Merging new Cloud and Air-Interface Capabilities to meet Requirements of Emerging Use Cases from Vertical Industries in 5G

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- Emerging New Use Cases from Vertical Industries
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  - Introduction of 3GPP's Cellular Approach
  - Modes of Operation, Resource Pooling

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Tactile Internet

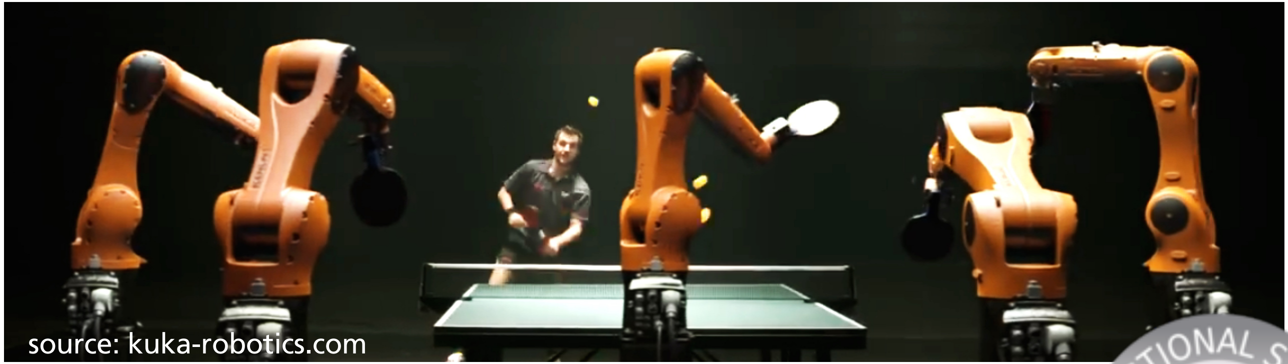
Paradigm Shift from Transmititing Information to Networked Control

Source: www.domeoproducts.com

Source: http://blogs.voanews.com/

Mission Critical Communication

New KPIs: Interaction Speed and Functional Safety & Security



source: kuka-robotics.com

source: www.prismagroup.it

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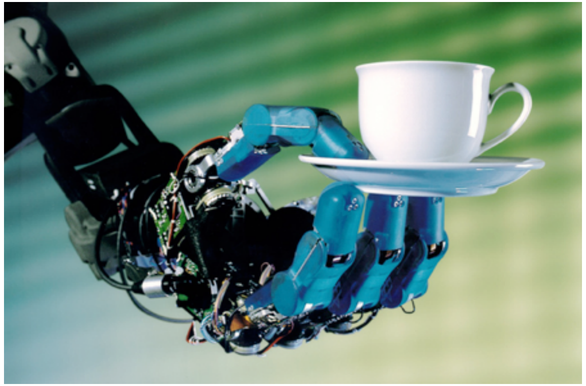
Robotics and Telepresence

source: https://netzoekonom.de



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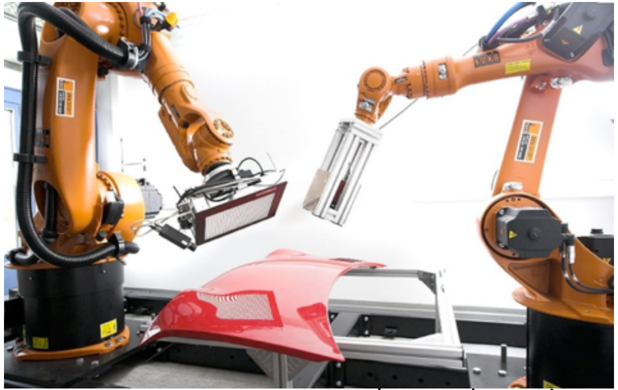

source: www.bogen-electronic.com

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Networked Virtual Reality

Source: www.telegraph.co.uk

Collaborative Driving

Driver assistance with AR of potentially dangerous objects and situations

Source: ITU TechWatch Report: The Tactile Internet

Augmented Reality

Collaborative event perception and virtual attendance of external users

Source: ITU TechWatch Report: The Tactile Internet

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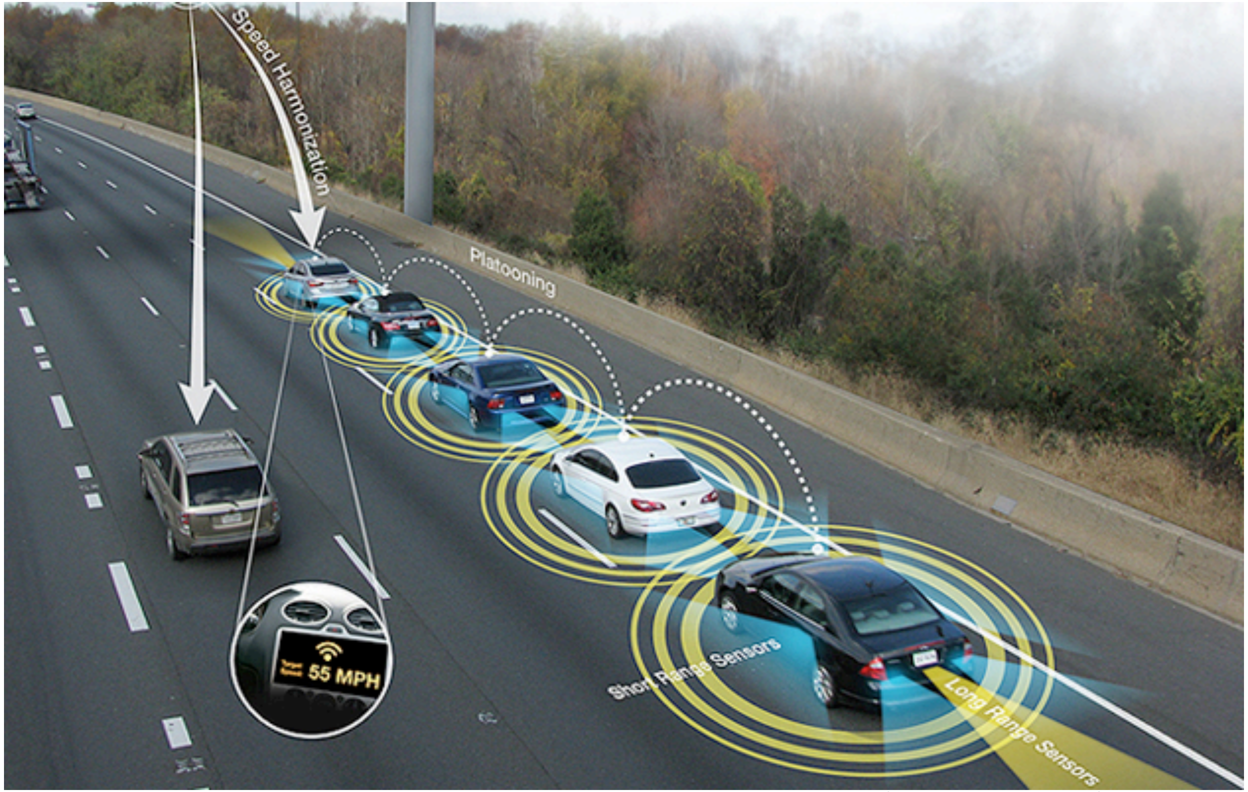
Road Traffic: Predictive Actions, Platooning…



Source: courtecy of the US Department of Transportation

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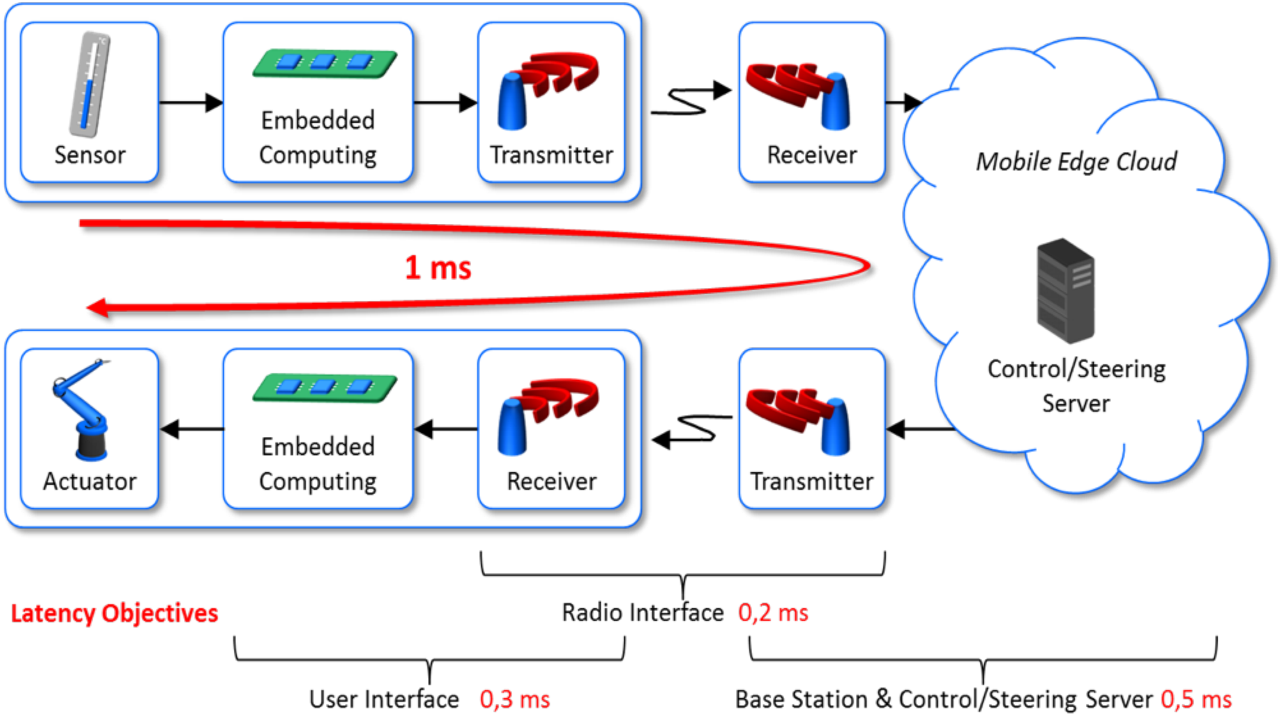
Serious Gaming

Source: www.rh.gatech.edu

URLLC – Ultra Reliable Low Latency Communication

Latency Budget Considerations for the Tactile Internet



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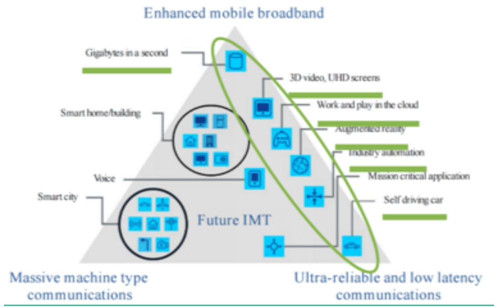
5G-MiEdge Project
Millimeter-wave Edge Cloud as an Enabler for 5G Ecosystem

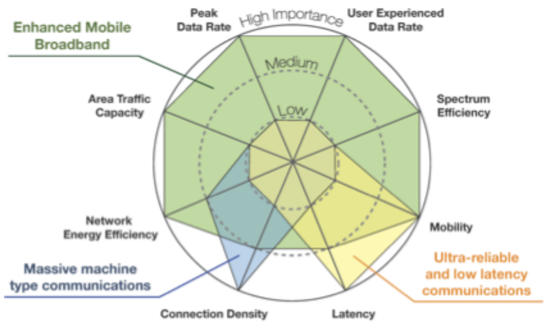
Key Capabilities of 5G (IMT2020) relevant for the Project

- 5G applications selected from ITU-R:
  - ✓ Enhanced MBB
  - ✓ Ultra-Reliable LLC
- Key capabilities
  - ✓ >10 Gbps peak user rate
  - ✓ >1000x system rate
  - ✓ <5 ms latency
- Background technological enablers
  - ✓ Millimeter-wave (mmWave) + HetNet for eMBB
  - ✓ Numerology + MEC for uRLLC
  - ✓ Multi-connectivity both for eMBB & uRLLC

3 Key application areas of 5G



8 Key Capabilities (KPIs) of 5G

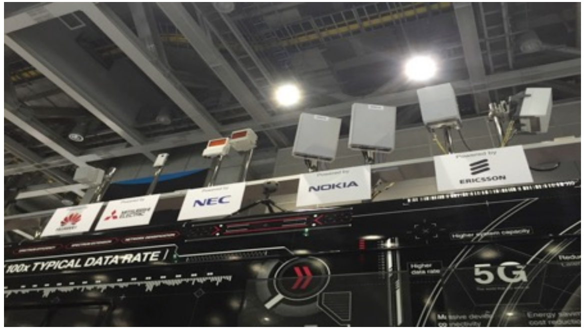


@ Recommendation of ITU-R M.2083-0, Sep. 2015

Trends of mmWave in 3GPP & IEEE

- Trends in 3GPP
  - ✓ Rel. 15 will finalize NR (phase 1) by June 2018
  - ✓ New NR bands to be included
    - 24.25 – 29.5 GHz
    - 31.8 – 33.4 GHz
    - 37 – 40 GHz
- Trends in IEEE
  - ✓ 802.11ad standardized in 2012
  - ✓ FCC expanded 60GHz unlicensed band up to 71GHz for 5G
  - ✓ Wi-Fi certified WiGig (11ad) from Oct. 2016
  - ✓ First commercial 11ad router in Japan from June 2017

5G antennas @ WTP'17

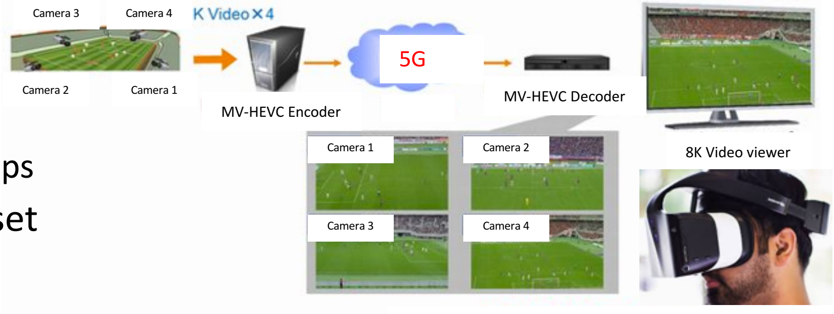


11ad supported Wi-Fi router

Requirements from 5G Applications (User Side View)

- VR/AR using multiple cameras
  - ✓ Expected big market in 5G
  - ✓ High data rate bet. cameras and media room
    - Uncompressed: 4x12 Gbps, compressed: 4x50 Mbps
  - ✓ High data rate bet. media room and mobile headset
  - ✓ End-to-end low latency < 5 ms

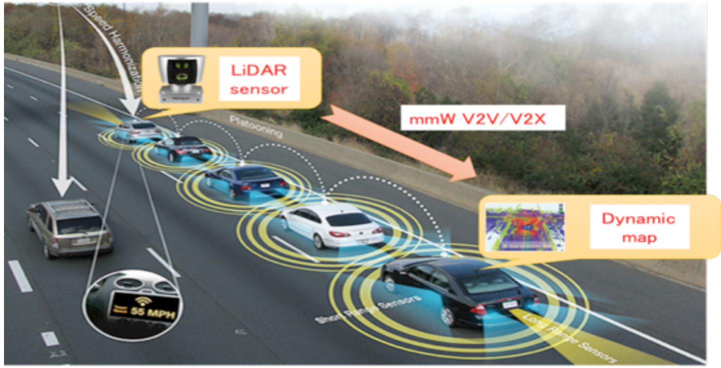
Augmented Reality using multiple cameras



Immersive virtual reality using multiple cameras

- Automated driving using extended sensors
  - ✓ Expected big market beyond 5G
  - ✓ Extended sensors for cooperative perception
  - ✓ High data rate between vehicles & RSUs
  - ✓ End-to-end low latency < 10 ms

Automated driving using extended sensors



High date rate & low latency are required at the same time

Problems of 5G Deployment (Operator Side View)

- CAPEX/OPEX
  - ✓ Cost of deploying a high number of mmWave small-cell BSs in dense areas
  - ✓ Cost of operating a high number of mmWave small-cell BSs (energy consumption)
  - ✓ Cabling cost of Ethernet cables with capacity >10 Gbps

- End-to-end latency
  - ✓ Non-ideal backhaul between 5G RAN and application provider
  - ✓ Slow data rate & long latency due to non-ideal backhaul

Dense urban scenario

Dense stadium scenario

5G MiEdge Project

5G-MiEdge: Millimeter-wave Edge Cloud as an Enabler for 5G Ecosystem

Objectives

- To combine mmWave access and Mobile Edge Cloud (MEC) to realize ultra high speed & low latency communications even with limited backhaul
- To develop a new cellular network control plane (liquid RAN C-plane) in order to enable a proactive resource allocation for the mmWave edge clouds
- To develop mechanism (new ecosystem) to realize user/application centric orchestration of deployed mmWave edge clouds (RAN virtualization)
- To contribute to the standardization of mmWave access and liquid RAN C-plane in both 3GPP and IEEE
- To demonstrate a joint test-bed of 5G-MiEdge project in the cities of Berlin and 2020 Tokyo Olympic game areas

Technology Contributions in 5G-MiEdge

Data rate
mmWave
Massive MIMO

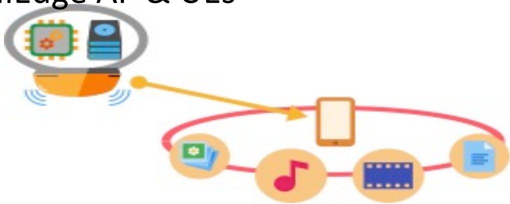
Multi-connectivity
HetNet
C/U splitting

E2E latency
MEC
Numerology

CAPEX/OPEX
Self backhauling
RAN virtualization

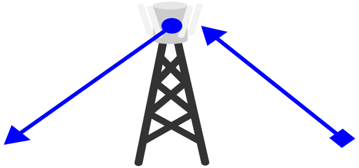
mmWave Edge Cloud

Prefetch/cache/run data/application of users and transfer them instantaneously bet. MiEdge AP & UEs



Liquid RAN C-plane

Collect context (location, action, etc.) information and provide traffic forecast to users and application providers



User/application centric orchestration

Network orchestration of MiEdge AP (SDN) by user or application provider

5G-MiEdge Use Cases

Omotenashi Service

- Download in-flight entertainment or VR city info
- >6 Gbps at waiting area

Moving hotspot

- Download entertainment and upload massive SNS
- >80Gbps in train and >2.6Gbps in bus

2020 Tokyo Olympic

- Immersive AR/VR, public video surveillance for security
- >500Gbps in stands and <5ms latency

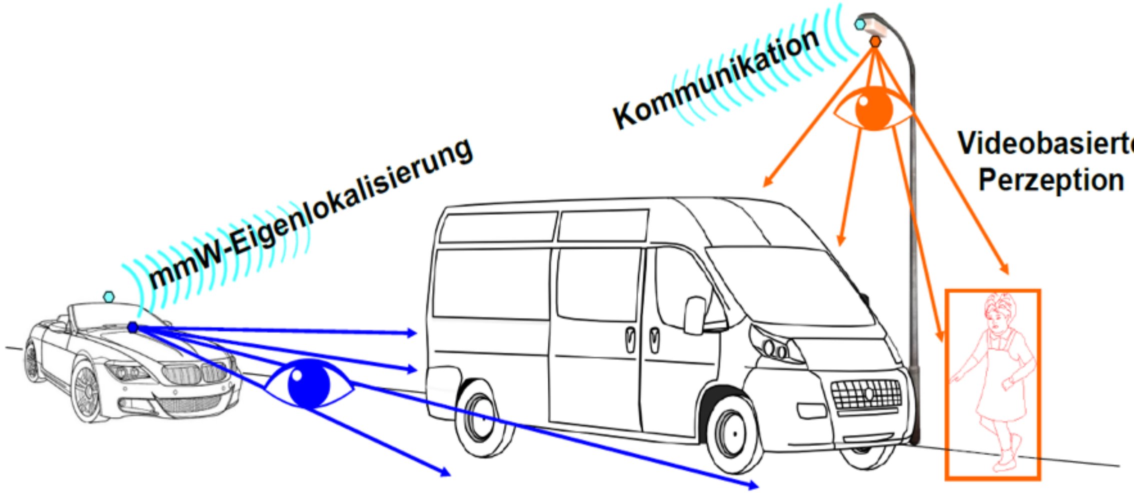
Outdoor dynamic crowd

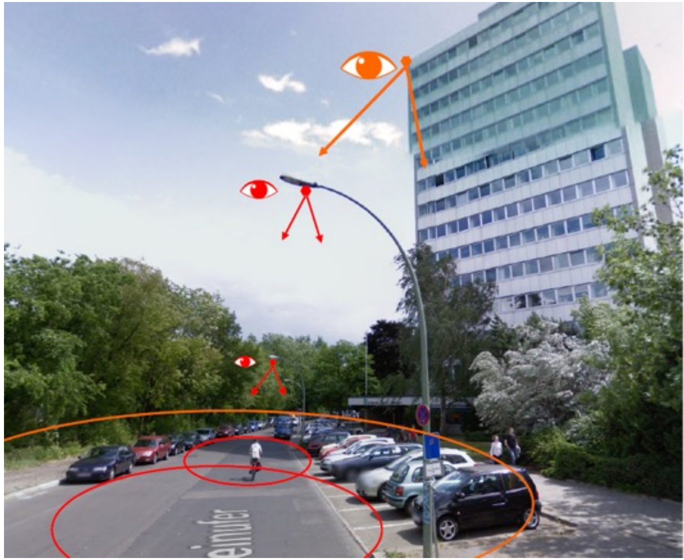
- Download VR city info and upload massive SNS
- 6Gbps in 1600m^2 -> 15Tbps in 4km^2

Automated driving

- Exchange sensor information for safety driving
- >1Gbps data rate and <10ms latency per link

Example: Street Perception with Extended Sensors





State of the Art in V2V Communication

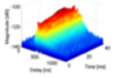
Human in the Loop – using Audio-Visual Communication

Conclusions from In-Situ Observation

Useful Features and observed limits of SOTA solution

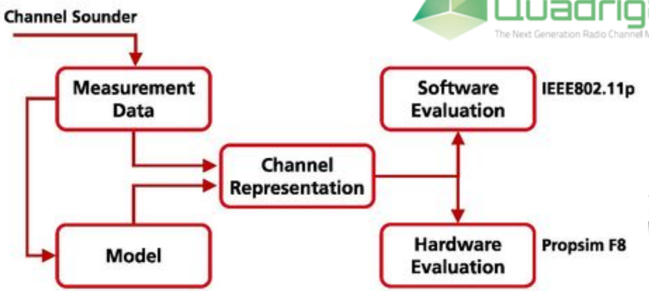
- **Embedded Mechanisms and Features**
  - Multi-Sensor based V2V - communication system design
  - Required shared spectrum, MAC protocol design and MCS levels
  - Packet prioritization mechanism
  - Packet Recovery
- **Limits**
  - prone to loss of individual connections
  - human in the loop
  - limited fairness (big vs small, fast vs slow)
  - damage and losses are far to high to be accepted by society in long term

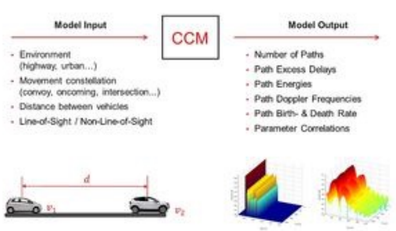
Radio Channels for V2X System Design



Time-variant Channel Impulse Response

Quadriga
The Next Generation Radio Channel Model





CAR 2 CAR COMMUNICATION CONSORTIUM

3GPP A GLOBAL INITIATIVE

cost

GreenTouch

recommendations to fora & standards

Virtual Field Trials on measured channels

Interoperability Testing e.g. of 802.11p

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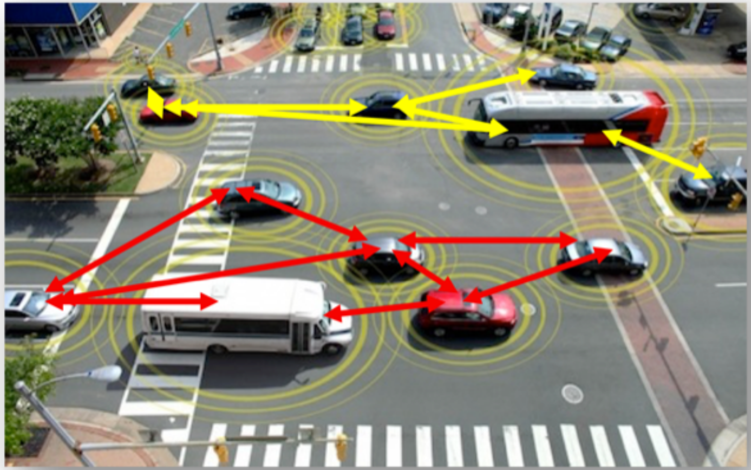
V2C supporting meshed D2D (1)

- New Network Topologies
  - Mix of Adhoc, Meshed, D2D,
  - Infrastructure assisted direct communication

➢ Moving Meshed Networks



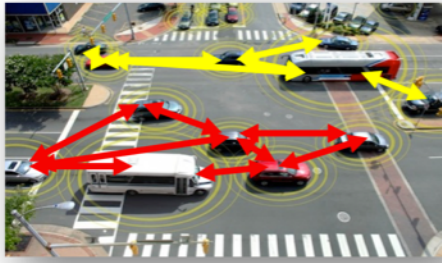
- Diverse information flow (w/ & w/o infrastructure support)
  - Broadcast,
  - Multicast,
  - BI-Unicast

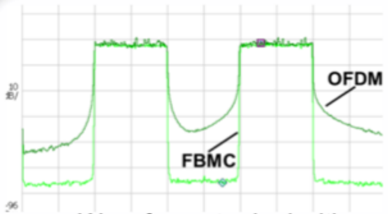
V2C supporting meshed D2D (2)

Need for beyond SotA technologies:

PHY (waveforms):
- Multi Access Interference for user plane
- Near-far power dynamics
- Self detection of interference range
- Multi-antenna support for multiplexing and interference mitigation
- Robust RACCH

MAC (Cognitive Spectrum Mgmt):
- Dynamic cluster reconfiguration
- Multi-cluster spectrum coordination (w/ & w/o coordinator)
- In-cluster RRM (robust and spectrum efficient)
- Adhoc Network autonomy if no infrastructure available
- Scalable c-plane / u-plane splitting





Waveforms to deal with Multi Access Interference

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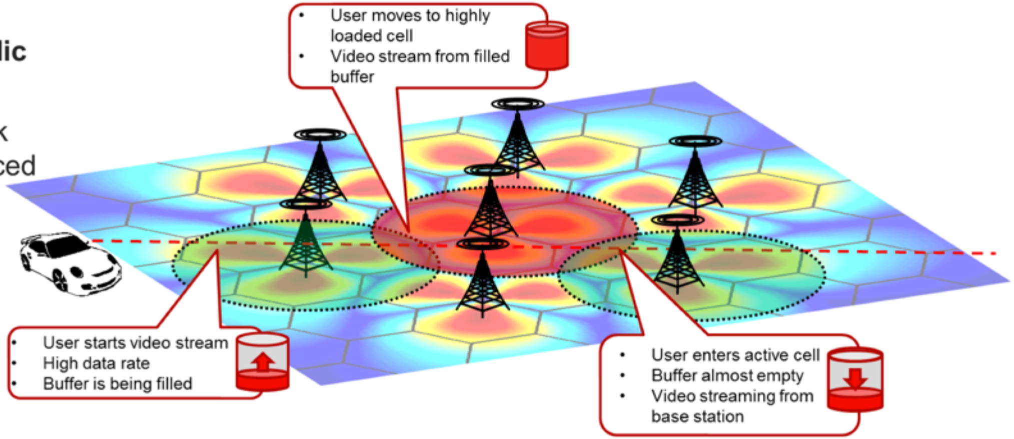
Optimized C2X Networking

- **Predictive analytics and knowledge management for mobility support of vehicles in cellular networks**
  - Building a knowledge base for context-aware seamless mobility support
  - Reconstruction of radio maps and cell load prediction
- **Anticipatory networking based on predictive analytics and knowledge management**
  - Anticipatory buffering to assure smooth media streaming (illustrated in the figure)
  - Anticipatory handover to avoid handover failures
  - Anticipatory traffic offloading to reduce cellular traffic load
- **Cellular networks with D2D communications and nomadic relays**
  - Interference-aware network topology control for enhanced network performance
  - Resource allocation and interference management



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5GAA

Paving the way to use 5G for the Automotive Industry

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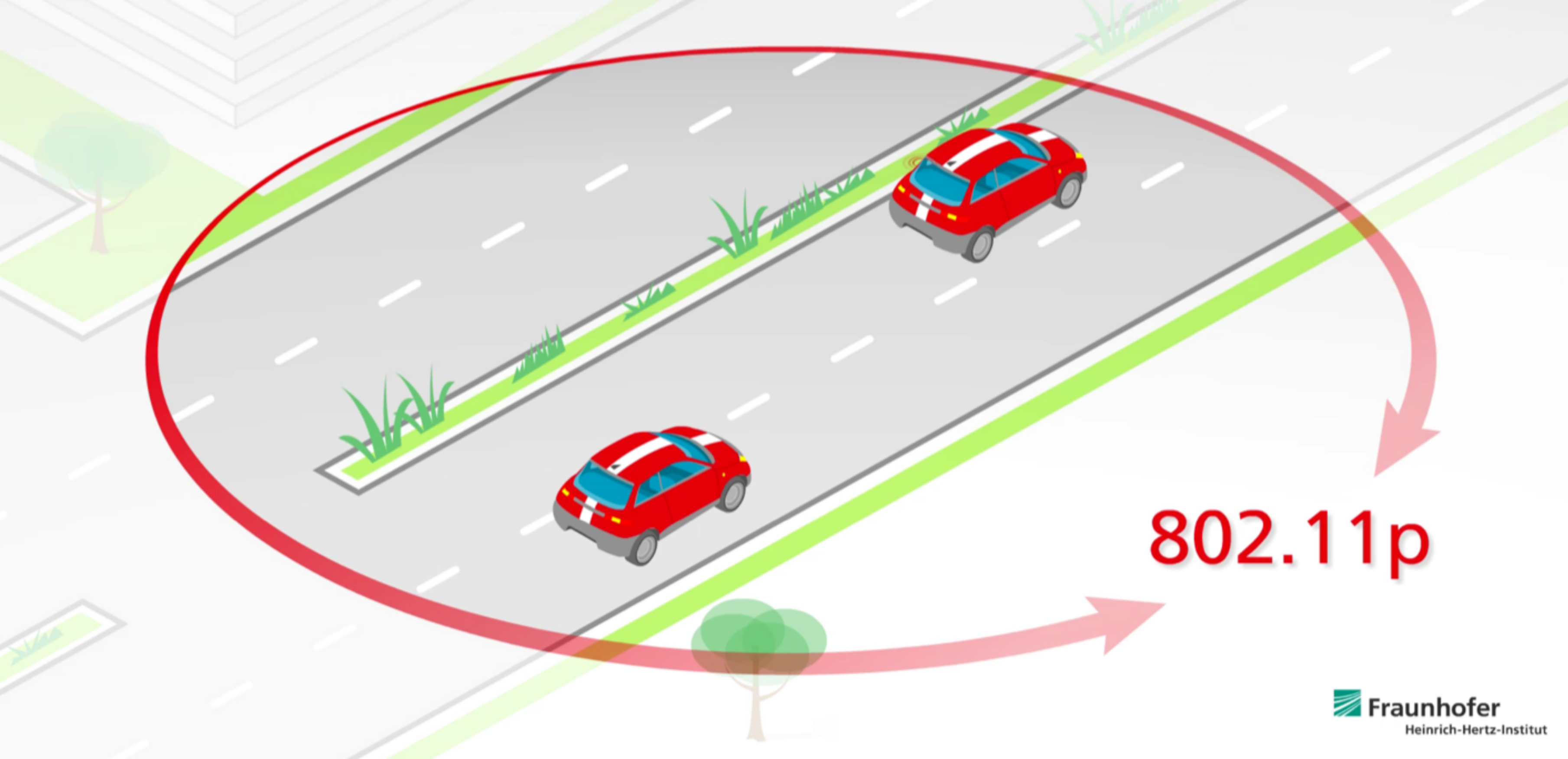
State of the Art in V2V Communication

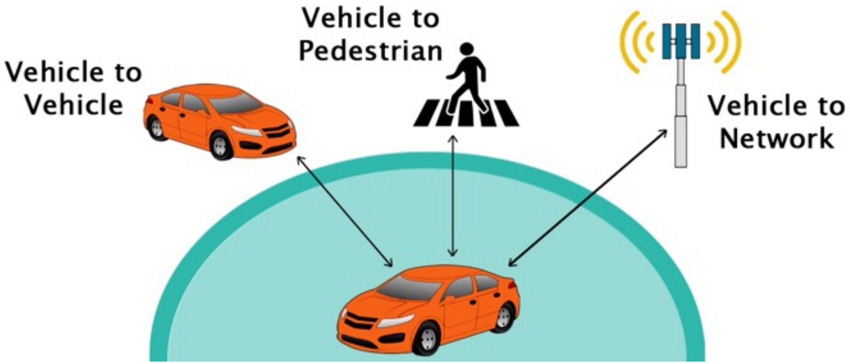
Environment Perception supported by IEEE 802.11p Wireless Technology



Recent Updates of 3GPP’s Cellular Approach

Introduction

- Cellular V2V specified in 3GPP LTE Rel. 14, advancements in LTE Rel. 15
- Based on the D2D communications specified in LTE Rel. 12 and 13
- V2X consists of 3 broad aspects
  - Vehicle to Vehicle (V2V)
  - Vehicle to Pedestrian (V2P)
  - Vehicle to Network/Infrastructure (V2I)
- Detailed working of V2X can be seen in
  - A New 5G Technology for Short-Range Vehicle-to-Everything Communications, R. Molina-Masegosa and J. Gozalvez



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V2X Overview
Modes of Operation

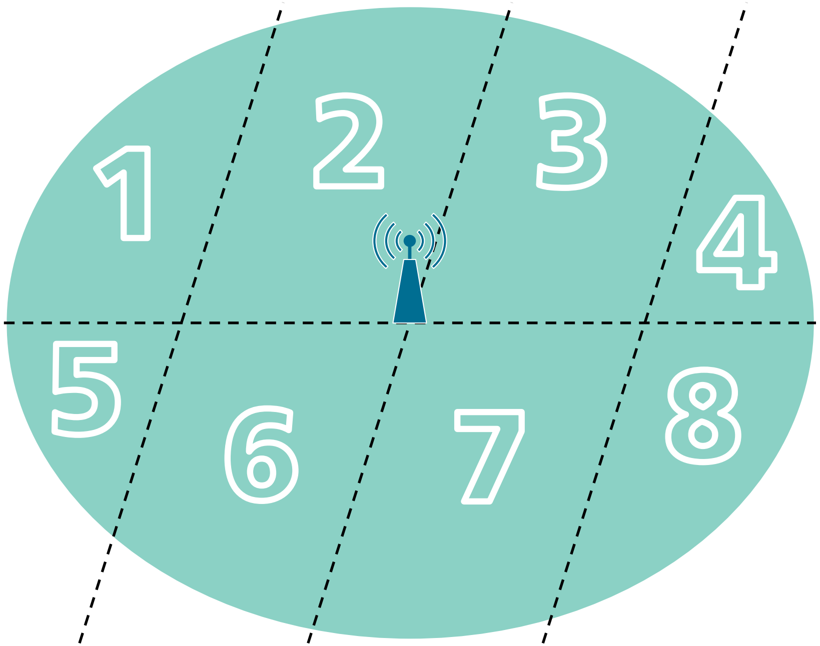
- Data transmitted directly between vehicles via Sidelink (SL) communications
- Mode 3 – Scheduled Resource Allocation
  - Centralized resource allocation by the eNB
  - Works only when UE is in coverage and in RRC_CONNECTED Mode
  - Receives control information from the eNB for resource allocation
- Mode 4 – Autonomous Resource Allocation (covers 802.11p scenarios, but with dedicated radio resources)
  - Distributed resource allocation by the UE
  - Works when both in and out of coverage (either RRC_CONNECTED or IDLE mode)
  - Carries out sensing of previous resources to determine resources for allocation

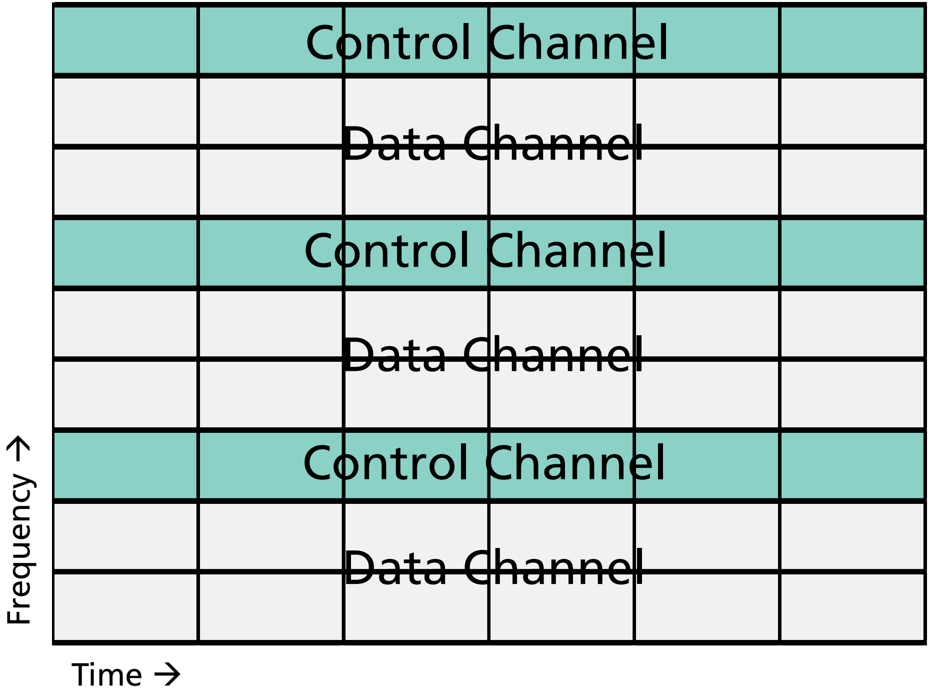
V2X Overview

Modes of Operation

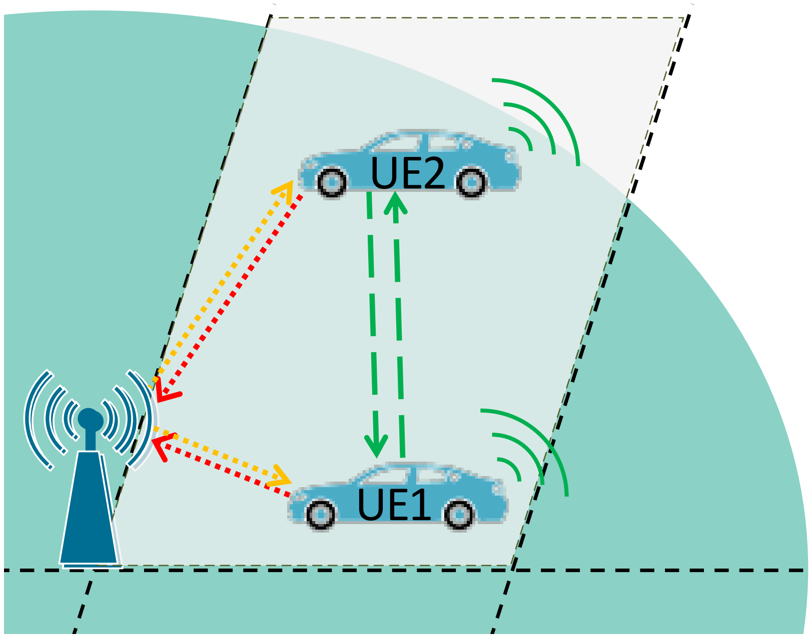
- PHY Sidelink Channels
  - PSDCH – Physical Sidelink Discovery Channel
  - PSCCH – Physical Sidelink Control Channel
  - PSSCH – Physical Sidelink Shared Channel
- Transmission Types
  - Semi Persistent Scheduled (SPS) Transmissions
    - Transmitter schedules data transmission in regular intervals over a duration
  - One Shot (OS) Transmissions
    - Single transmission event

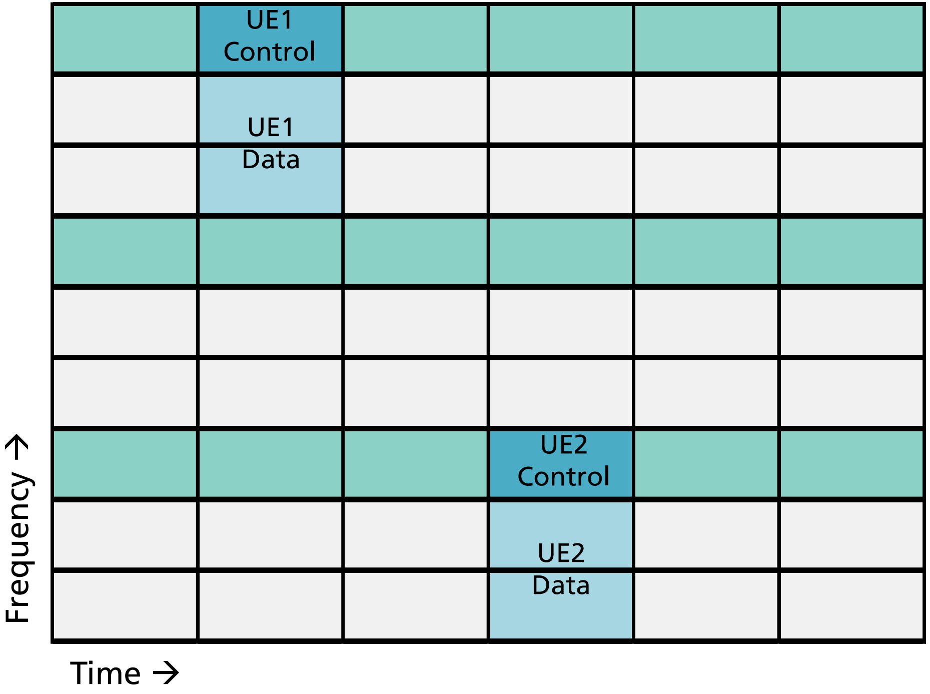
V2X Overview
Resource Pools





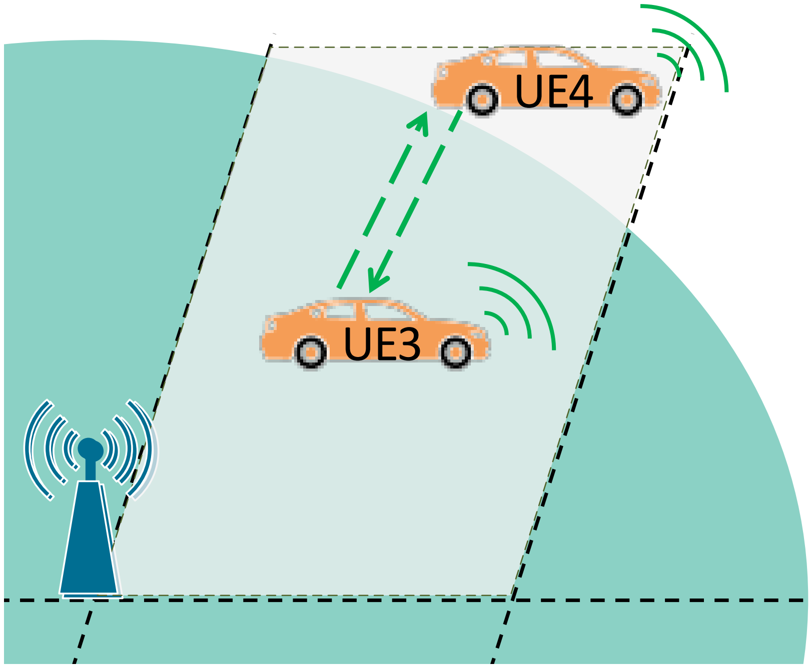
V2X Overview
Allocation of Resources

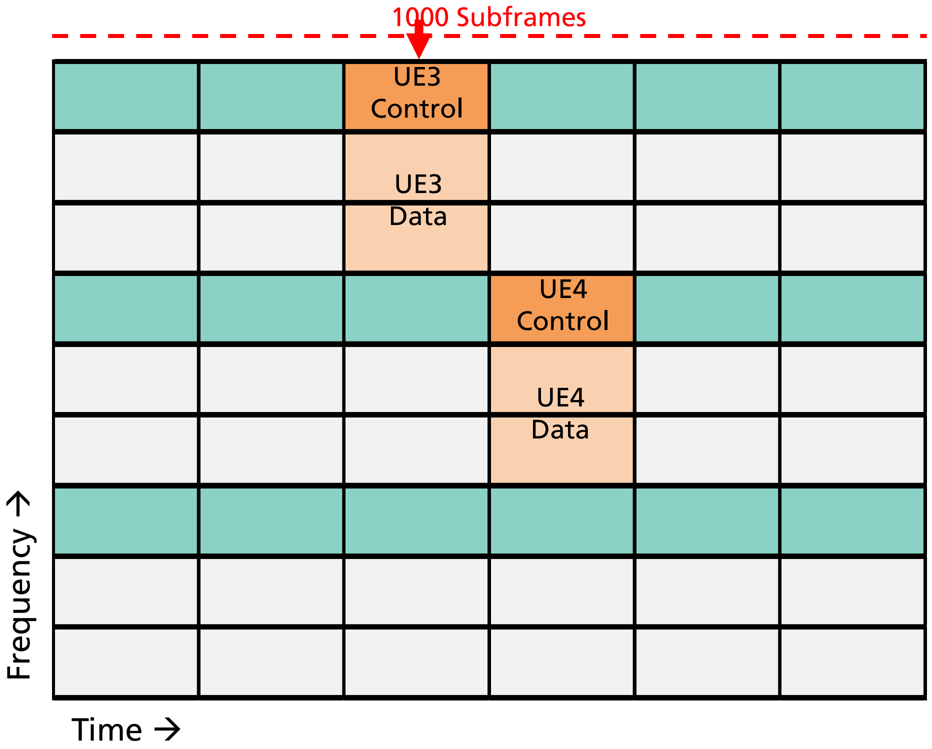




V2X Overview

Allocation of Resources





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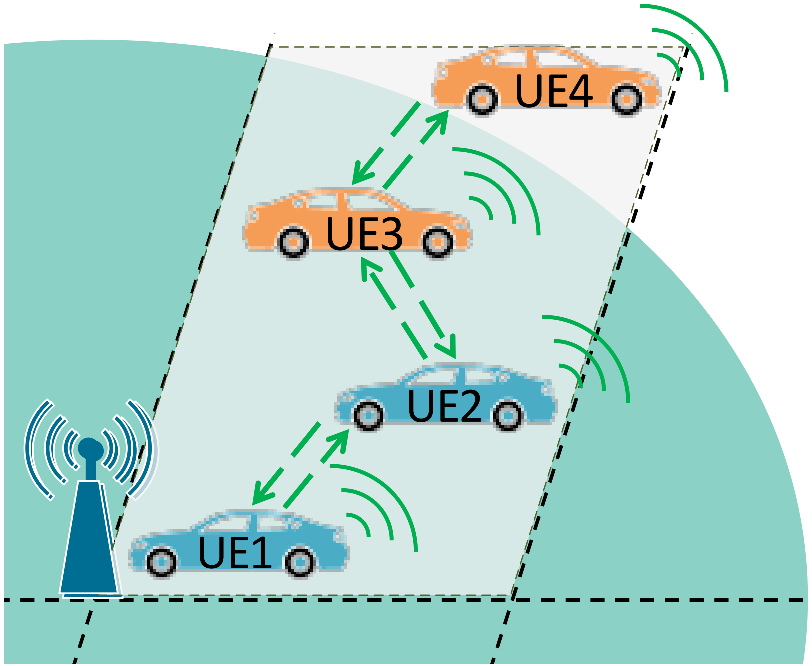
Problem Statement

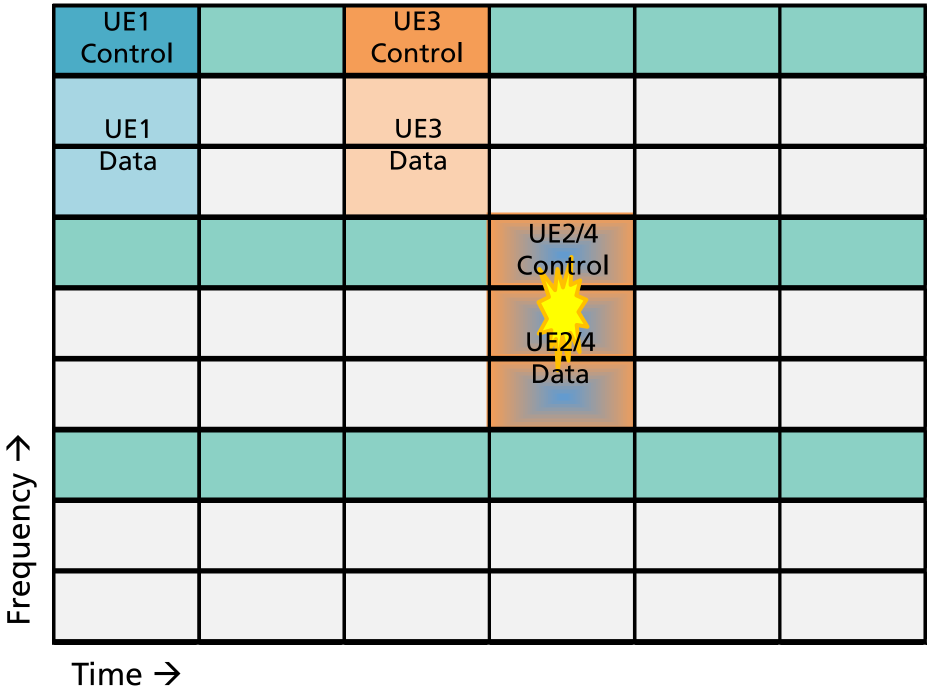
Collisions in Shared Transmit Resource Pool

- Independent resource pools for mode 3 and mode 4 is not very spectrally efficient
- Using a shared transmit resource pool for both mode 3 and mode 4 poses a few problems
  - Mode 4 UEs scan the previous subframes and can detect as to whether UEs are using a given resource
  - eNB is not aware of the resources used by mode 4 UEs
    - Mode 3 UEs do not use sensing, instead relies entirely on the information given by the eNB
    - eNB allocates resources to mode 3 UEs which are already in use by mode 4 UEs
  - Causes collisions between mode 3 and mode 4 UEs
- Details can be seen in TDoc R1-1720112 by Fraunhofer

Problem Statement

Collisions in Shared Transmit Resource Pool

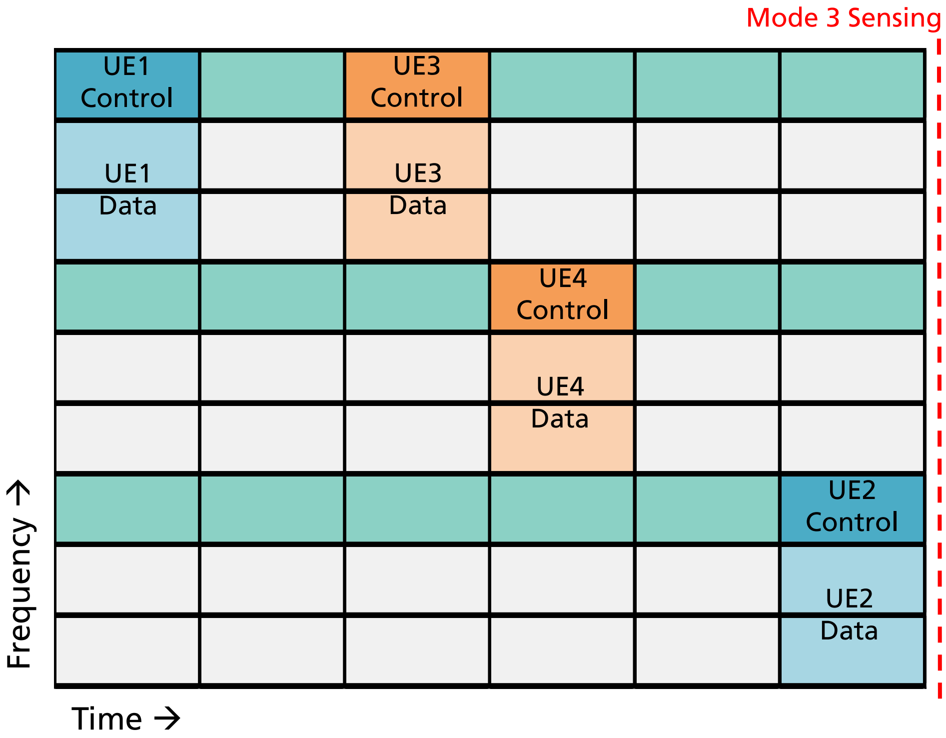




Solution

Reporting by Mode 3 UEs

- Mode 3 UEs also carry out scanning and sensing of previous resources in transmit resource pool
- Sends this occupancy report to the eNB
  - eNB avoids resources with higher probability of collisions with mode 4 UE allocations
  - Allocates these resources for mode 3 UEs



Conclusions

Summary and Possible Future Works

- eMBB+uRLLC require joint optimization of Air-Interface & MEC capabilities
- many new use cases promise value to society and are enablers for vertical industries
  - robotics
  - live events
  - manufacturing (Industry 4.0)
  - Vehicular Communication using extended sensors
- V2X SOTA Technology Approaches
  - IEEE
  - 3GPP

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