Introduction to 5G – with Applications Part 2

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Outline

- Part 1 5G - New era of Mobile Communications
  - Towards a Smarter Society
  - Basics of 5G
- Part 2 - Cellular V2X
  - Designing the 5G 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

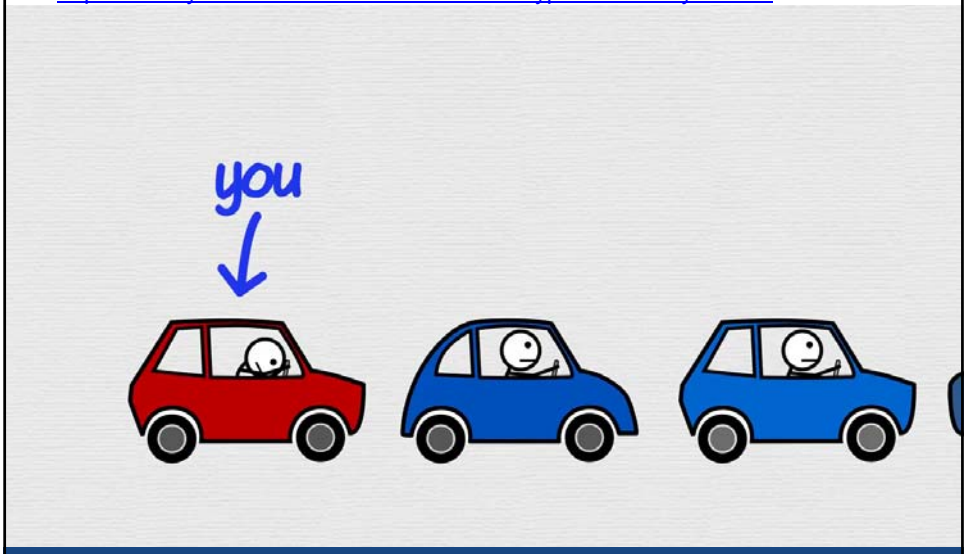
Functions in Intelligent Transportation Systems (ITS)

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

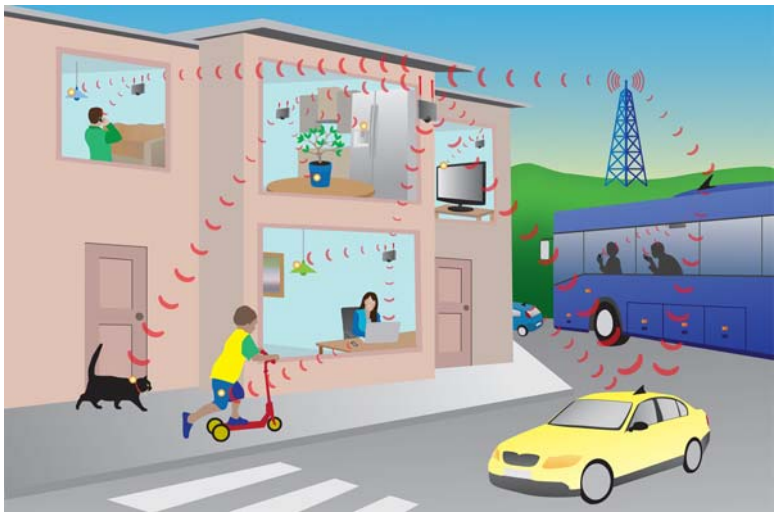
Source: Wikipedia

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"



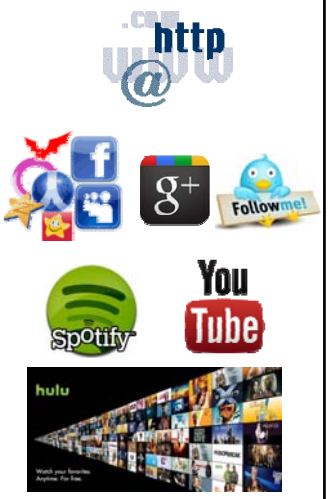
Increasing Need for Mobile Broadband

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%

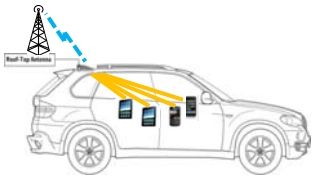
Source: Cisco VNI Mobile, 2011

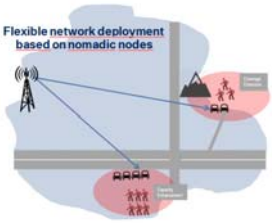


Moving Networks in the METIS project

"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





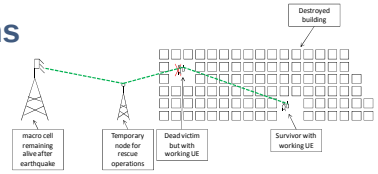
- **Cluster #2: Flexible network deployment based on nomadic network nodes**
  - Requirement: High Data Rate
  - Relaying inside vehicles is not considered here!

- **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

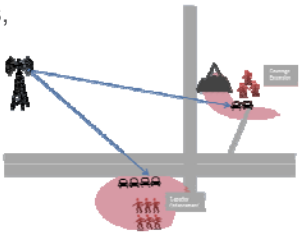
- **Traffic volume**: 480 Gbps/km^2
- **User data rate:** 100/20 Mbps in DL /UL with 95% availability

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.

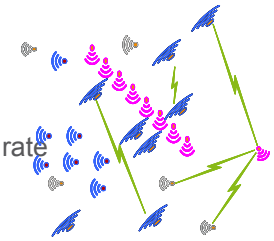
- **User data rate:** 100/20 Mbps in DL /UL
- **Latency**: Less than 10 [ms] with 95% reliability
- **Mobility:** Up to 350 km/h

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%

General Motors' EN-V concept

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

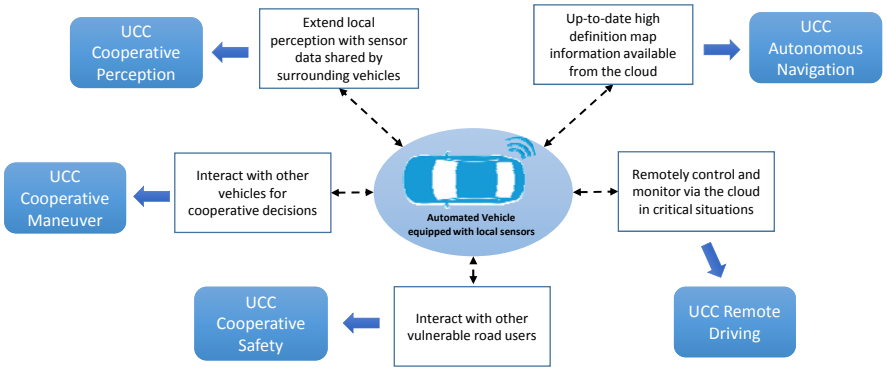
5G PPP Phase 2 Project
June 2017 – May 2019
30 Full time researchers
8 M€ budget

5GCAR contact

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

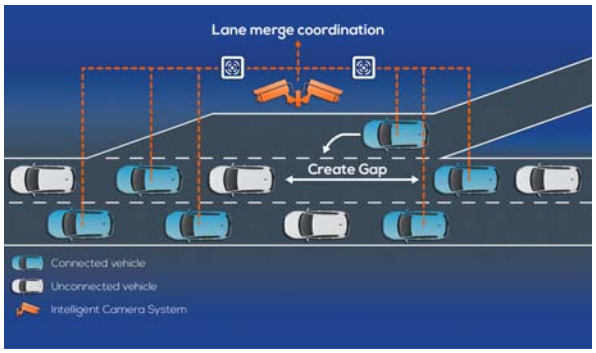
Email
5GCAR-Contact@5g-ppp.eu

5GCAR Use Case Classes



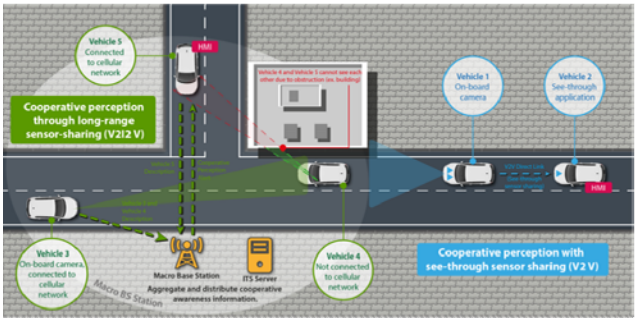
Lane Merge Coordination

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



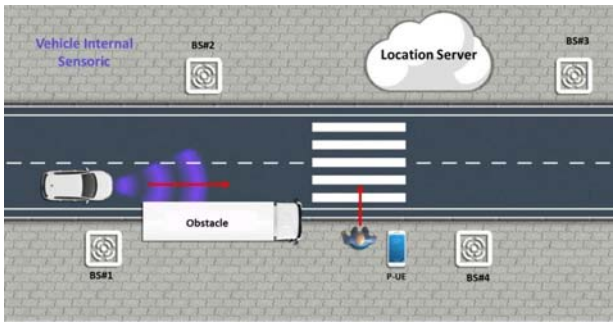
Cooperative Perception for Maneuvers of Connected Vehicles

- 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

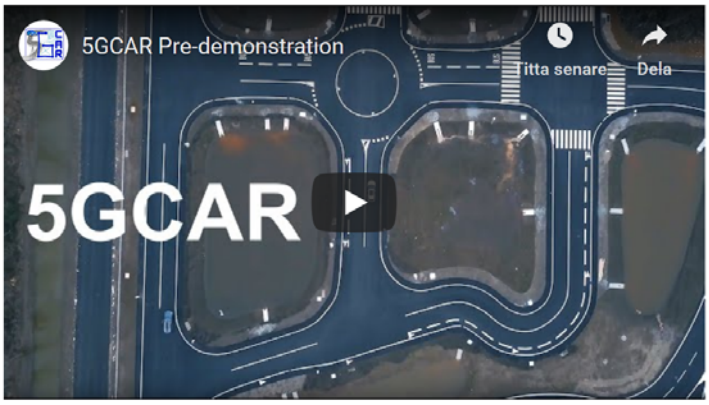
- Pedestrian-UEs and CAR V-UE send out specific waveforms to infrastructure
- Base stations receive it, and the location server triangulates the positions
- Positions are sent via Infrastructure to Car (optional to Pedestrians, app required)
- Potentially triggering warnings via Alert message to Car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



Phantom Auto's Remote Driving

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

5GCAR Pre-Demonstration



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

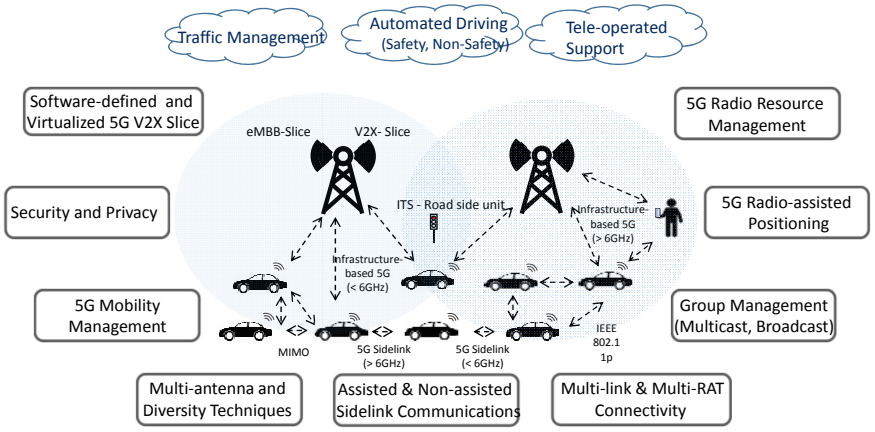
Designing the 5G V2X Radio Interface

– Towards a Reliable High Capacity Infrastructure Interface

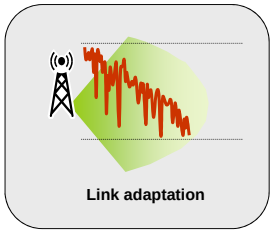
- Robust
- High capacity
- Low latency
- Support multicast/broadcast
- Efficient also for small packets

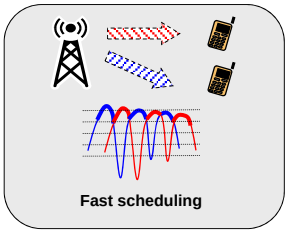
Ultra-Reliable Low-Latency Communication (URLLC).

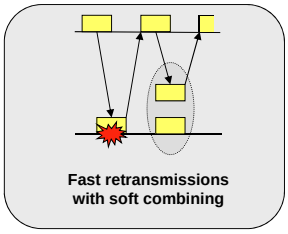
Concept and key technical components



Recap: Adaptive Transmission



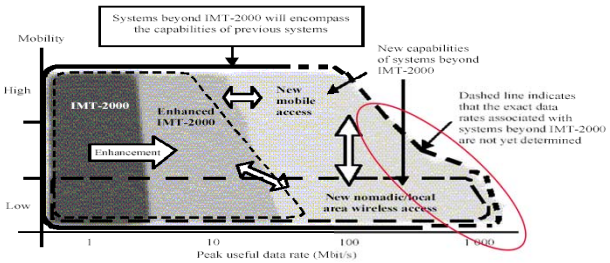




- Frequency-channel-dependent scheduling & fast link adaptation
  - Spectrally efficient transmission
  - Adapt per spatial chunk (resource block) layer to small-scale fading
- Non-frequency adaptive transmission (for fast terminals, multicast, ...)
  - Robust transmission
  - Adapt per frame to shadow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

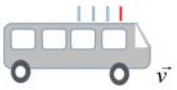
How to Improve Channel State Information (CSIT) at High Speed?

IMT Advanced requirements at high speed:



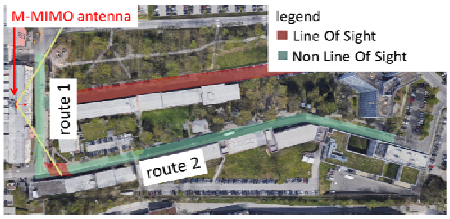
10 times lower requirements at high speed!

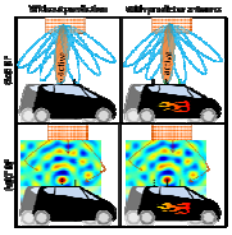
5GCAR V2X Radio Interface

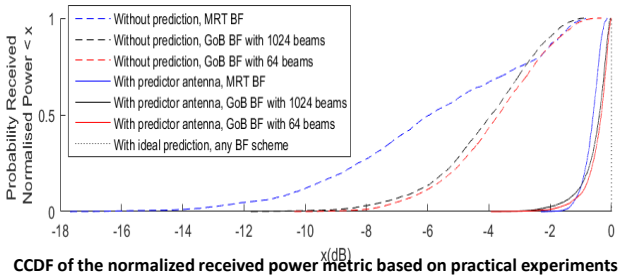


Example: Predictor antenna

- 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.





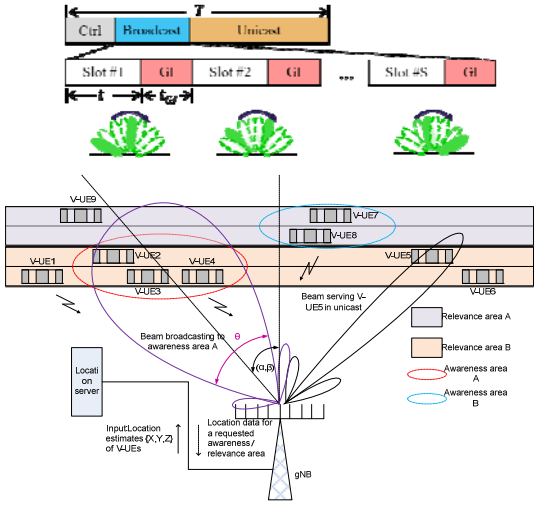


CCDF of the normalized received power metric based on practical experiments

5GCAR V2X Radio Interface

Example: Beam based V2X broadcast

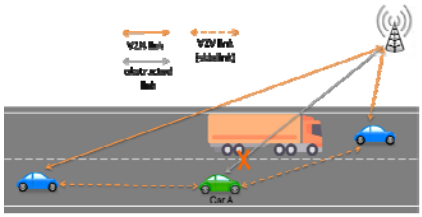
- Utilization of multicast / broadcast transmission at mmWave band to vehicles
  - Enable high data rate V2N/I communication links with resource efficient transmission of common content to multiple V-UEs.
- Highly directional transmission and reception considerably complicates the beam-based broadcast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

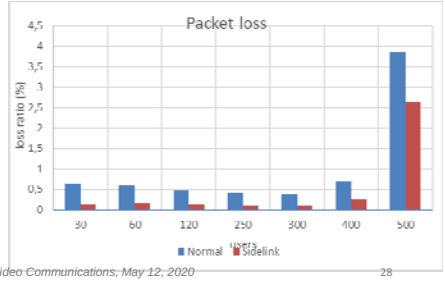


5G V2X radio interface

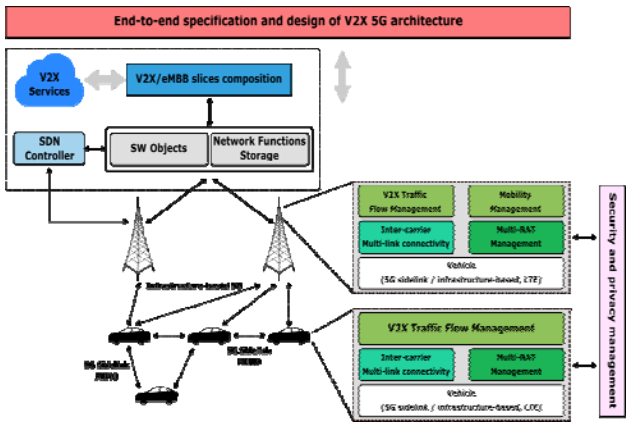
Example: Sidelink assisted cellular communication

- 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.



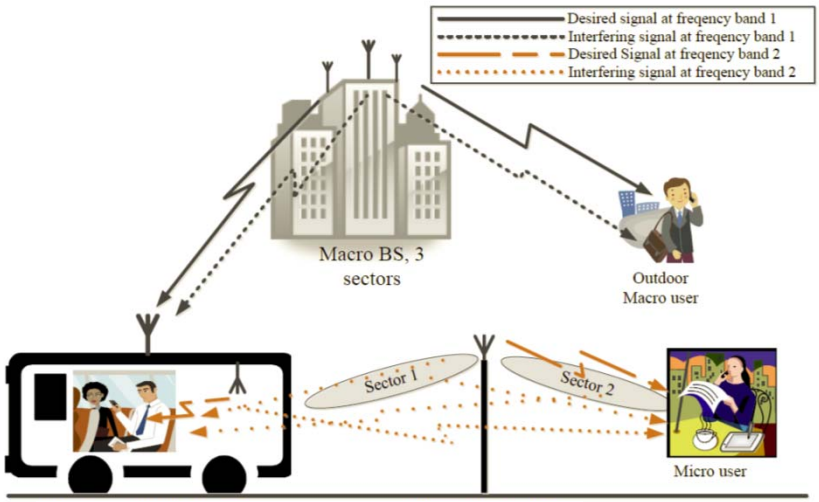


V2X System Level Architecture



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

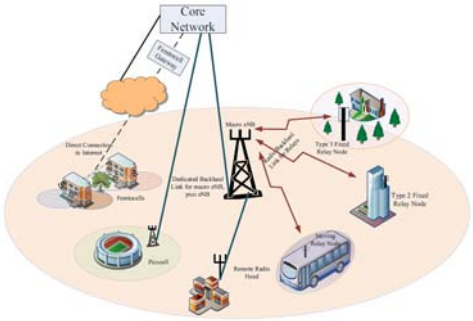
Moving Base Station (MBS) to form Moving Cells/Networks



Moving network serving users in a vehicle

Micro BS at street level, 2 sectors

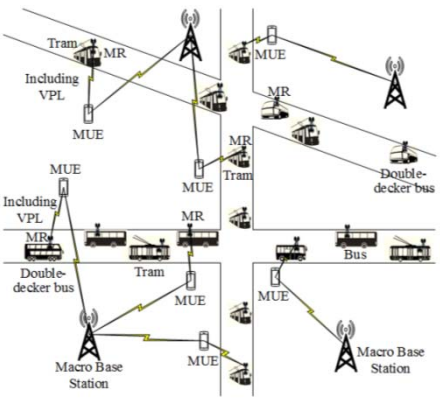
Integrated Moving Networks

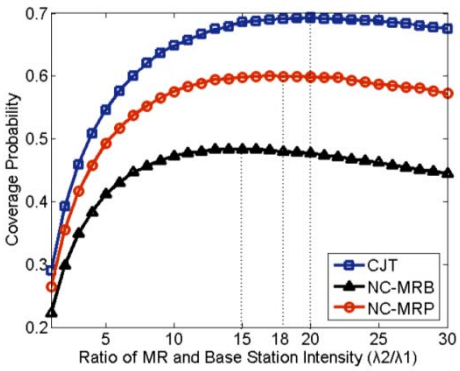


With CSIT based on evolved Predictor antenna systems we can *fully integrate* moving base stations in a generalized HetNets

- 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
- Spider (soft) handover schemes
- Coordinated MultiPoint (CoMP)-like schemes

Potential of Moving Relay Enabled Cellular Networks in Dense Urban Scenarios

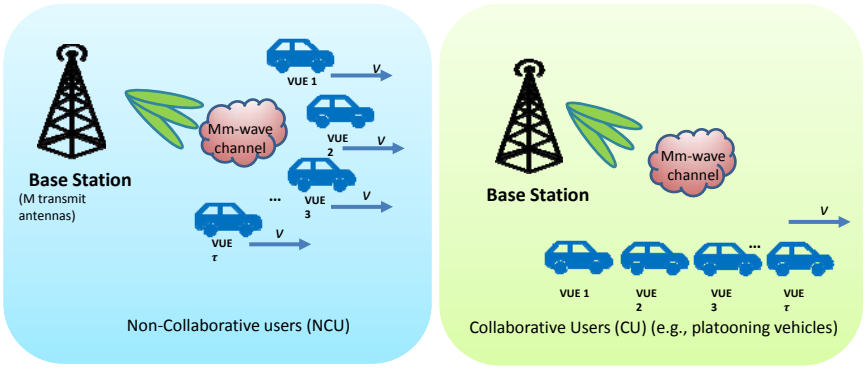




CJT: Bias based joint processing CoMP
NC-MRP: Non-coordinated maximum-received power-based association
NC-MRB: Non-coordinated Moving Relay-biased association

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

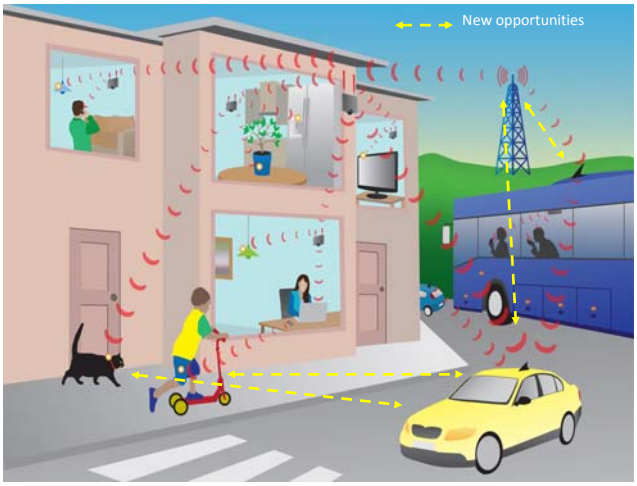


β antennas for each car

$N = \tau * \beta$ 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.

Integrated Moving Networks: Mutual Opportunities



Potential mutual benefits:

Better mobile systems efficiency

- Vehicles collect side information to improve resource allocation and performance of the mobile network
- Vehicles act as moving base stations

More reliable and secure V2X links

- Network assisted V2X – improved scalability, reliability, range/ information horizons
- Connect Vulnerable Road Users (VRUs) not part of dedicated V2X systems, such as Pedestrians, cyclists, pets, … to the Traffic Safety/Traffic Efficiency protocols

New disruptive business opportunities

- Exploit vehicle sensed data
- Micro-operators of moving base stations

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

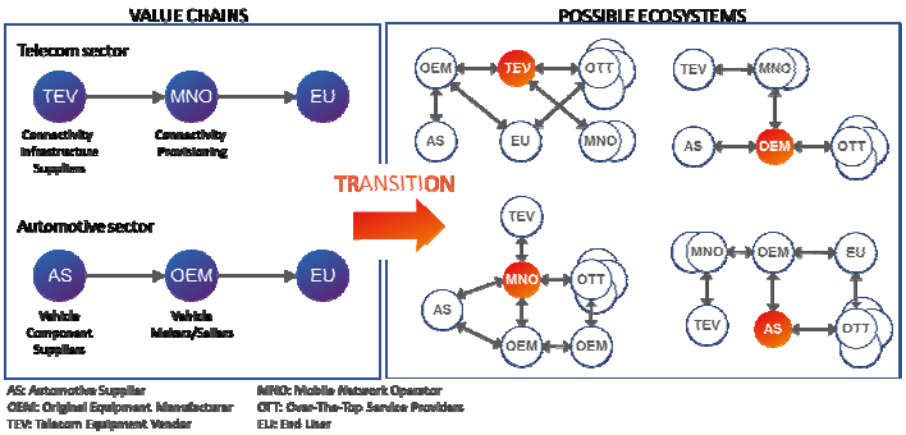
Technological components

- 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



D2.2 Intermediate Report on V2X Business Models and Spectrum

Take Home Messages

- IEEE 802.11p already supports basic Intelligent Transportation Systems (ITS) functions
- Cellular-Assisted V2X can do much more than ad-hoc V2X networks
  - 4G (rel. 14, LTE-V) already exists, evolved 5G will support massiveness and robustness of advanced Network assisted ITS, Autonomous vehicles and enhanced Mobile Broadband (eMBB) to vehicles
- 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 both 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