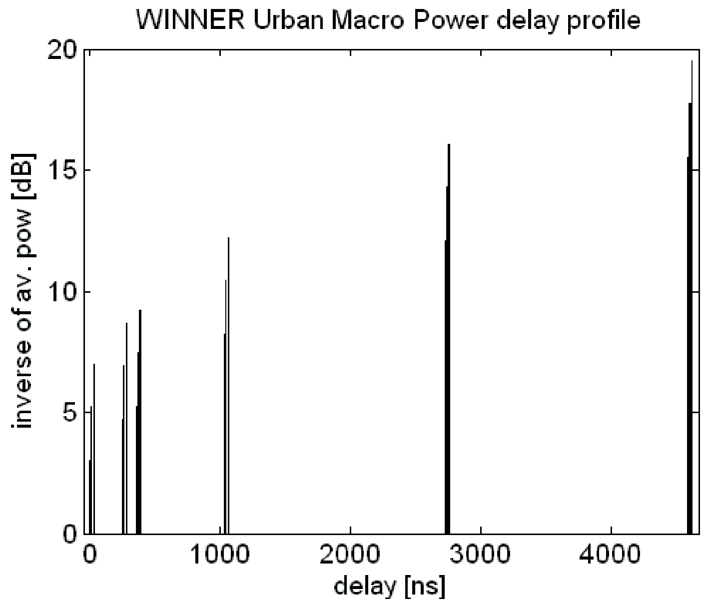
6. UL overlapping pilot symbols:
Used for prediction

Short prediction horizon enables vehicular speeds!

• *Note, example! For final WINNER II Reference Design: See deliverable D6.13.14*

Prediction Horizon and SINR Limit at 5 GHz FDD Downlink





Jake's Doppler spectrum assumed.

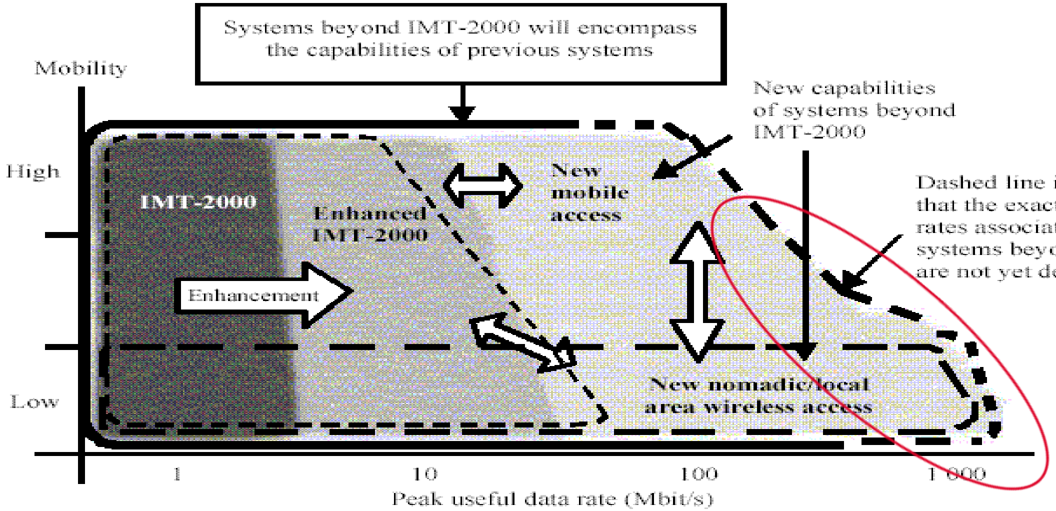
Prediction error target: NMSE=0.15.

Prediction horizon: vD/λ

30 km/h	50 km/h	70 km/h
<0 dB, 0.117λ	**6 dB**, 0.195λ	**12.5 dB**, 0.273λ

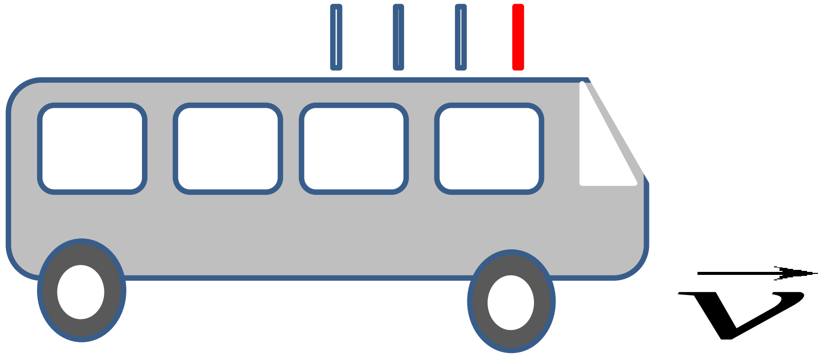
How to Improve CSIT at High Speed?

IMT Advanced requirements at high speed:



10 times lower requirements at high speed!

The Predictor Antenna Concept



Idea: Antenna elements of an antenna array may act as predictors for next antenna element.

- Can be combined with conventional prediction based on past data to boost performance further.

Challenges: Possible decorrelation due to

› Effects of the moving vehicle on the standing wave pattern

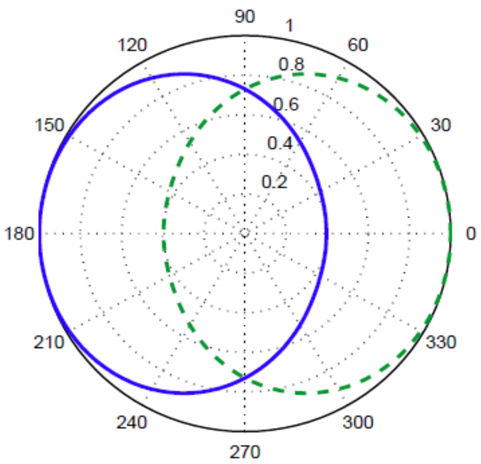
6 › Non-equal scattering environment around the antennas

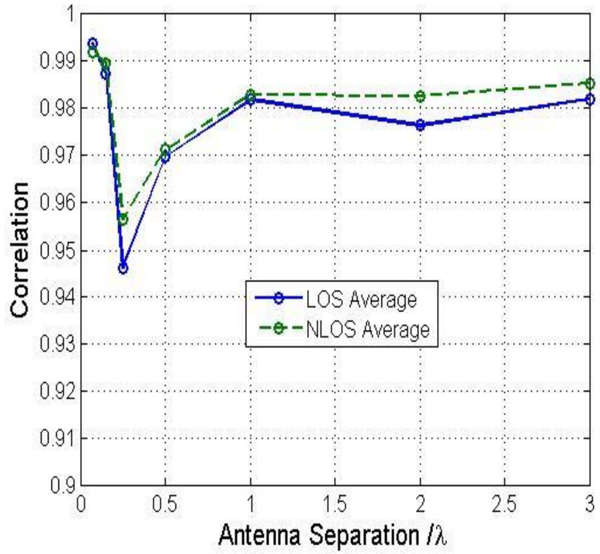
› Mutual electromagnetic coupling of antennas (Vaughan 1991)

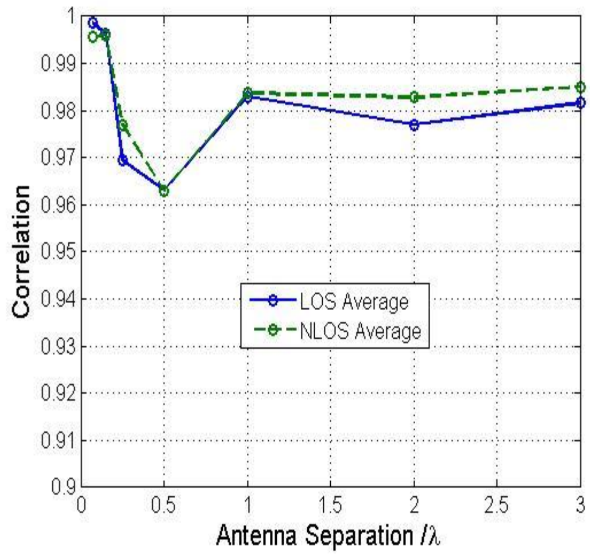
Predictor Antenna Experimental Results

- Two antennas in urban environment (line-of-sight, non-line-of sight).
- 20 MHz OFDM downlink at 2.68 GHz, measurements at 45-50 km/h

With Antenna embedded pattern compensation:



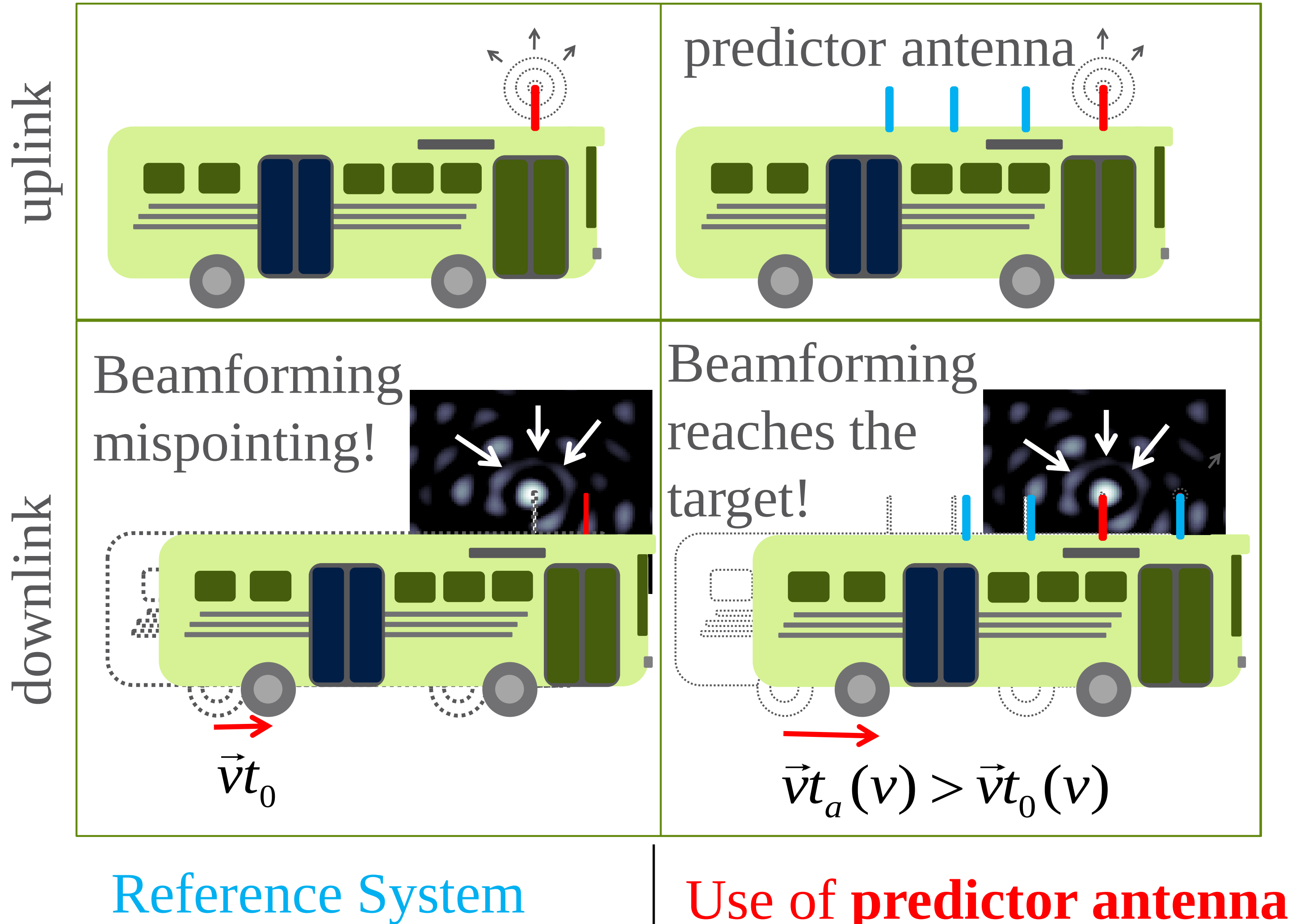




› Prediction horizon beyond **3λ** seems feasible => x10 better – enables closed loop schemes at high speed >1 GHz !

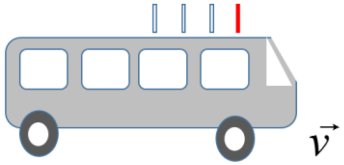
- *N. Jamaly, R. Apelfrojd, A. Belen Martinez, M. Grieger, T. Svensson, M. Sternad and G. Fettweis, "Analysis and Measurement of Multiple Antenna Systems for Fading Channel Prediction in Moving Relays," EuCAP'2014, April 2014, Haag, The Netherlands.*
- *M. Sternad, M. Grieger, R. Apelfrojd, T. Svensson, D. Aronsson, A. Belen Martinez "Using "Predictor Antennas" for Long-Range Prediction of Fast Fading for Moving Relays," IEEE WCNC, Paris, 2012.*

Application to Massive MIMO Downlink Beamforming



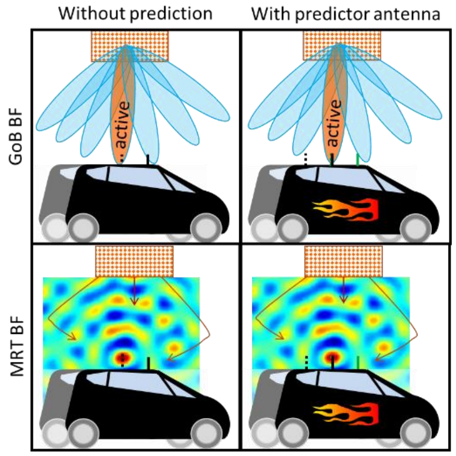
- *D. Thuy, M. Sternad and T. Svensson, "Adaptive Large MISO Downlink with Predictor Antenna Array for Very Fast Moving Vehicles," ICCVE'2013, Dec 2013, Las Vegas, USA.*

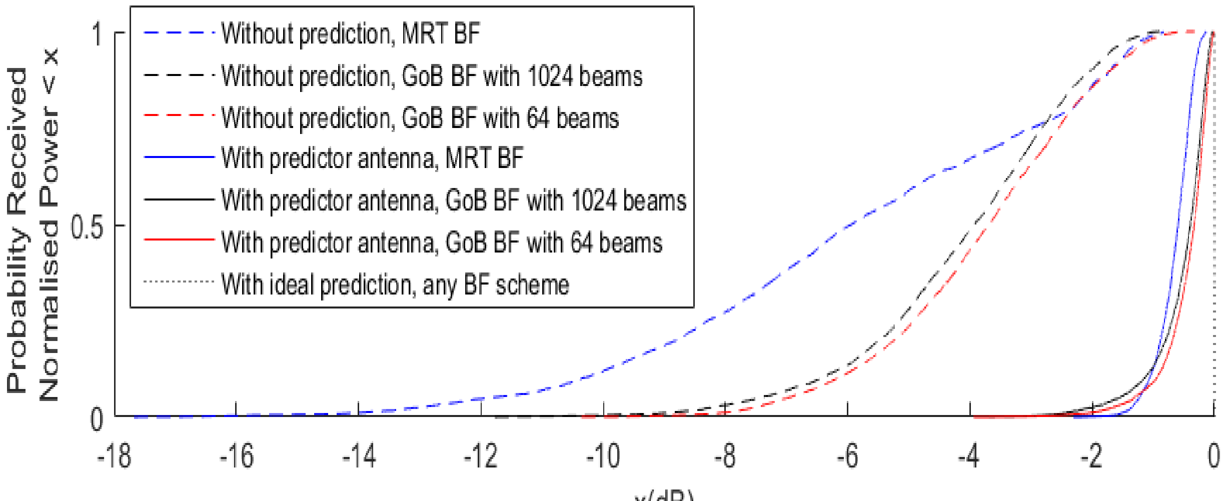
5GCAR V2X Radio Interface



Example: Predictor antenna

- From concept to real measurement
- Results shows the channel estimates provided by the predictor antenna are accurate enough to support adaptive M-MIMO with high speed UEs.
- Sensitivity analysis e.g. antenna coupling, velocities etc.



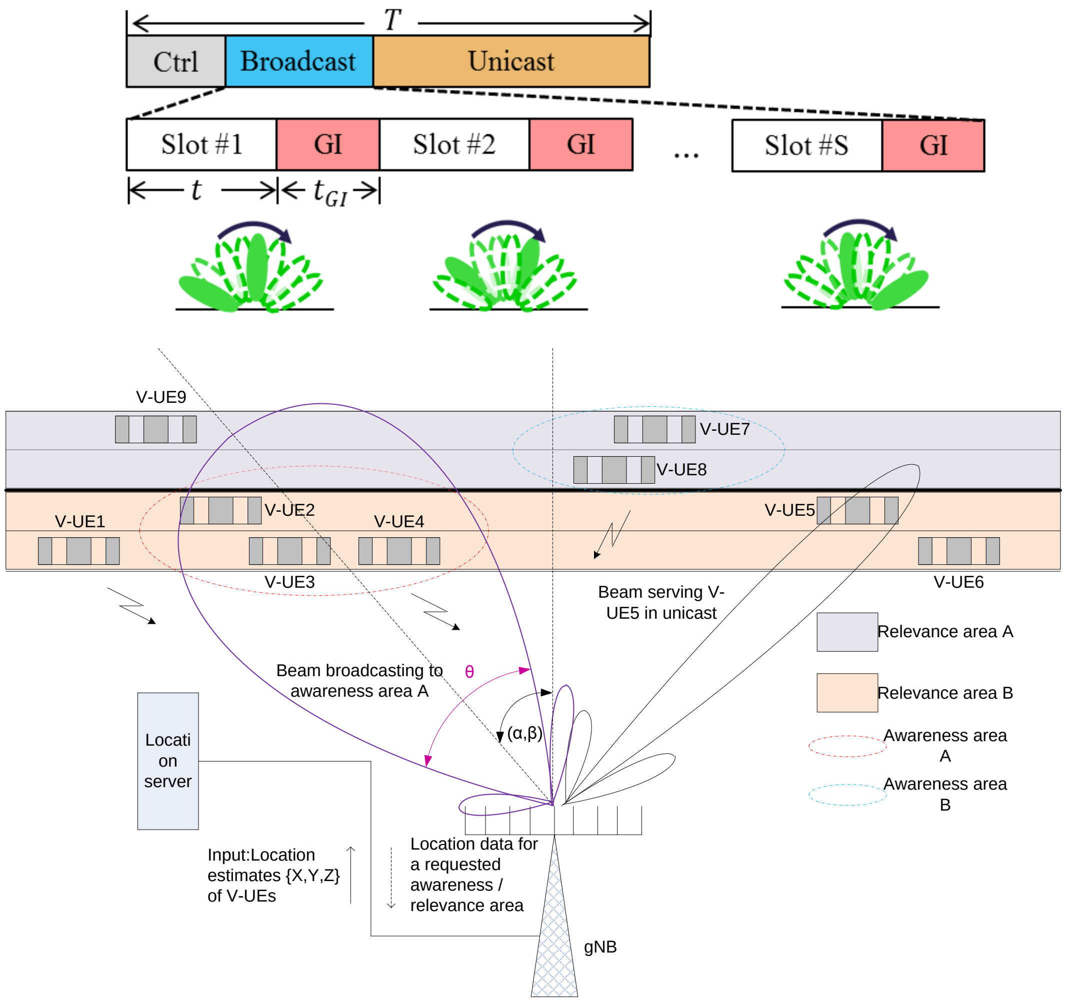


CCDF of the normalized received power metric based on practical experiments

5GCAR V2X Radio Interface

Example: Beam based V2X broadcast

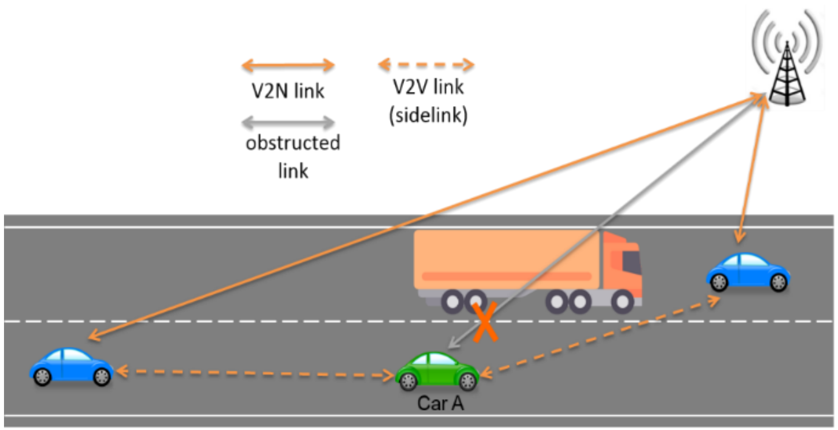
- Utilization of multicast / broadcast transmission at mmWave band to vehicles
  - Enable high data rate V2N/I communication links with resource efficient transmission of common content to multiple V-UEs.
- Highly directional transmission and reception considerably complicates the beam-based broadcast for V2X communications
  - Location based beamforming and frame structure design could be an enabler.



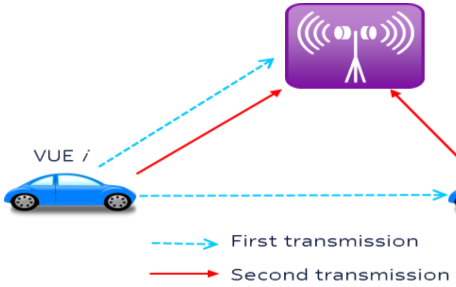
5G V2X radio interface

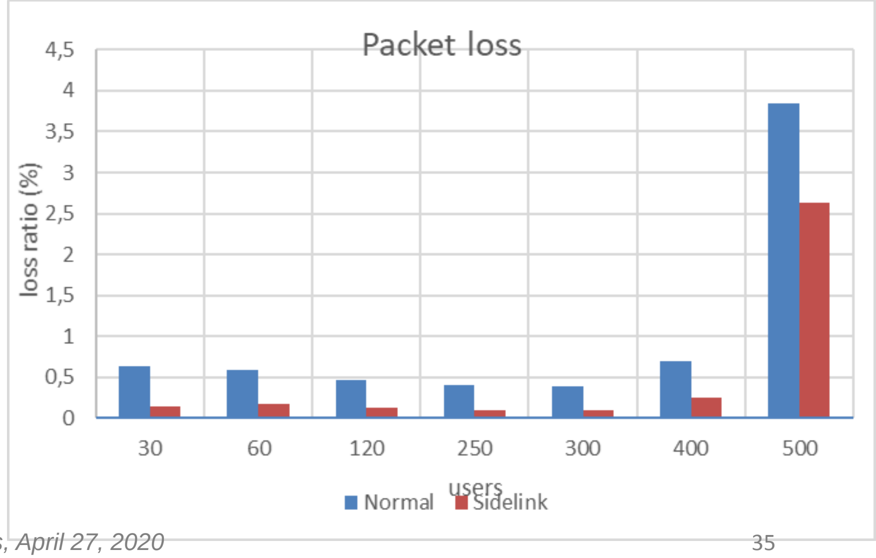
Example: Sidelink assisted cellular communication

- All vehicles maintain a V2N connection to the 5G gNB and at the same time V2V links to other vehicle(s) in the vicinity (after D2D discovery).

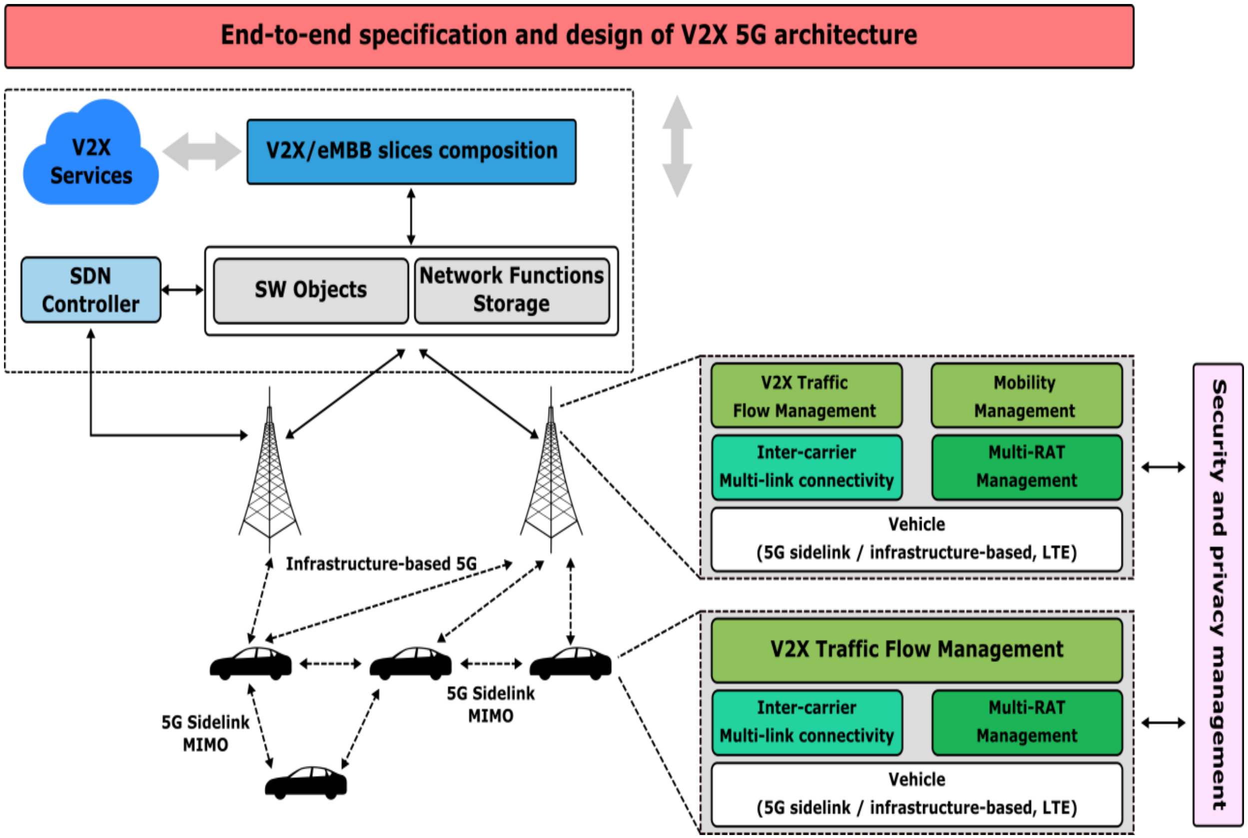


- V2V sidelink can be used to enhance the reliability of the regular V2I link both DL and UL.



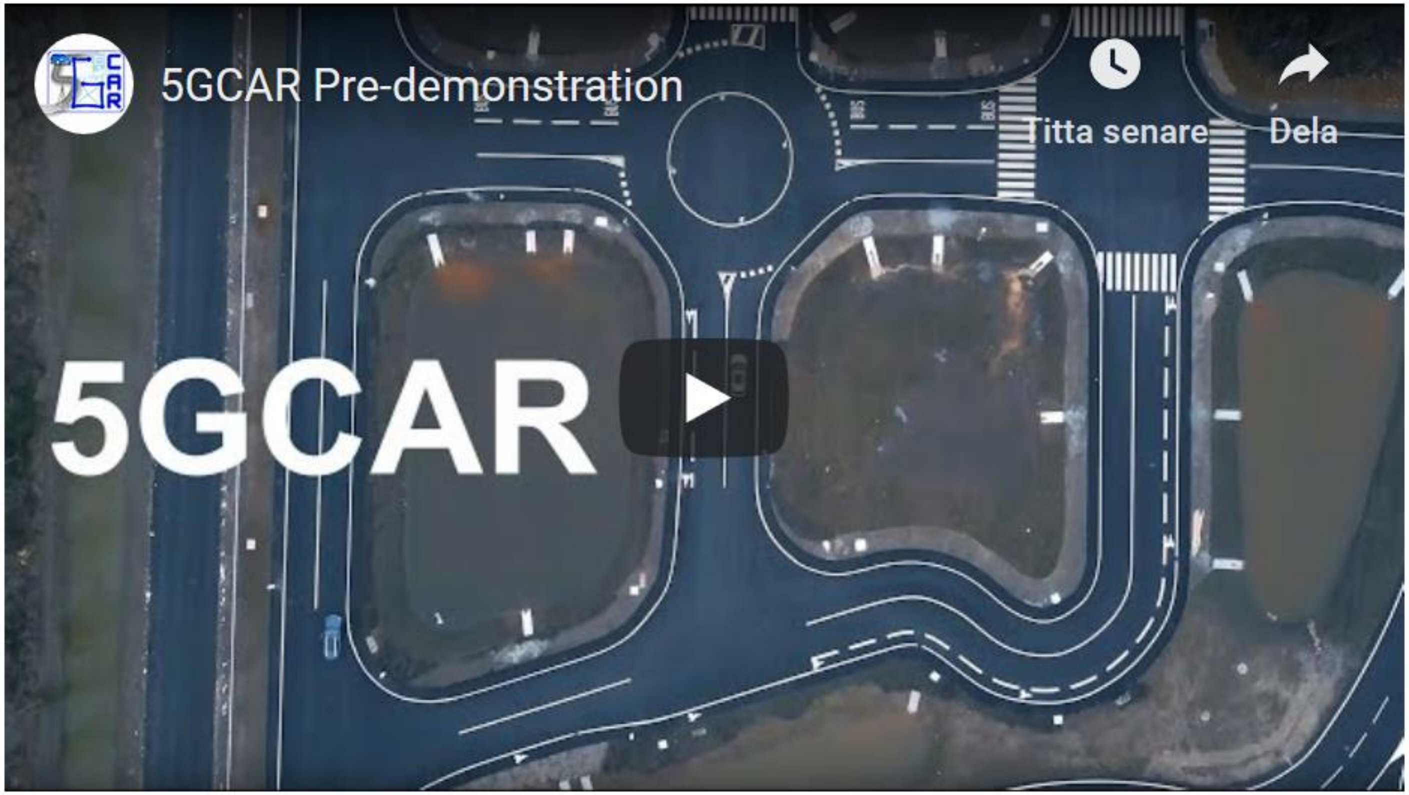


V2X System Level Architecture



- Support of multi-operator
- Security and privacy
- Smart Zoning
- Dynamic use of Multi-RAT and Multi-Links
- Use of advance context information

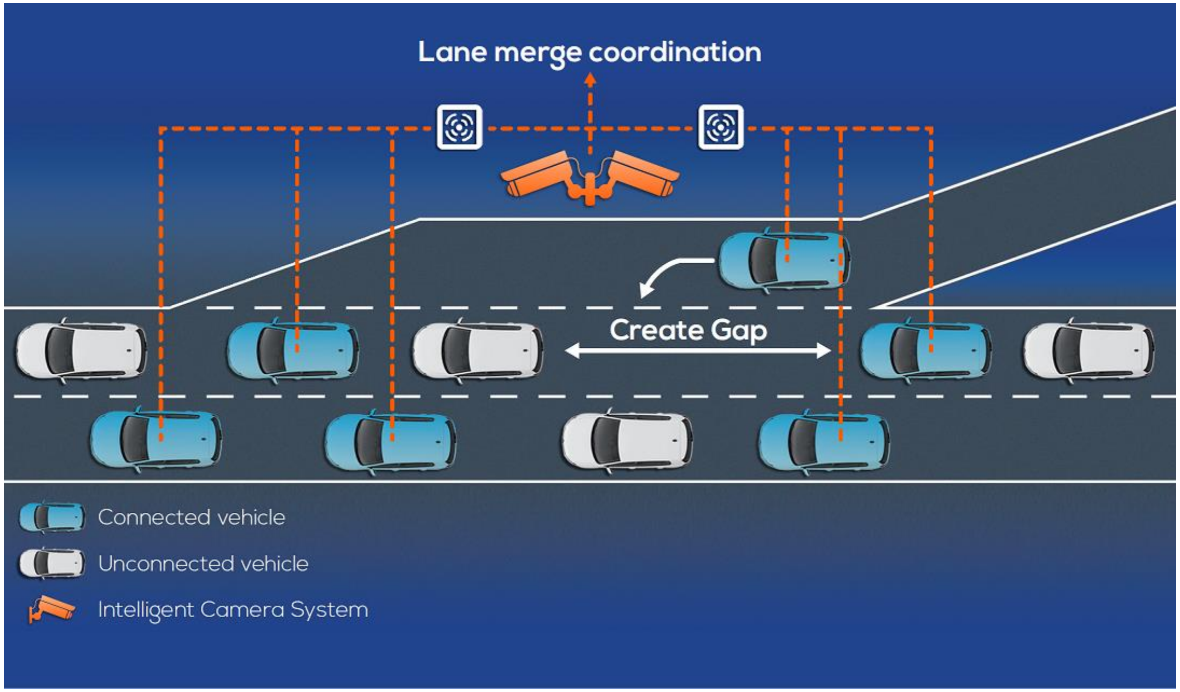
5GCAR Pre-Demonstration



Video from final demo available at: https://5gcar.eu/

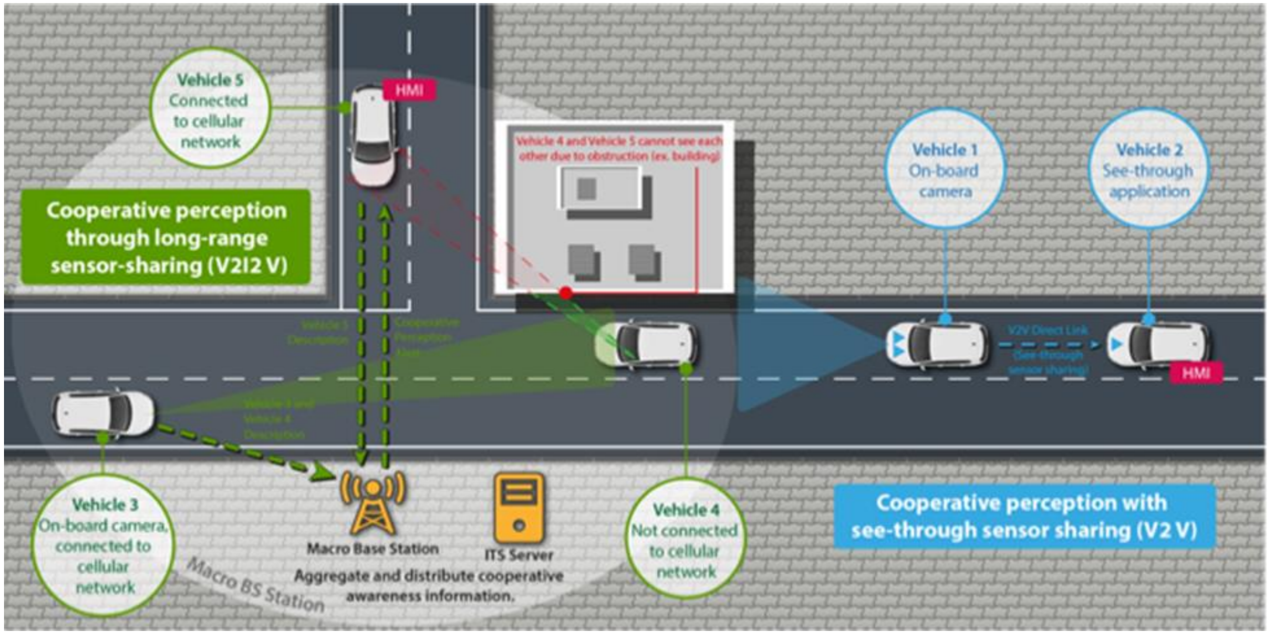
Lane Merge Coordination

- Connected vehicles make room for an entering vehicle
  - Coordinated by a central entity
  - Camera system for detection of unconnected vehicles



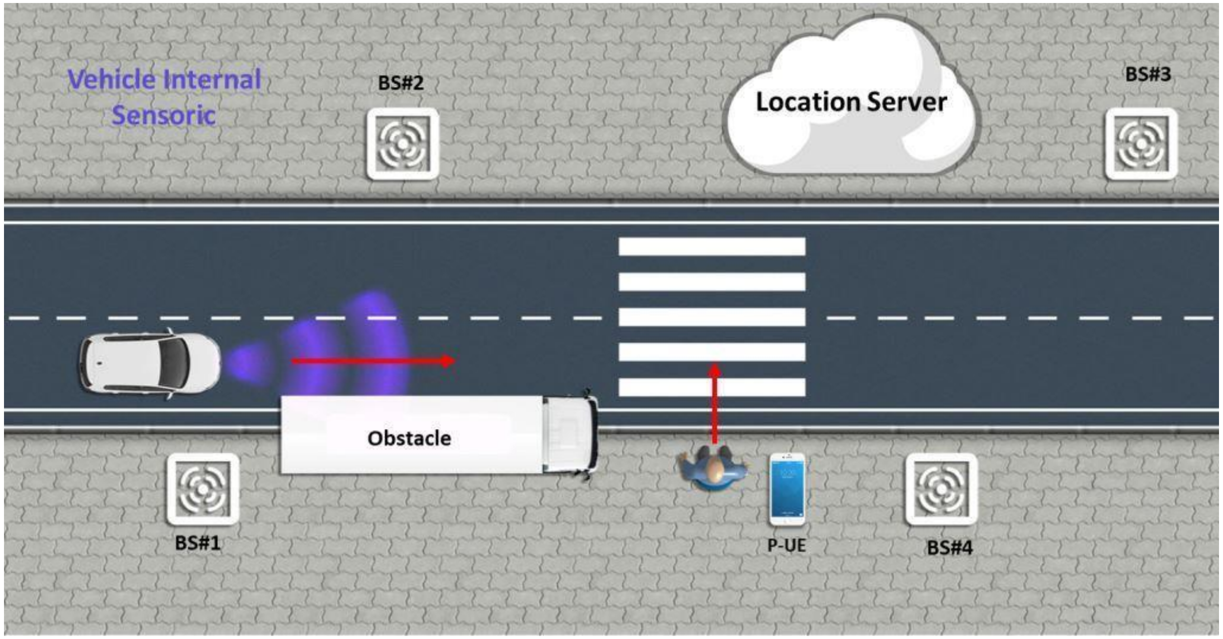
Cooperative Perception for Maneuvers of Connected Vehicles

- Camera-equipped vehicle streams region of interest from video (and other sensor data) to a rear vehicle
- The rear vehicle displays the received information as overlay over the occluded area



Vulnerable Road User Protection

- Pedestrian-UEs and CAR V-UE send out specific waveforms to infrastructure
- Base stations receive it, and the location server triangulates the positions
- Positions are sent via Infrastructure to Car (optional to Pedestrians, app required)
- Potentially triggering warnings via Alert message to Car (optional to pedestrian)



Role of 5G in Automotive Industry

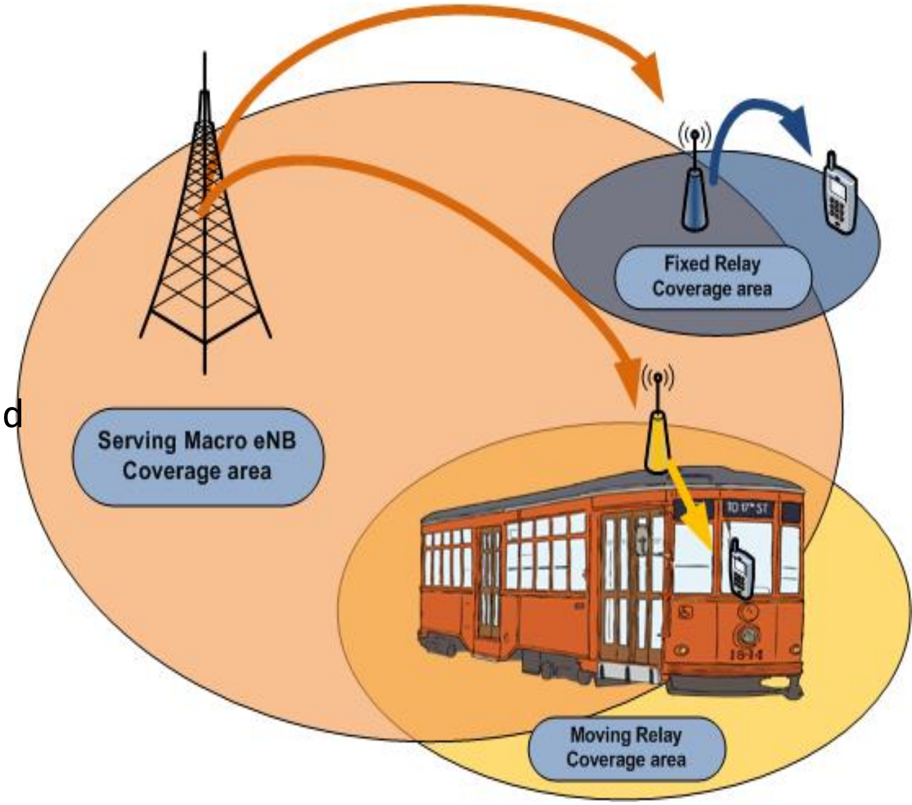
- **New 5G radio technology for more advanced automotive services of** infotainment and a continuously safer system, while leverage on existing infrastructure and device support
- **Cost-effective** coverage, e.g. in rural areas
- **Coverage** is key for Automated Driving (AD) since if e.g. an (Original Equipment Manufacturer) OEM or transport company are liable than one would need to control if in AD or not
- **Cellular** can accommodate both long range and short range communication, e.g. on licensed spectrum
- **Reliability and low latency** connectivity in high mobility
- **QoS** can be used to e.g. prioritise OEM traffic over MBB
- To be **secured** from potential attacks and ensure privacy (e.g. how much personal location information is stored and possible to access for others)

Towards Integrated Moving Networks - Moving Relays/BSs/Cells

- *Vehicles are natural hot spots!*
- *Avoid vehicular penetration loss (VPL): 25-30 dB and more for >6Ghz*
- *Improve UE battery life time*
- *Enable closed-loop schemes for fast moving users*
- *Onboard multi-service resource control*

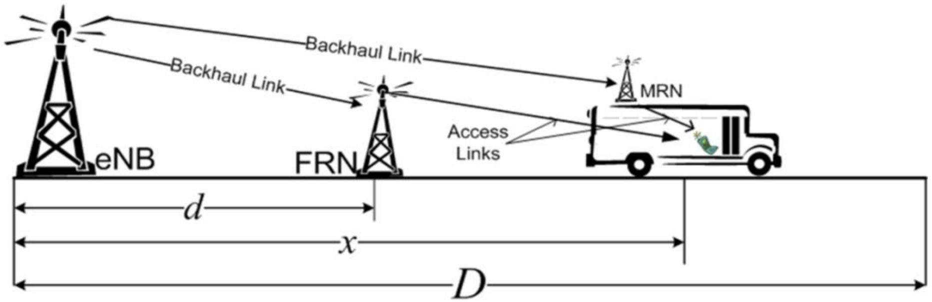
Challenges

- Backhaul design for moving relays/BSs/cells
- Resource allocation/partitioning for macro users and moving cell users
- Interference coordination
- Handover with assured QoS
  - Group user approach?
- Cooperation involving moving relays/base stations
- How to best serve outdoor users with moving base stations

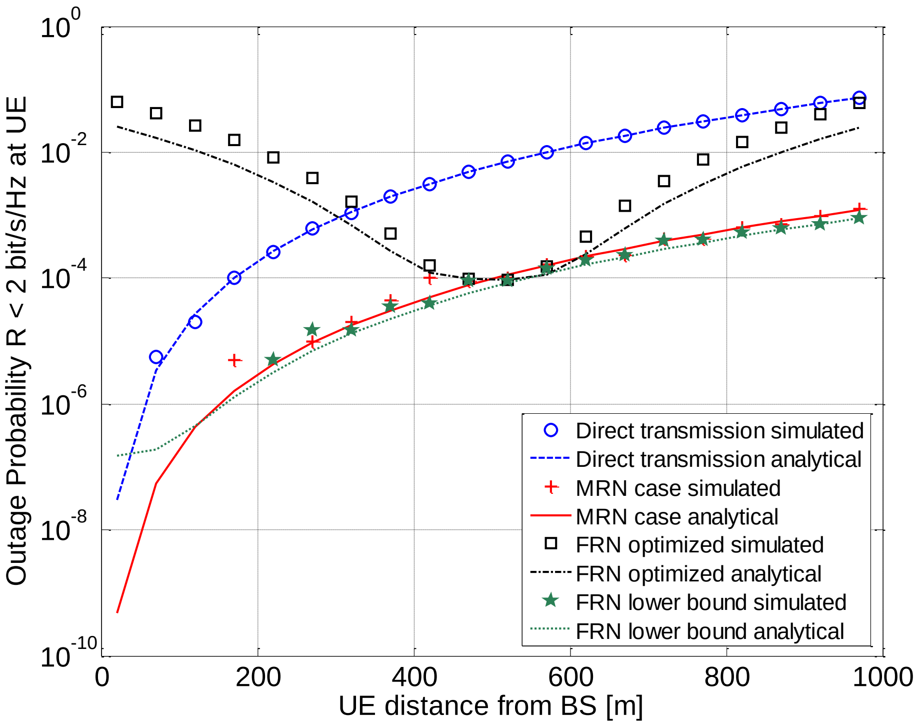


- Y. Sui, A. Papadogiannis, J. Vihriälä, M. Sternad, W. Yang, T. Svensson, IEEE "Moving Relay Nodes: A promising solution to boost performace of vehicular users", Special Issue IEEE Communications Magazine.

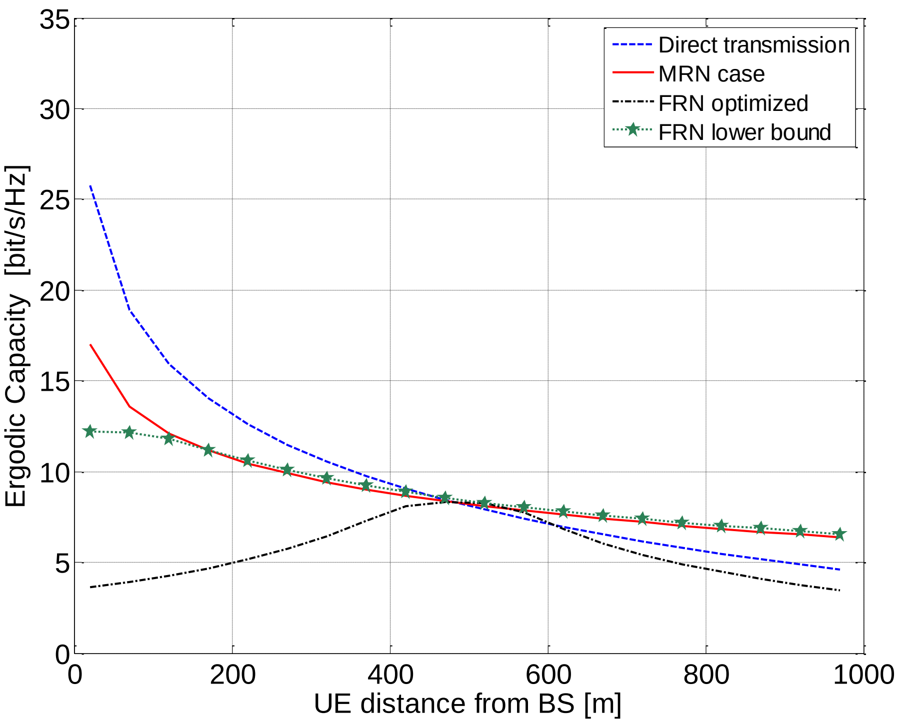
Moving Relay System



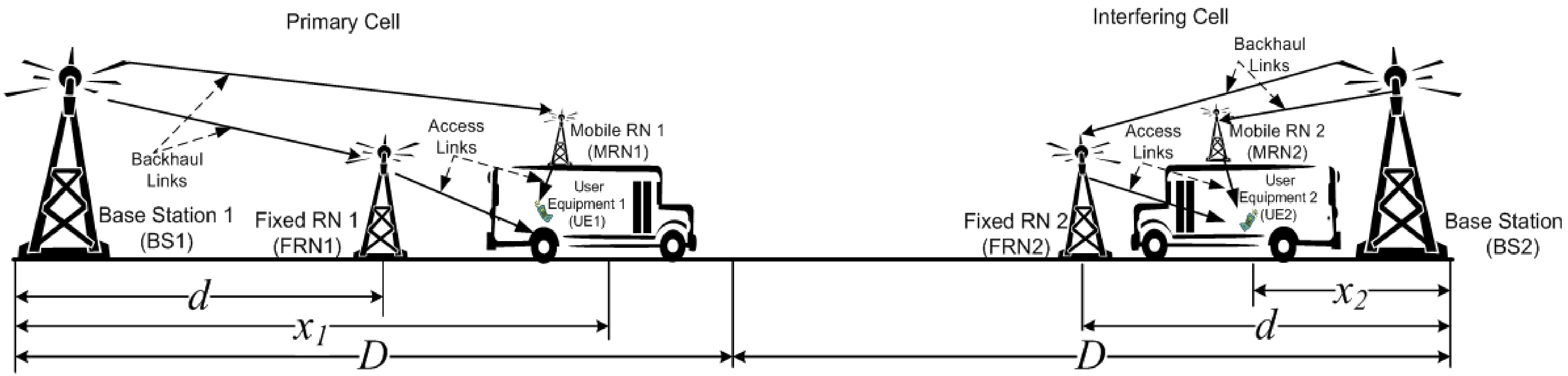
Outage Probability at 25dB VPL



Ergodic Capacity at 25dB VPL



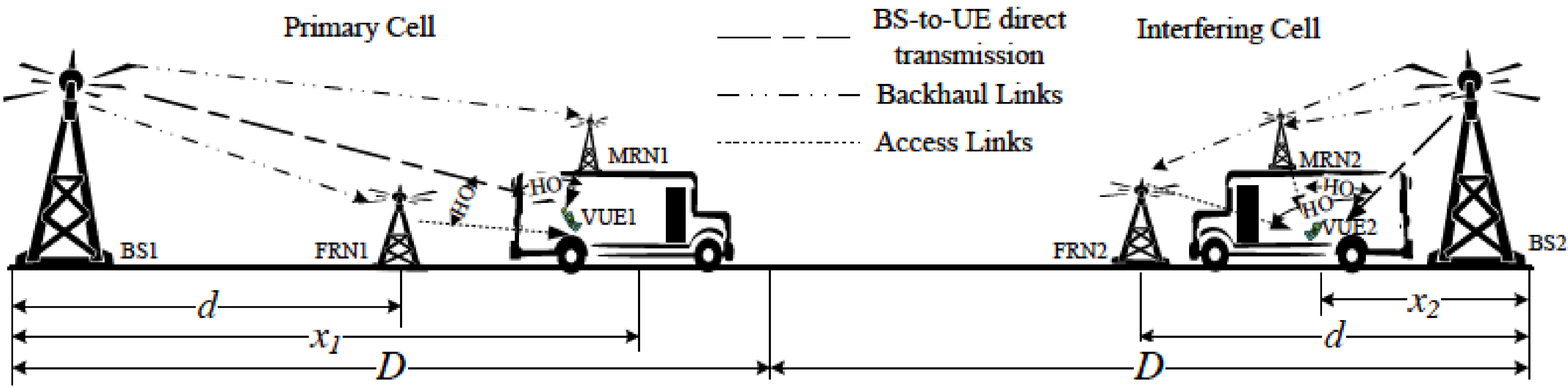
Two Cell System Model



- Target: Vehicular UE
- Considered Metric: Outage Probability
- Schemes: Direct transmission (base line), Fixed Relay Node (FRN) and Moving Relay Node (MRN) assisted transmission.
- A two cell deployment: Primary cell and Interfering Cell

- Sui, Y. ; Papadogiannis, A. ; Yang, W. et al. (2012). Performance Comparison of Fixed and Moving Relays under Co-channel Interference, IEEE 4th Int. Workshop on Heterogeneous and Small Cell Networks (HetSNets), Globecom 2012.

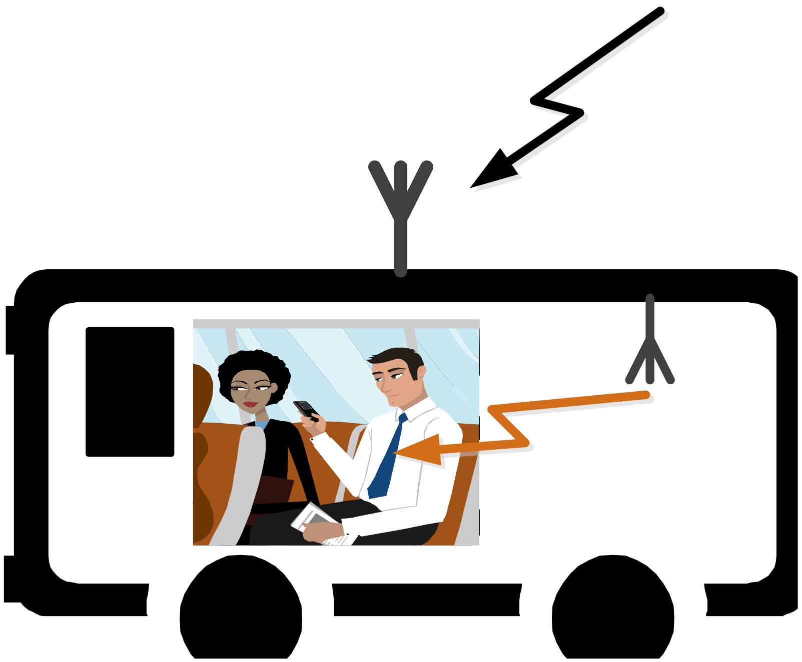
Handover Optimization



- ➢ Short Time-to-trigger (TTT) lowers the power Outage Probability.
- ➢ Longer TTT reduce the Ping-Pong handover rate

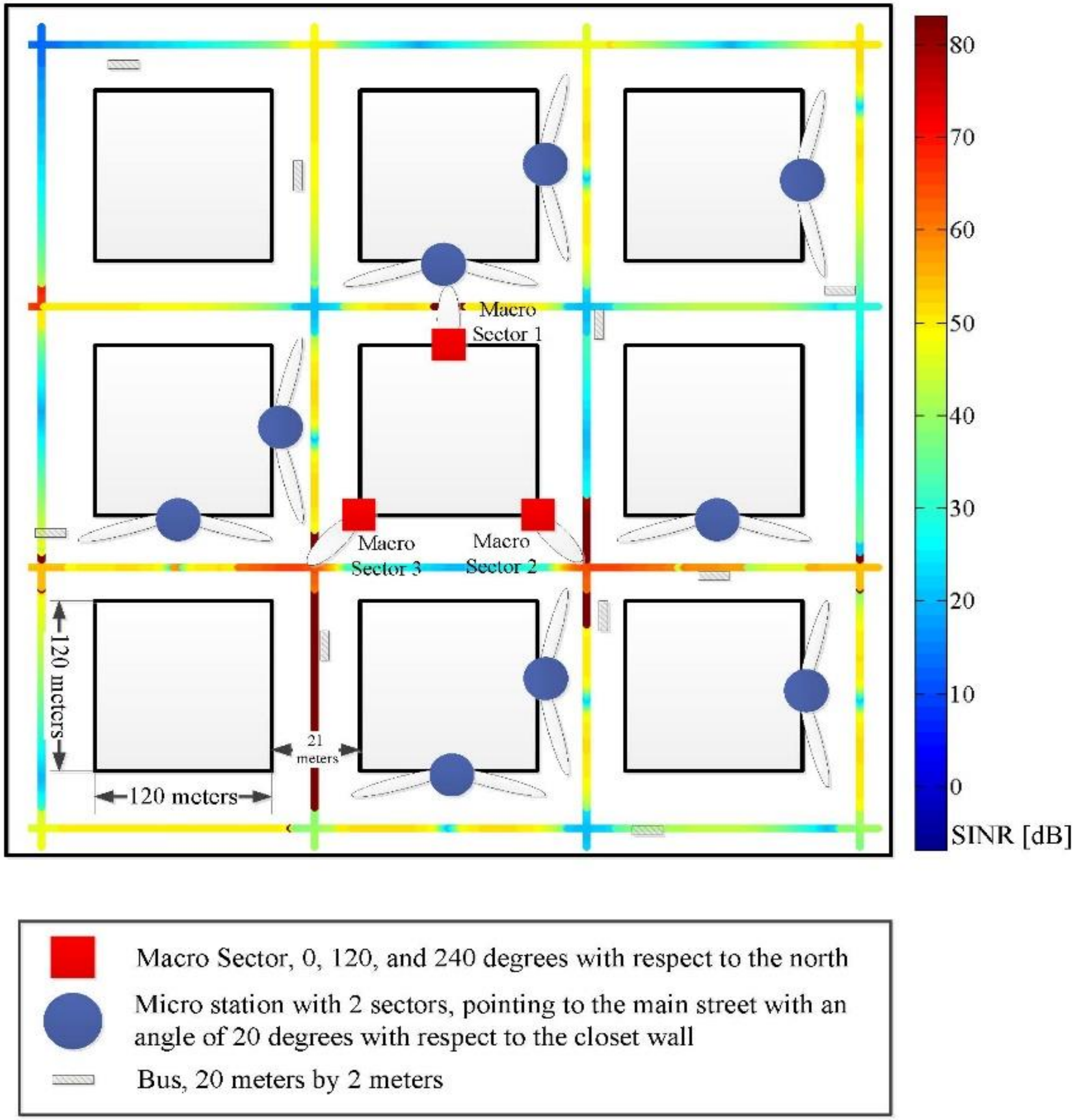
Y. Sui, Z. Ren, W. Sun, T. Svensson and P. Fertl, "Performance Study of Fixed and Moving Relays for Vehicular Users with Multi-cell Handover under Co-channel Interference," ICCVE'2013, Dec 2013, Las Vegas, USA.

Moving Base Station (MBS) to form Moving Cells/Networks



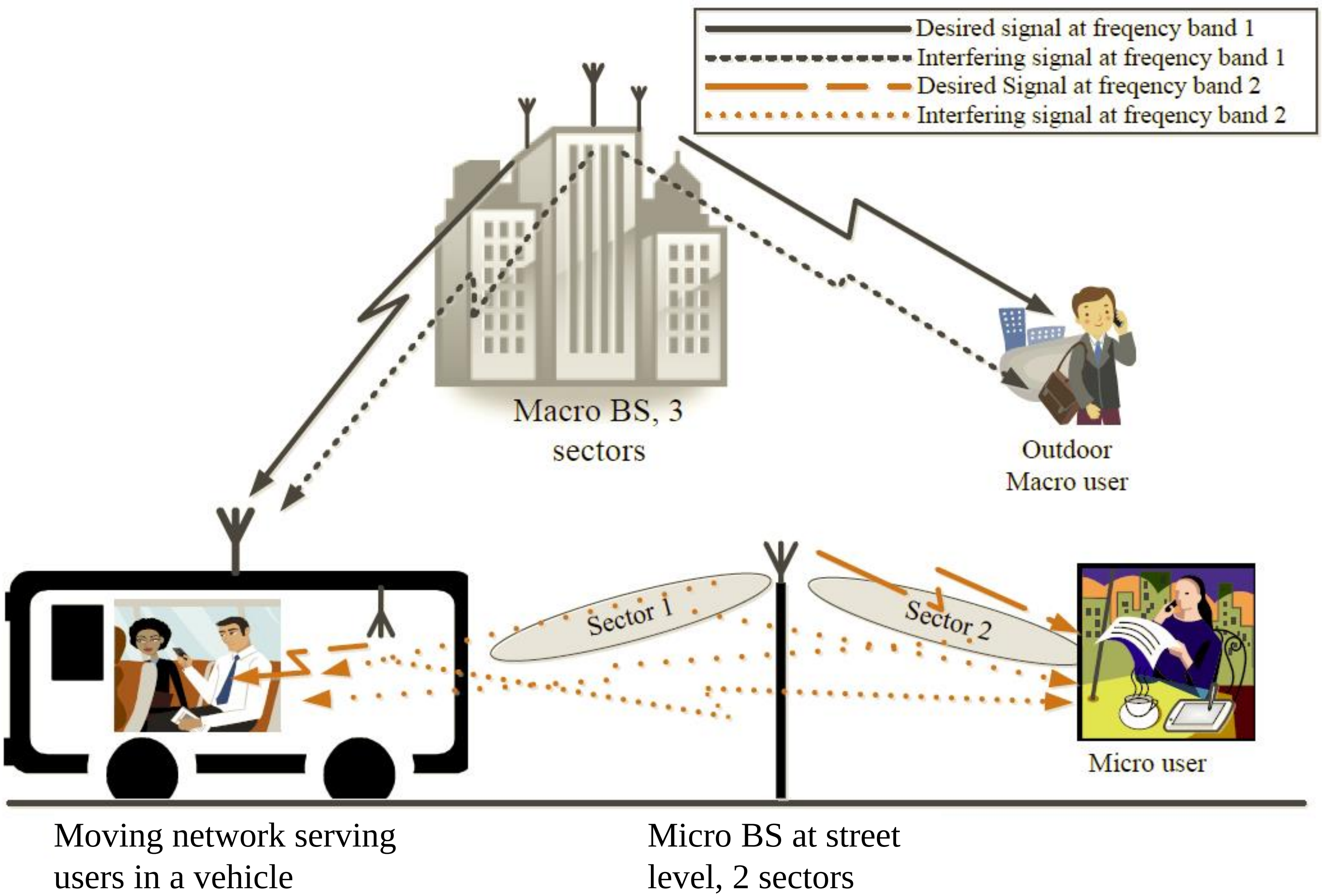
- Full-duplex out-band moving base stations (MBSs) forming a moving network (MN) inside vehicles
- Independent resource allocation within vehicle
- Context awareness buffering and scheduling
- Potential for caching system

System Model



- METIS Test Case 2
- Calibration setup in D6.1
- Macro sectors at 800 MHz with 20 MHz bandwidth
- Micro sectors at 2.6 GHz with 80 MHz bandwidth
- Moving Networks are out-band and full-duplex
- Public transportation vehicles enter the streets according to a Poisson distribution with a speed of 50 km/h.

Illustration of the Interference Situation

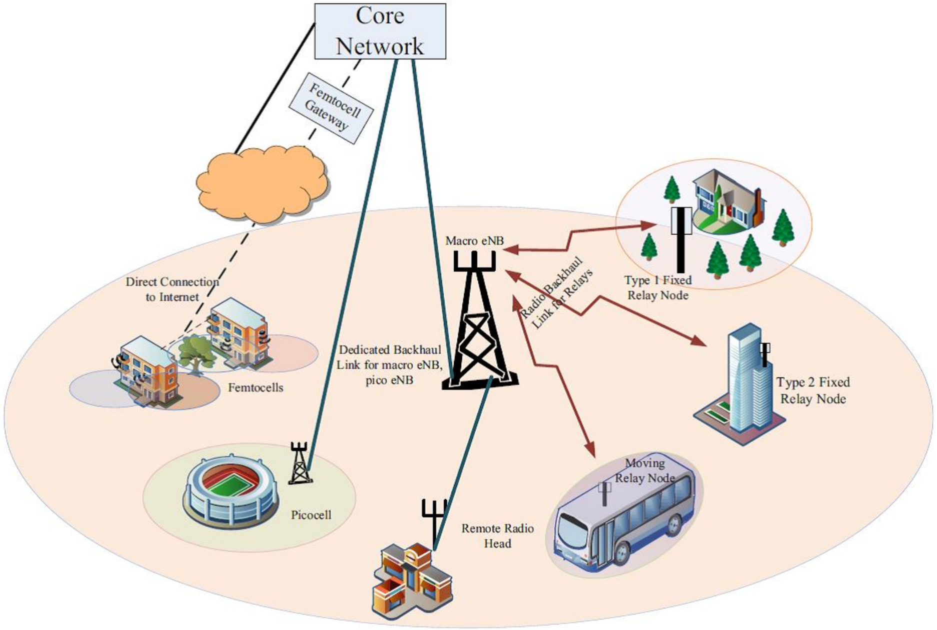


Summary of Observations

- Moving relays/base stations are very useful in low interference scenarios [2]
- Interference management is very important for the use of MNs in ultra-dense urban scenarios
- With advanced interference coordination (ICIC) schemes, the use of MNs can improve the experience of VUEs without significantly degrading the performance of outdoor UEs. High VPL is beneficial. [2]
- Advanced backhaul links are the key to further boost the performance of MNs. [2]

- *Y. Sui, I. Guvenc, T. Svensson, "Interference management for moving networks in ultra-dense urban scenarios", EURASIP Journal on Wireless Communications and Networking 2015*
- *Y. Sui, A. Papadogiannis, J. Vihriälä, M. Sternad, W. Yang, T. Svensson, IEEE "Moving Relay Nodes: A promising solution to boost performance of vehicular users", Special Issue IEEE Communications Magazine.*
- *METIS D3.2 "First performance results for multi-node/multi-antenna transmission technologies", April 2014*
- *METIS D4.3 "Final report on network-level solutions", to appear Feb 2015*
- *Y. Sui, I. Guvenc, and T. Svensson, "On the Deployment of Moving Networks in Ultra-dense Urban Scenarios", IEEE International Conference on 5G for Ubiquitous Connectivity (5GU), Nov, 2014*

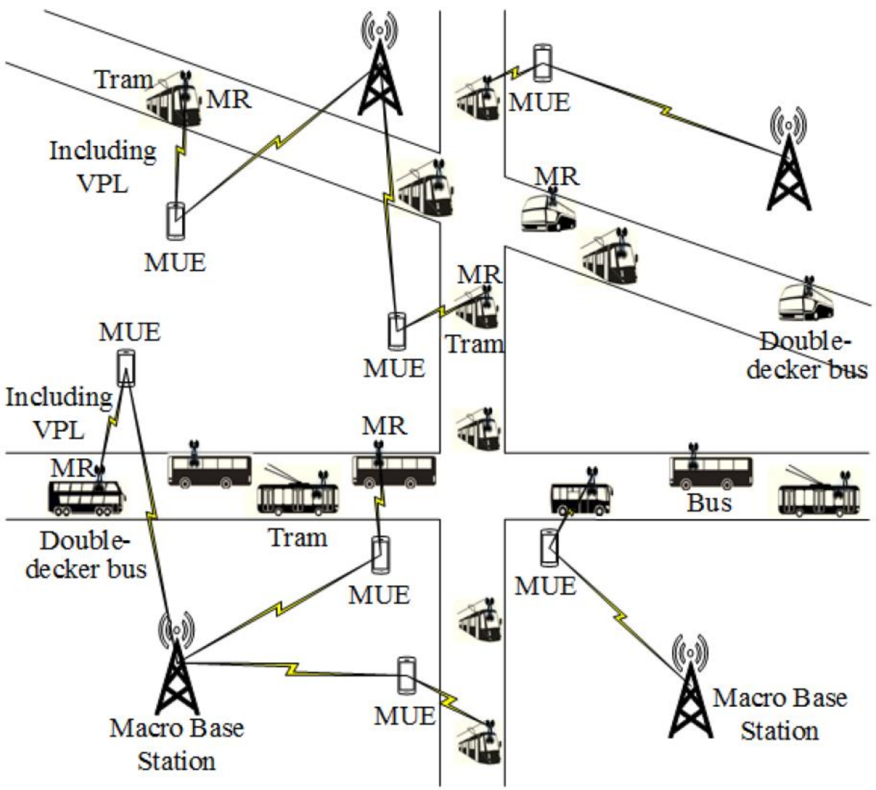
Fully Integrated Moving Cells in *Dense* Small Cells Heterogeneous Network (HetNets)

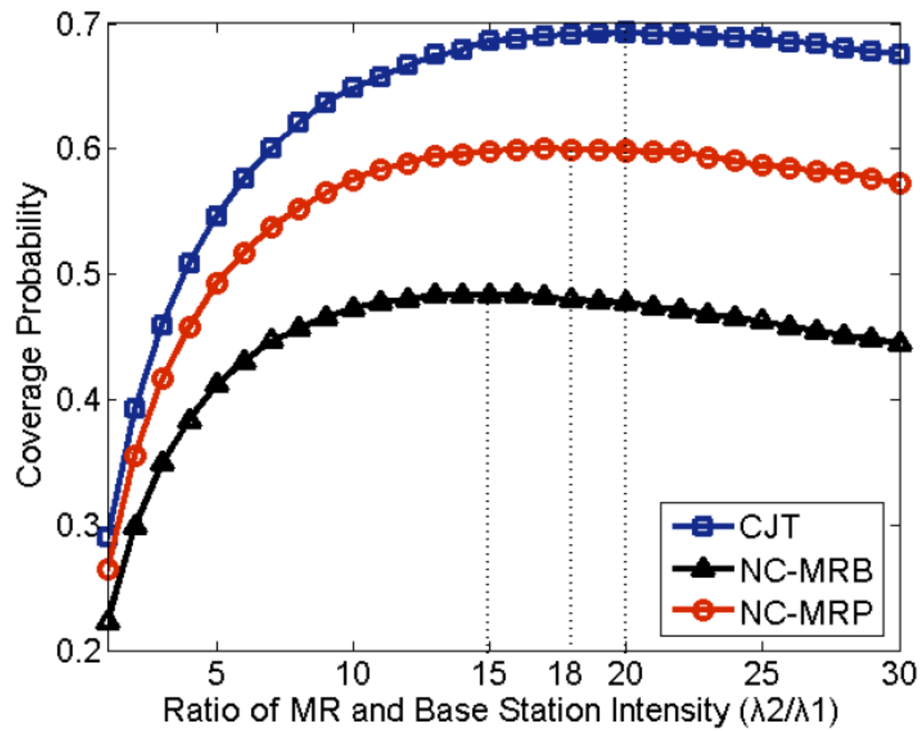


With CSIT based on evolved Predictor antenna systems we can *fully integrate* moving base stations in a generalized HetNets

- CoMP-like schemes
- Spider (soft) handover schemes
- Using moving base stations to serve both in-vehicle and out-of-vehicle users
- Opportunistically utilize moving nodes as ad hoc base stations forming hybrid networks consisting of network infrastructure nodes and less controllable nodes to enable cost efficient services in mega cities

Potential of Moving Relay Enabled Cellular Networks in Dense Urban Scenarios





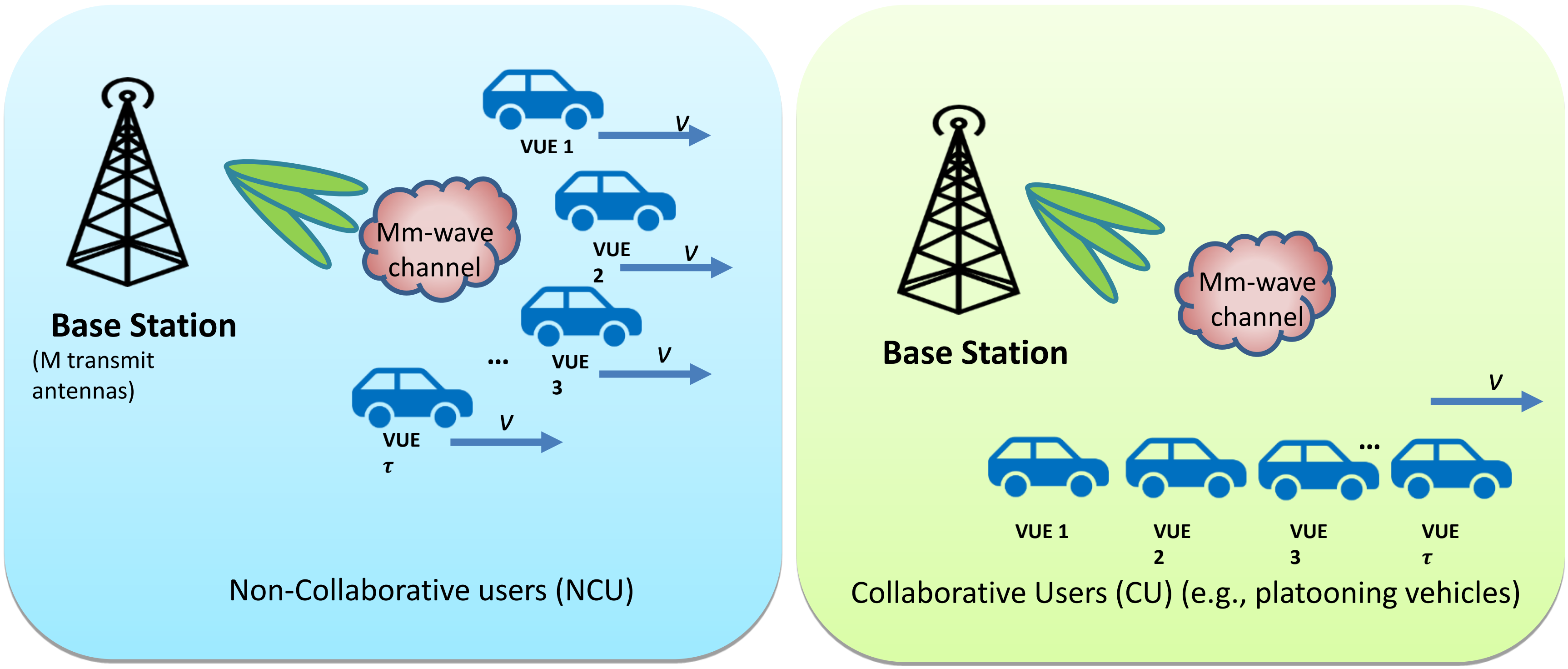
CJT: Bias based joint processing CoMP

NC-MRP: Non-coordinated maximum-received power-based association

NC-MRB: Non-coordinated Moving Relay-biased association

X. Tang, X. Xu, T. Svensson, X. Tao, "Coverage Performance of Joint Transmission for Moving Relay Enabled Cellular Networks in Dense Urban Scenarios", in IEEE Access, vol. 5, no. , pp. 13001-13009, 2017.

Cooperative Beam Finding for Vehicles

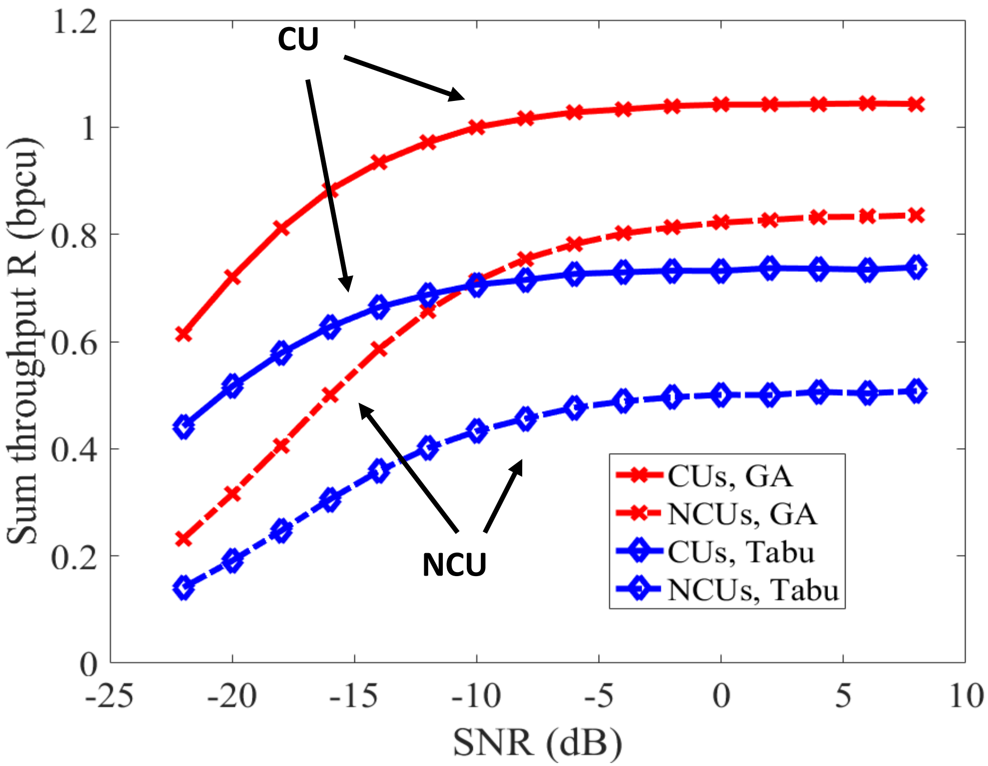


β antennas for each car

$N = \tau * \beta$ antennas at the receiver side

H. Guo, B. Makki, T. Svensson, "Genetic-Algorithm Based Beam Refinement for Initial Access in Millimeter-Wave Mobile Networks", Wiley-Hindawi Wireless Communications and Mobile Computing, Special Issue on Recent Advances in 5G Technologies: New Radio Access and Networking, June 2018.

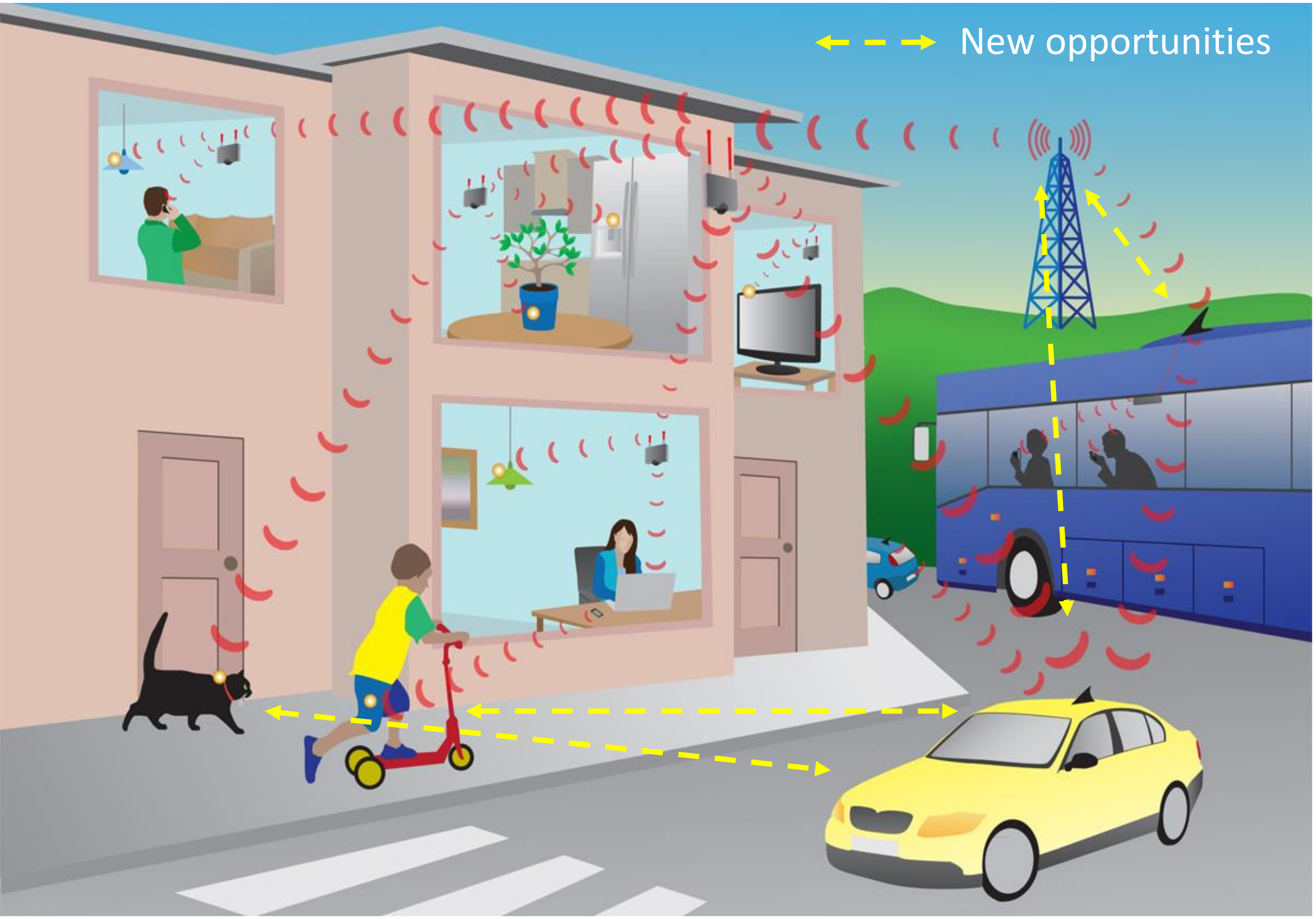
Simulation Results for Cooperative/Non-cooperative Beam Finding



- Simulation of CUs and NCUs for GA and Tabu. M = 32, τ = 4, N = 8, k = 0.
- Substantial gains with cooperative users (CU) over non-cooperative users (NCU) with the two considered Genetic Algorithm (GA) and Tabu search algorithms.
- The performance gain with CU over NCU increases with SNR.

H. Guo, B. Makki, T. Svensson, "Genetic-Algorithm Based Beam Refinement for Initial Access in Millimeter-Wave Mobile Networks", Wiley-Hindawi Wireless Communications and Mobile Computing, Special Issue on Recent Advances in 5G Technologies: New Radio Access and Networking, June 2018.

Integrated Moving Networks: Mutual Opportunities



- **<u>Mutual benefits!</u>**
- **Better mobile systems efficiency**: Vehicles collect side information to improve the resource allocation and performance of the mobile network
- **More reliable V2X links**: Connect non-vehicular users to the Traffic Safety/Traffic Efficiency protocols (Pedestrians, cyclists, pets, …)
- **New disruptive business opportunities:** exploiting vehicle sensed data

Ongoing Research on Integrated Moving Networks at Chalmers

- Enabling technologies for Integrating ad-hoc network elements like moving base stations to 5G HetNets
  - Evolved predictor antenna systems (sensitivity analyses, mm-wave scenarios, …)
  - Advanced closed loop (massive) MIMO cooperative moving backhaul links based on predictor antenna concept
  - Design closed-loop and cooperative interference coordination in ultra-dense heterogeneous networks
  - Pro-active resource allocation utilizing side-information (like road infrastructure information, driving route information, positioning and social networks) for moving base stations
  - Jointly optimize overall resource allocation to optimally serve in-vehicle **and** out-vehicle users using ***hybrid networking*** consisting of infrastructure and ad-hoc network elements
- Analyze performance of hybrid networks using stochastic geometry (both user specific and network specific metrics like outage, throughput, latency and energy efficiency)
- Analyze and develop handover schemes in hybrid networks
- Multi-node multi-beam tracking at mm-wave
- Integrated security and communications for automotive 5G scenarios

The work has considered <=6 GHz, current main focus on >6 GHz carrier frequencies

Business models

Services

- Emergency call
- Remote diagnostics
- Car sharing
- OTA software updates
- Predictive maintenance
- Environment perception through Wireless connectivity and sensor sharing
- Dynamic map
- Video streaming/gaming
- Parking reservation/payment

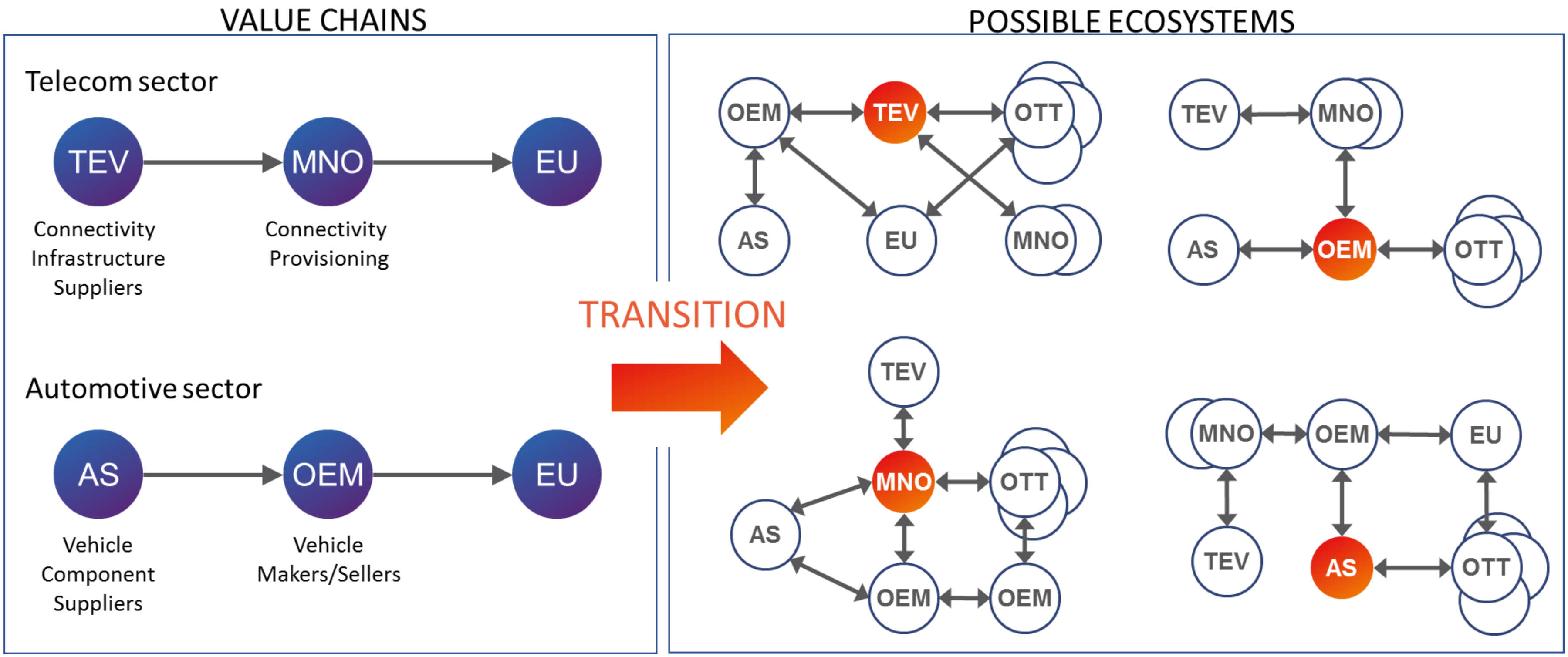
Technological components

- Network densification
- Network slicing
- Mobile Edge Computing
- Sidelink communication
- Cellular radio based positioning and tracking
- Integrated moving networks

Practicalities

- Profile/SIM card provisioning
- Routing strategy
- Roaming and inter-operator coordination
- Network technologies and OEMs status

Business models



AS: Automotive Supplier
OEM: Original Equipment Manufacturer
TEV: Telecom Equipment Vendor

MNO: Mobile Network Operator
OTT: Over-The-Top Service Providers
EU: End User

D2.2 Intermediate Report on V2X Business Models and Spectrum

Take Home Messages

- Cellular-Assisted V2X can do much more than ad-hoc V2X networks
- Vehicles should play an active role in such networks
- Advanced infrastructure links would be a key enabler
- CSIT based closed loop transmission enabled by Predictor antennas enables
  - Enhanced robustness and energy efficiency in the moving backhaul link
  - Potential spatial multiplexing in the moving backhaul link
  - Potential to fully integrate moving small cells in a HetNets concept
    - CoMP-like interference coordination
    - Efficient soft (spider) handover approaches
    - Using moving BSs to serve outdoor users also in interference limited scenarios
- Additional opportunities to explore
  - Full duplex in the moving backhaul links
  - mm-wave communication in MNs
  - Context information in MNs for mutual benefit of VUEs and UEs
  - Integrated security and communications for automotive 5G scenarios
- **Integrated Moving Networks: Mutual opportunities for enhanced mobile networks and ITS services!**
- **Business models needs to be considered as an integral part of system design**

Further reading on MNs: A. Osseiran, J. Monserrat, O. Queseth, P. Marsch, ..., T. Svensson, et, al. "5G Mobile Communications Technology ", Cambridge University Press, June 2016. ISBN: 9781107130098. – Chapter 11

5G and Beyond: A New Era Has Begun

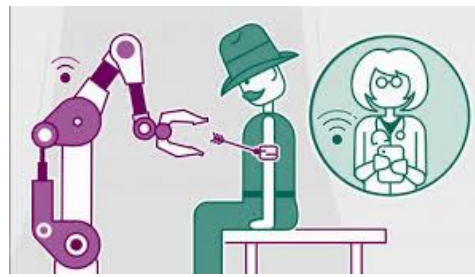
Internet -> Mobile Internet -> …

-> Wireless => Internet of Things

Source: https://www.aeteurope.com/news/technologies-secure-internet-things/

-> Robustness, Low latency => Internet of Skills

Still work to be done:
”Beyond 5G”



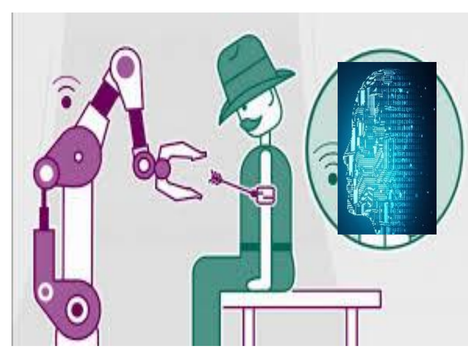
Source: https://www.ericsson.com/thinkingahead/the-networked-society-blog/2017/02/14/virtual-reality-comes-age-internet-skills/

What about 6G?

Convergence of computing, communications, storage and Artificial Intelligence
=> Massive and Distributed (i.e. local) Internet of Skills

6G?

Source: https://towardsdatascience.com/ai-the-future-of-technology-and-the-world-86f59d0cf720



6G?

- Massive and Distributed (i.e. local) Internet of Skills
- Massive AI driven automation
- Augmented Reality (AR)
- Joint communications and sensing

Sustainable and secure networking

Holistic performance metrics => need for holistic research

- **Latency**
- **Total communications efficiency including enabling data**
- **Energy efficiency**
- **Security – deeply integrated**

Enabling Technologies for 6G(?)

Key words: Terahertz communications, New topologies, Non-terrestrial access components, Cellular as a sensor, Zero-energy devices and backscattering.

- **(0.x)THz communications, Free space optical communications, Optical wireless communications**
  - Use cases
  - Waveforms, Beamforming
  - Distributed large MIMO, mobility
- **Joint communications <-> Sensing**
  - Context and mapping information for pro-active resource allocation
  - Localization aided communications
- **Shaping the propagation environment**
  - Reconfigurable Intelligent Surfaces (RIS)
- **Vertical convergence => 3D networks**
  - Vertical cells/beams
  - Satellite networks, Airborne networks (UAVs) for coverage
- **Network topologies**
  - Moving base stations => ”Integrated Moving Networks”
  - Self-deployed ad-hoc network elements
  - Wireless/photonics/free space optics joint communications
  - Licensed/unlicensed
  - Role of user terminals in next generation wireless networks?
- **Access-Backhaul-Fronthaul/Core network convergence**
  - Convergence in communications <-> computing <-> storage
  - Out-of-system measurements, Large data set aided
- **The role of ML/AI in wireless access/backhaul/fronthaul networks**
  - Based on offline data
  - Based on online data
- **Zero-energy**
  - Energy state-aware/harvesting based networks
  - Backscattering devices
- **Flexible agile networks vs Energy efficiency**
  - Dynamic centralization/decentralization architecture
  - PHY/MAC Network slicing enablers
  - Flexible duplexing
  - Adapt to instantaneous performance metric: throughput, latency, reliability, energy efficiency, security, …
  - Utilize locality
- **Security**
  - The role of physical layer security
- **Spectrum flexibility**

Open Master Thesis Topics within Wireless Systems (30/60 credits)

Contact: Tommy Svensson tommy.svensson@chalmers.se

Potential areas:

- **Cellular V2X**
- **Waveform design for mm-wave/sub-THz communications**
- **Cooperative mm-wave/sub-THz communications (cell-free massive MIMO)**
- **Integrated access and backhaul (IAB)**
- **Reconfigurable Intelligent Surfaces (RIS)**
- **ML/AI based air interface design**
- **…**

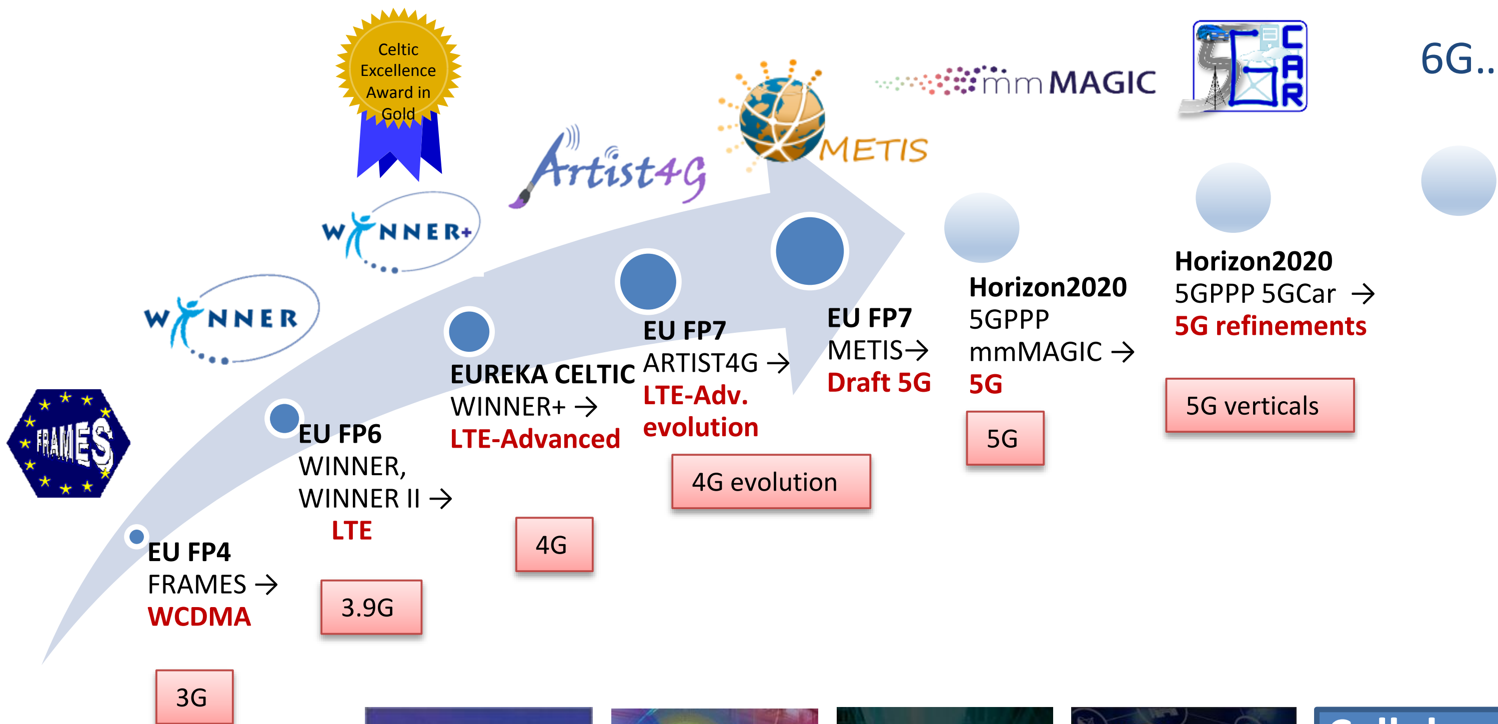
Projects to be defined.

Active Research Topics and Collaborators in Wireless Systems Research Area

- Cooperative communications
  - CoMP with HARQ, HetNets, Relaying, Mesh networks
  - Massive MIMO
  - D2D, Finite block length
- Ultra-dense wireless networks
  - Cooperative hybrid beamforming
  - Initial access
  - mm-wave based integrated access, backhaul and fronthaul
  - Hybrid RF-FSO
  - Joint fiber-wireless
  - Coverage and mobility analyses using stochastic geometry
  - THz
- Cellular-V2X
  - Moving backhaul (V2I) links
  - Interference coordination
  - Moving BSs
  - Pro-actice resource allocation
  - Integrated moving networks
  - Secure communications
- Internet of Things (IoT)
  - Waveforms
  - Energy harvesting networks
  - Architecture
- Satellite return links
- Energy efficient networks
- Enablers for network slicing

Communications Systems group at Chalmers University of Technology

Impacts Wireless Standards: 3G, 4G, 5G, and counting...

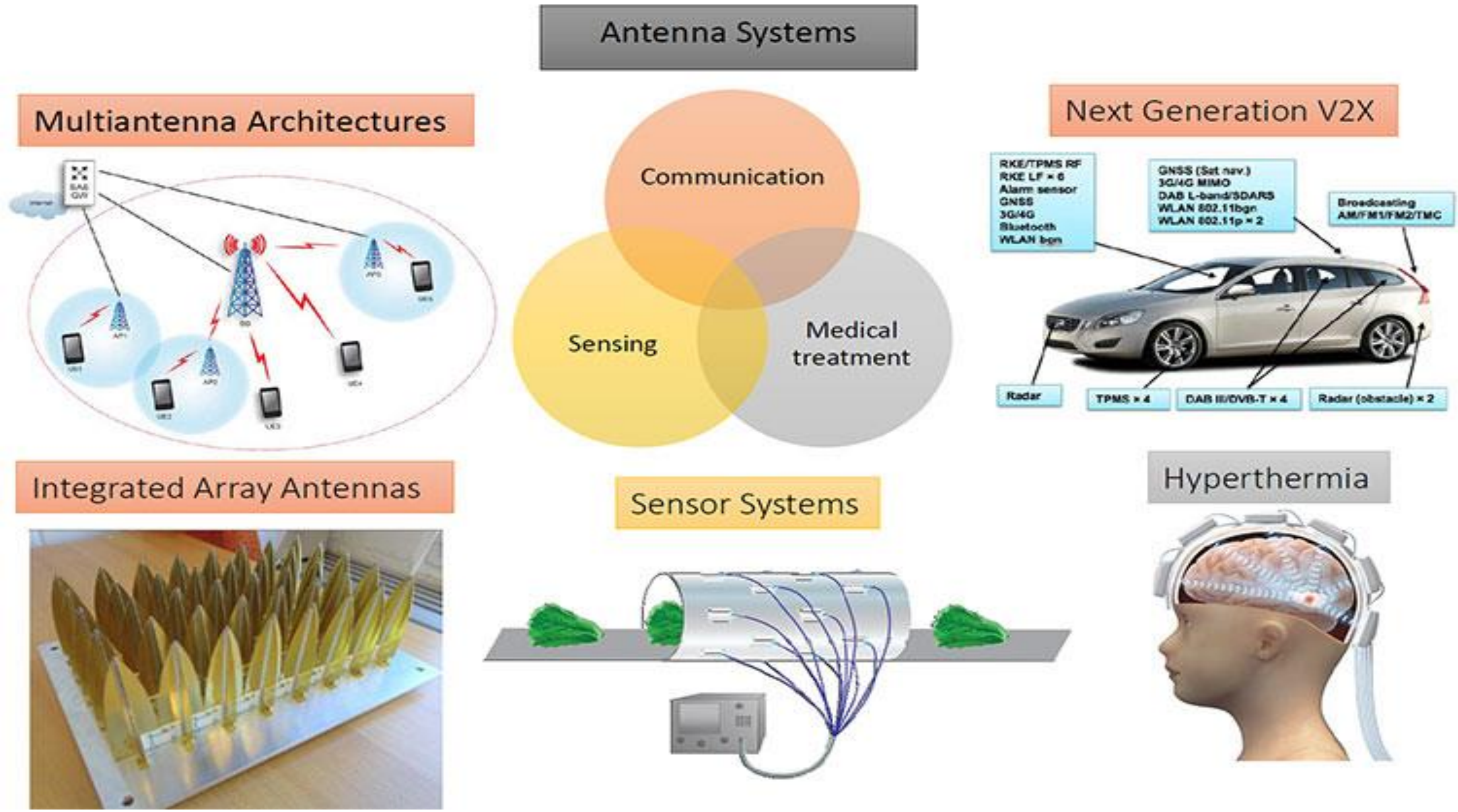


Cellular V2X for Connected Automated Driving
Wiley, *2020*
To appear

https://5g-ppp.eu/5gcar
https://5g-mmmagic.eu
https://www.metis2020.eu
https://ict-artist4g.eu
http://projects.celtic-initiative.org/winner+
http://cordis.europa.eu/infowin/acts/rus/projects/ac090.htm

ChaseOn Antenna Systems Research Center at Chalmers

- Five interconnected projects in Communication, Sensing, and Medical treatment, 14 industrial partners.



Multiantenna wireless architectures for next-generation wireless systems — MANTUA (2017-2022)

Aim

- Develop advanced antenna systems and solutions for 5G and beyond 5G wireless communication networks

Objectives

- Determine the functionalities to be performed at each node of heterogeneous wireless networks for optimal performance in terms of capacity, coverage, latency, energy efficiency, and reliability
- Develop centralised/decentralised cooperative MIMO techniques approaching the optimal performance identified above
- Demonstrate the identified solutions on a hardware testbed

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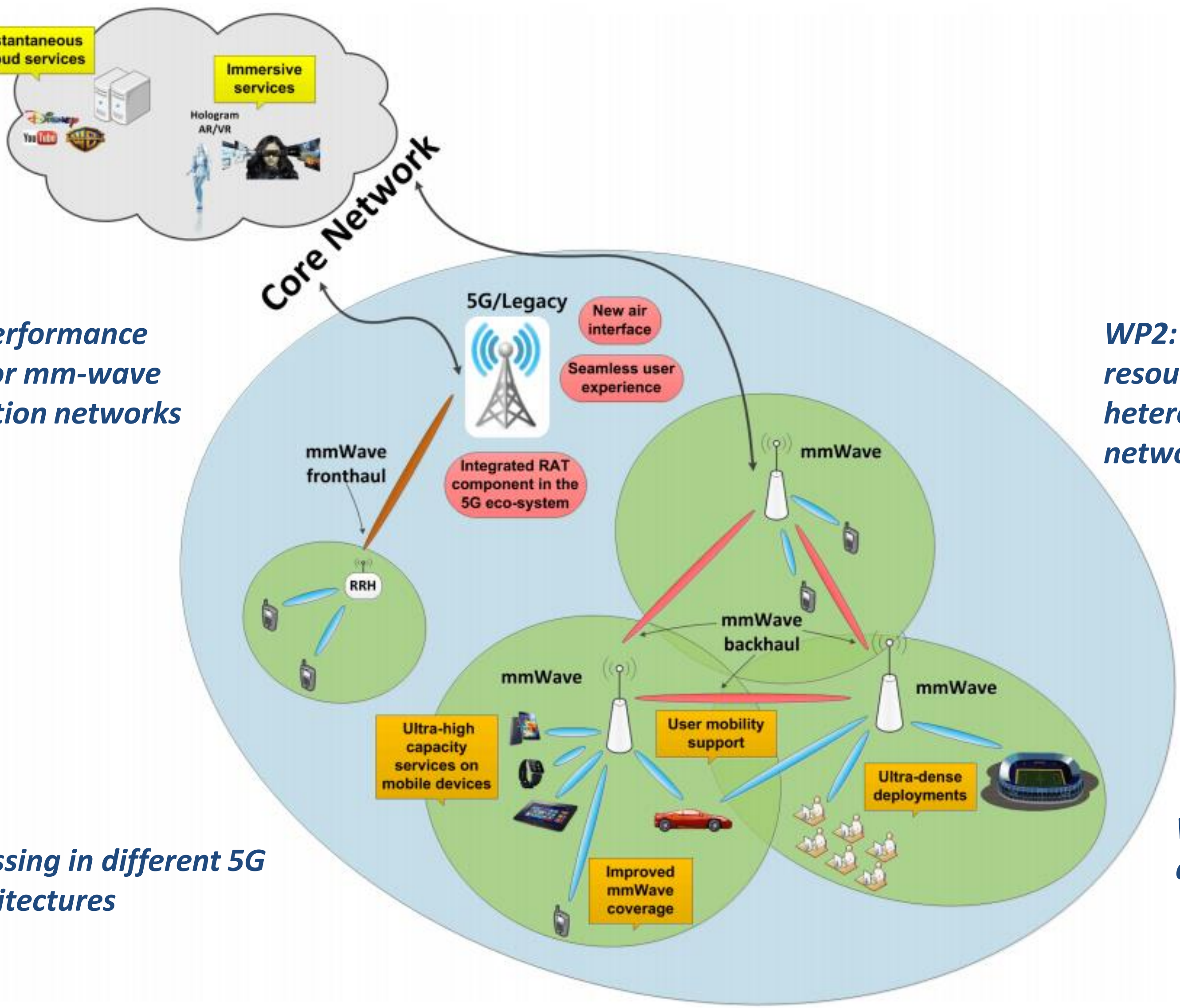
MANTUA : Converged mmWave Access-Backhaul/Fronthaul Network

WP0: Key performance indicators for mm-wave communication networks

WP2: Cooperation and resource allocation in dense heterogeneous mm-wave networks



WP1: Processing in different 5G system architectures

WP3: Demonstration activities