Wireless Communications of the Future

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Autonomous Moving Systems: A new Challenge

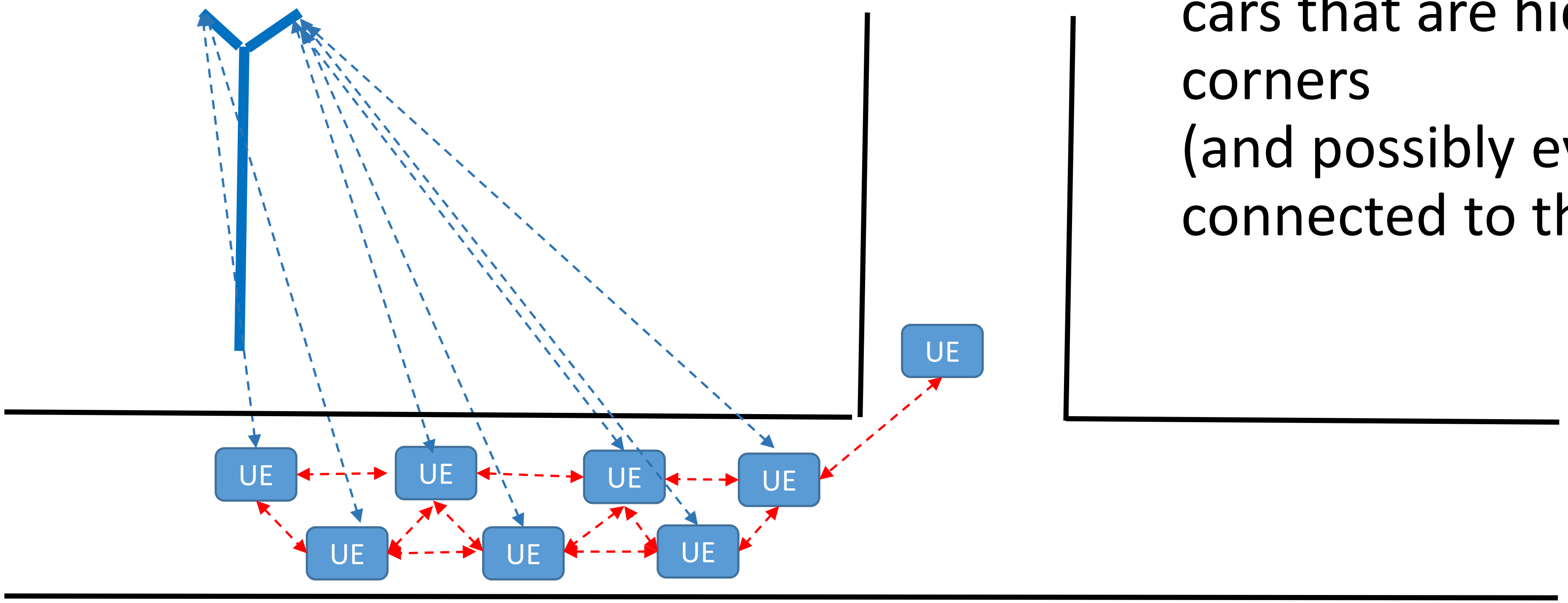
- Main Fields of Operation

  - Industry 4.0: autonomous robots find their way through an industrial environment to finish their tasks

  - Autonomous Driving: vehicles become more and more autonomous in arbitrary traffic conditions → **very challenging** as many lives are at risk

  - Both applications have in common that they require a continuous communication with neighbours as well as a coordinating station → **large (limited) bandwidth with harsh constraints on low latency**

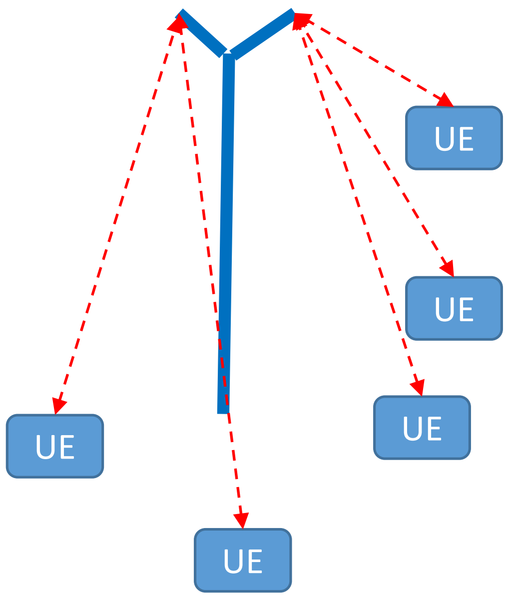
Potential Solution: NOMA Techniques



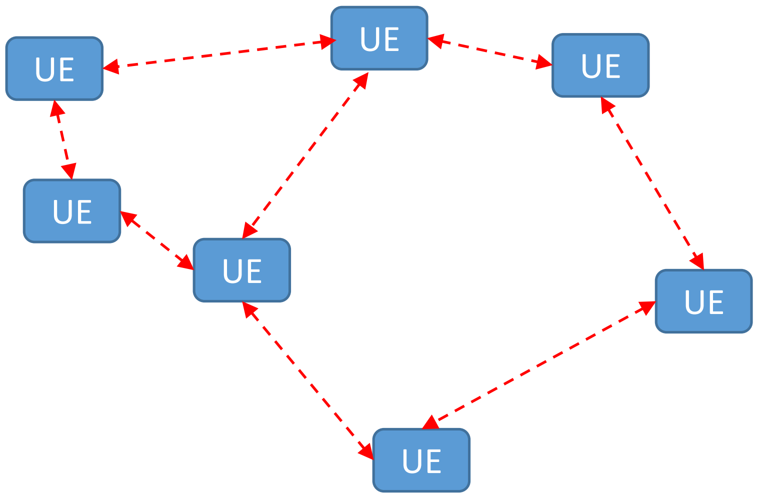
- In cities they may detect cars that are hidden by corners
  (and possibly even not connected to the BS)

Classic networks are

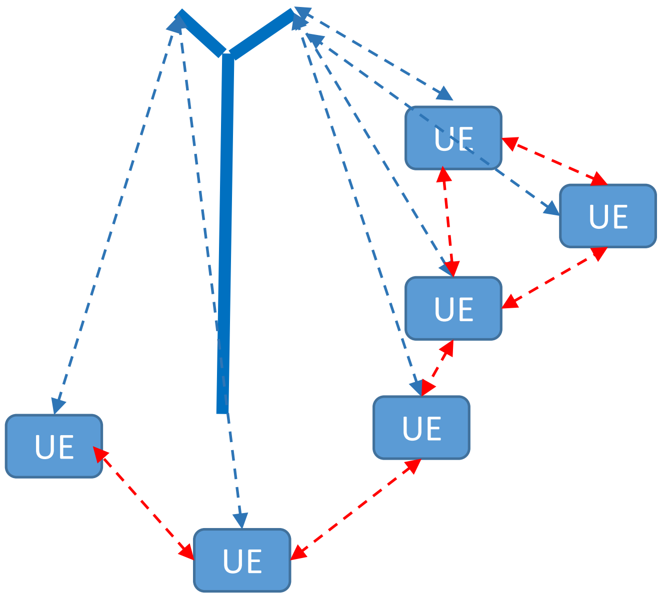
- either centralized



- or adhoc

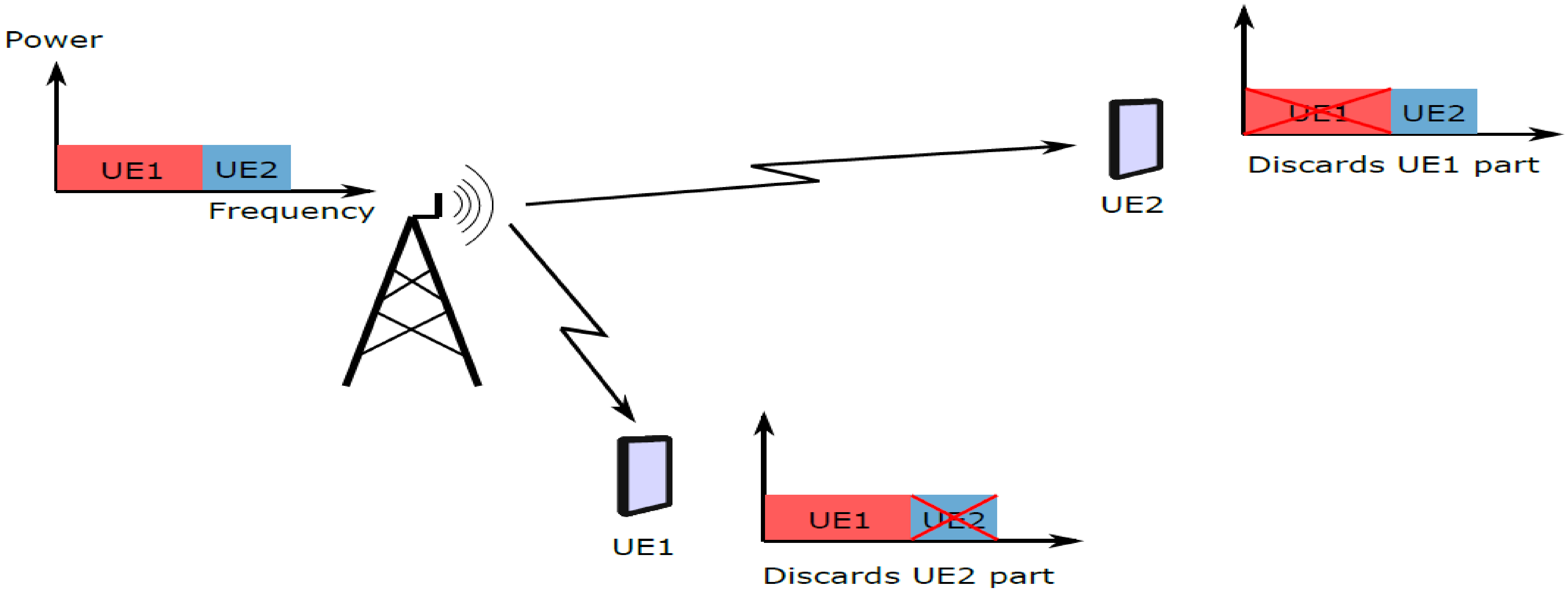


→ hybrid



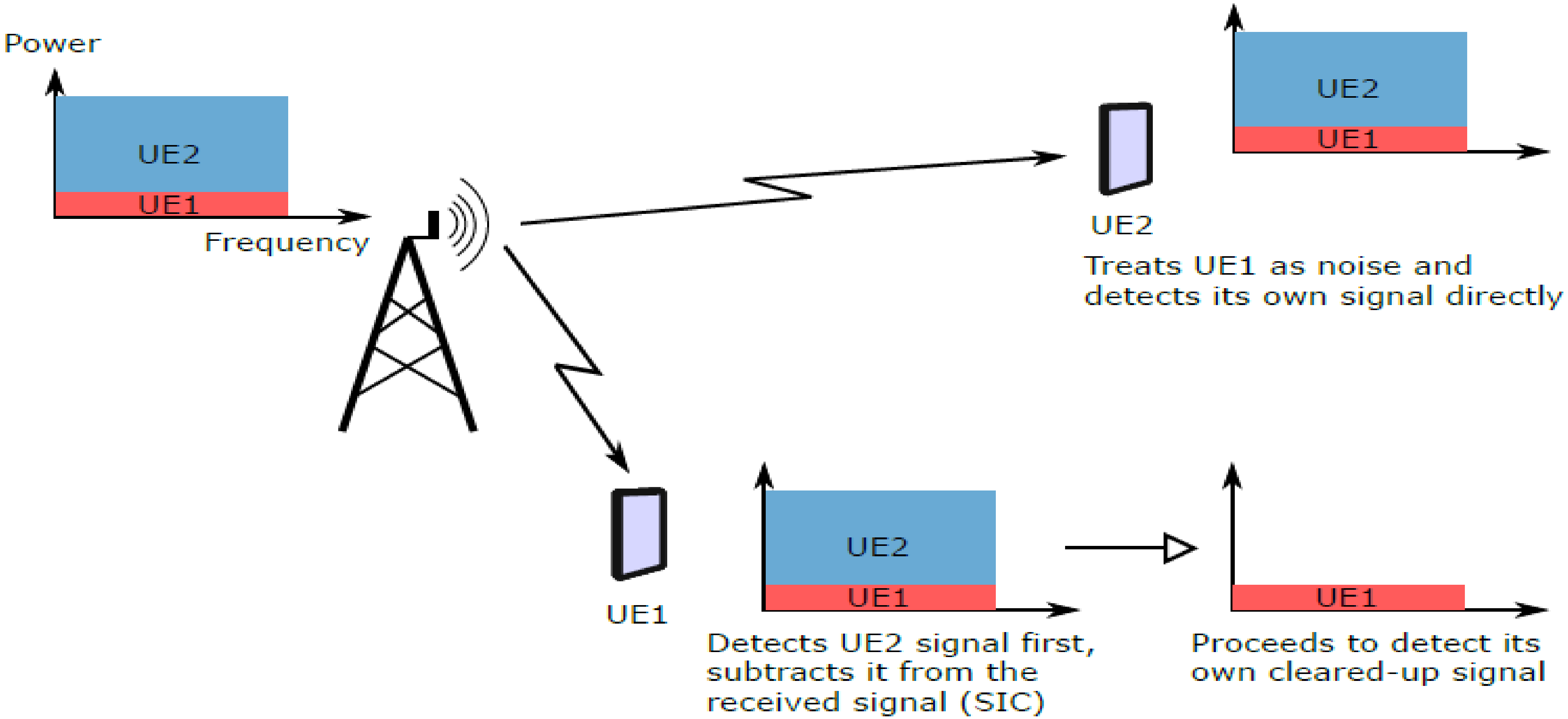
Classic OMA System:

- Consider the following OMA system.
- The resources are divided between the two UEs.



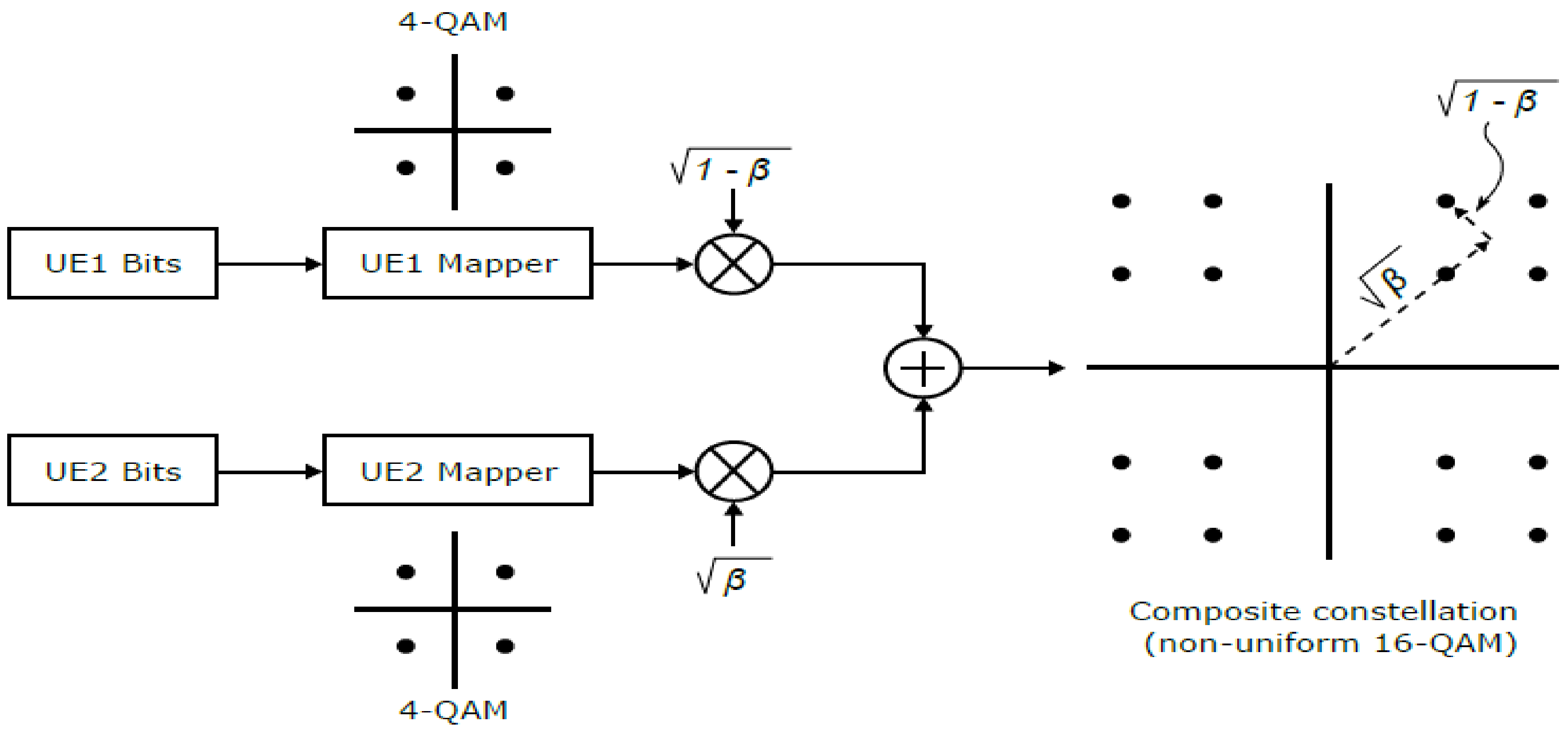
New NOMA System:

- Now consider the Power NOMA case.



How does it work?

- The transmission is basically a superposition.



MultiUser Superposition Transmission (MUST) Specification # 36.859 - 3GPP, Rel. 13&14

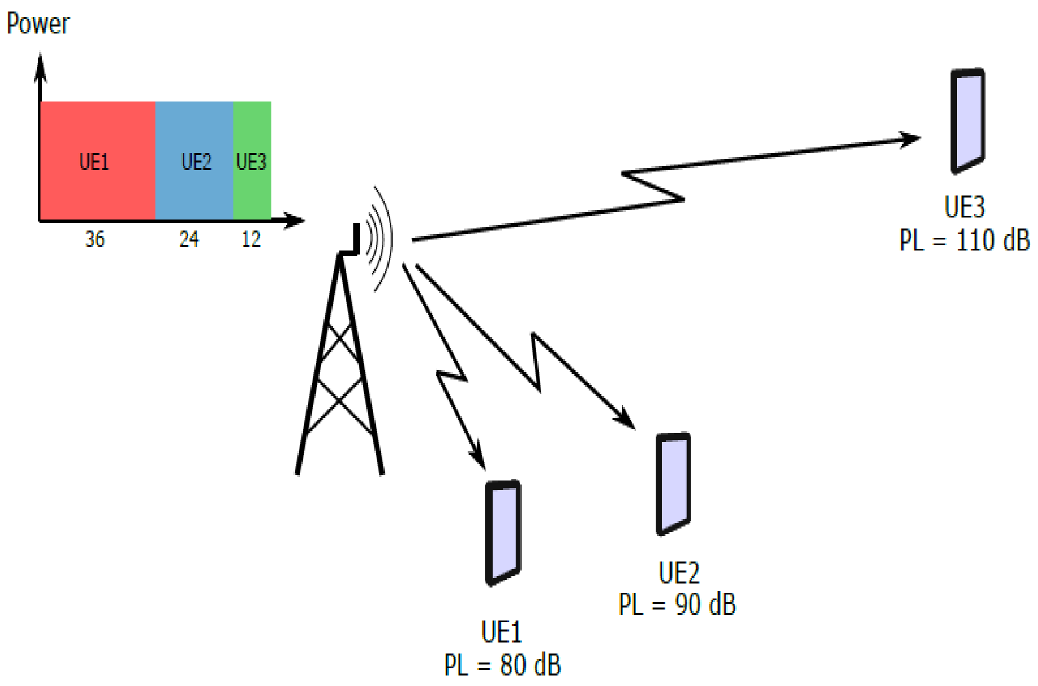
- Three power ratios are defined for each combination of the QAM mappings of NearUE and FarUE.

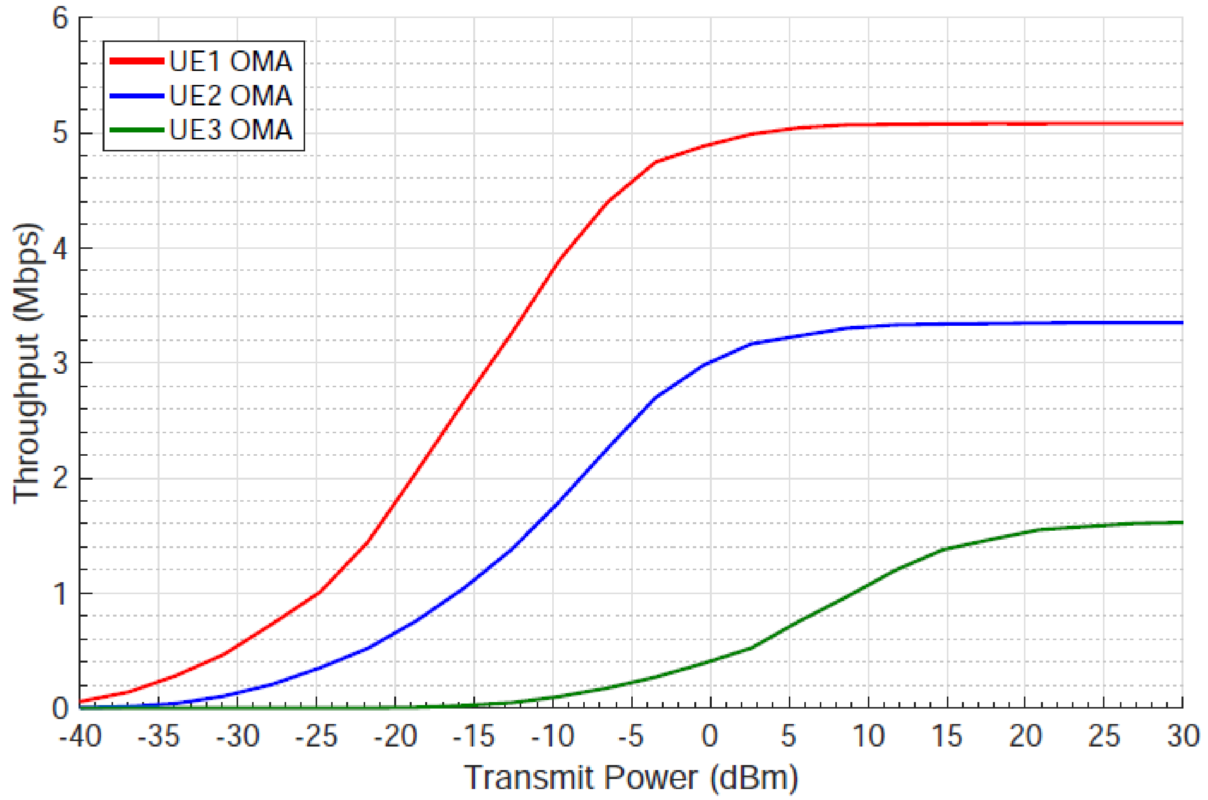
MUSTIdx	Value
00	No MUST
01	MUST, power ratio 1
10	MUST, power ratio 2
11	MUST, power ratio 3

- The scheduler controls the power allocation using those three power ratios.

NOMA Example

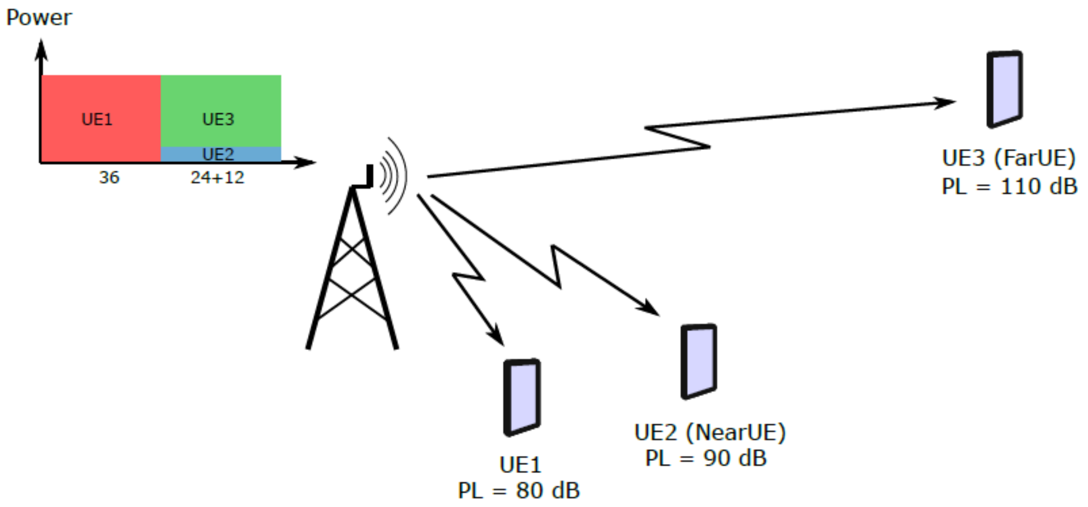
- Consider the OMA system

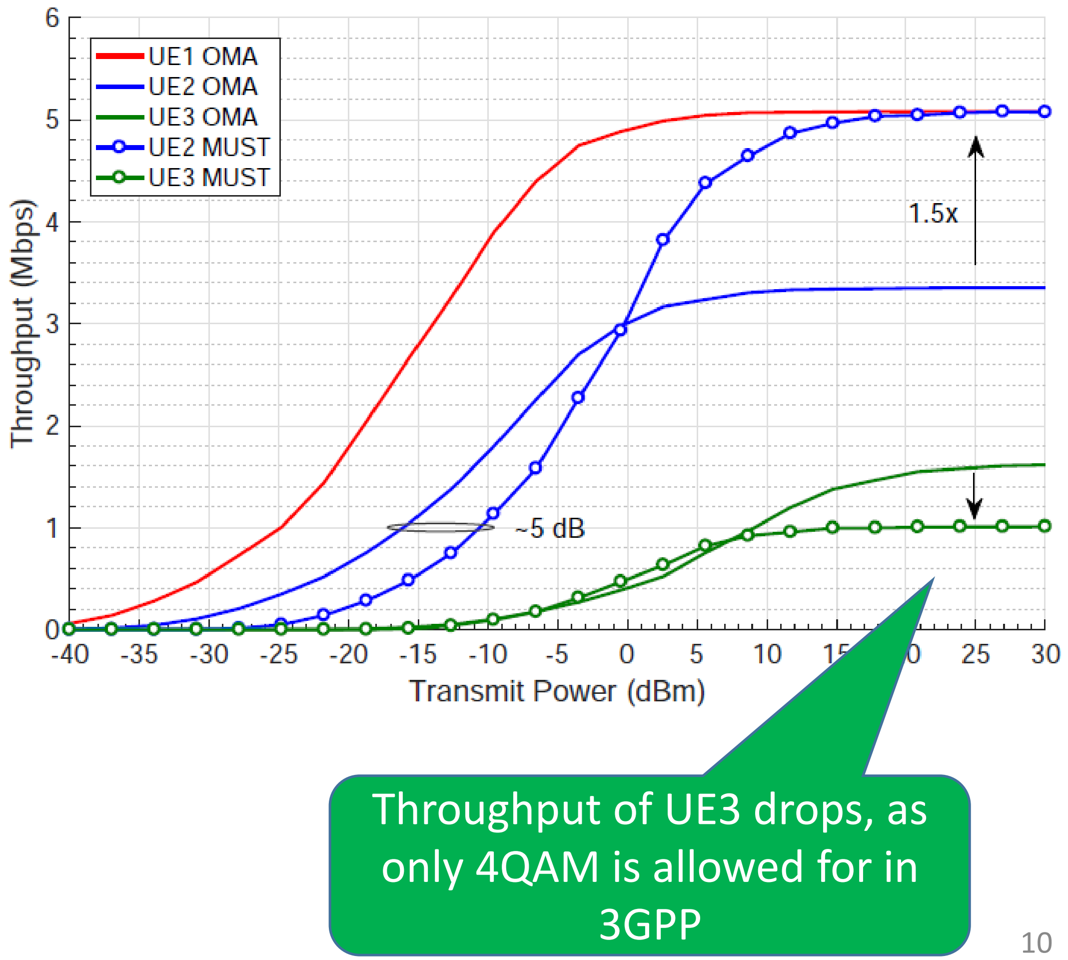




NOMA Example

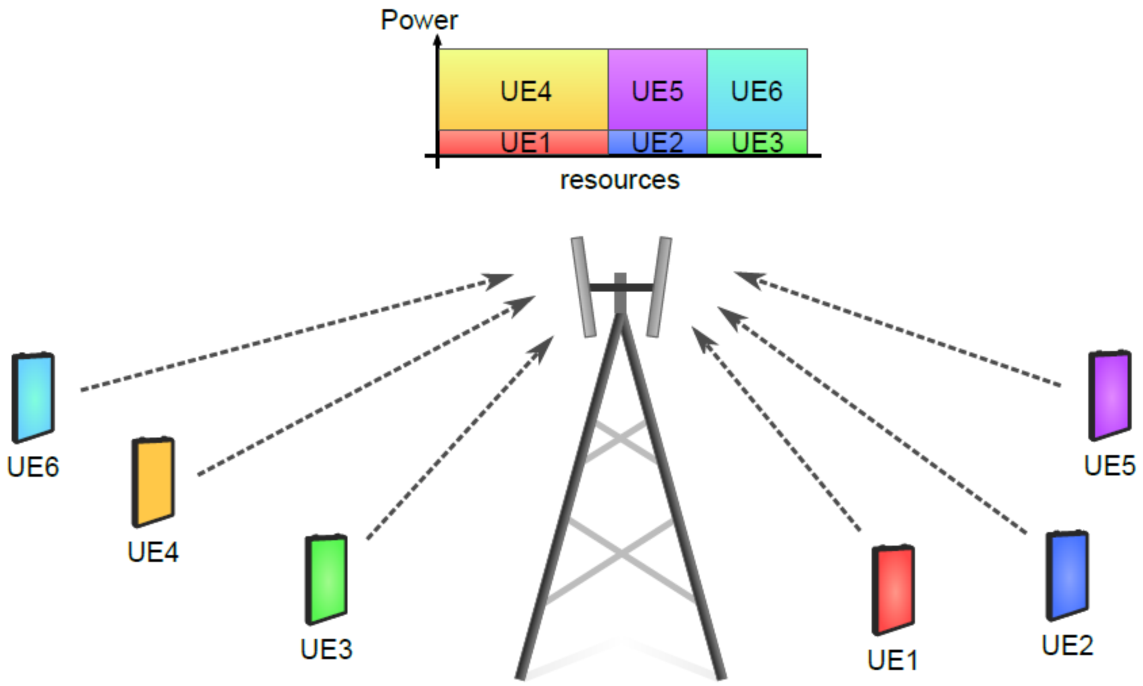
- Now consider the MUST system





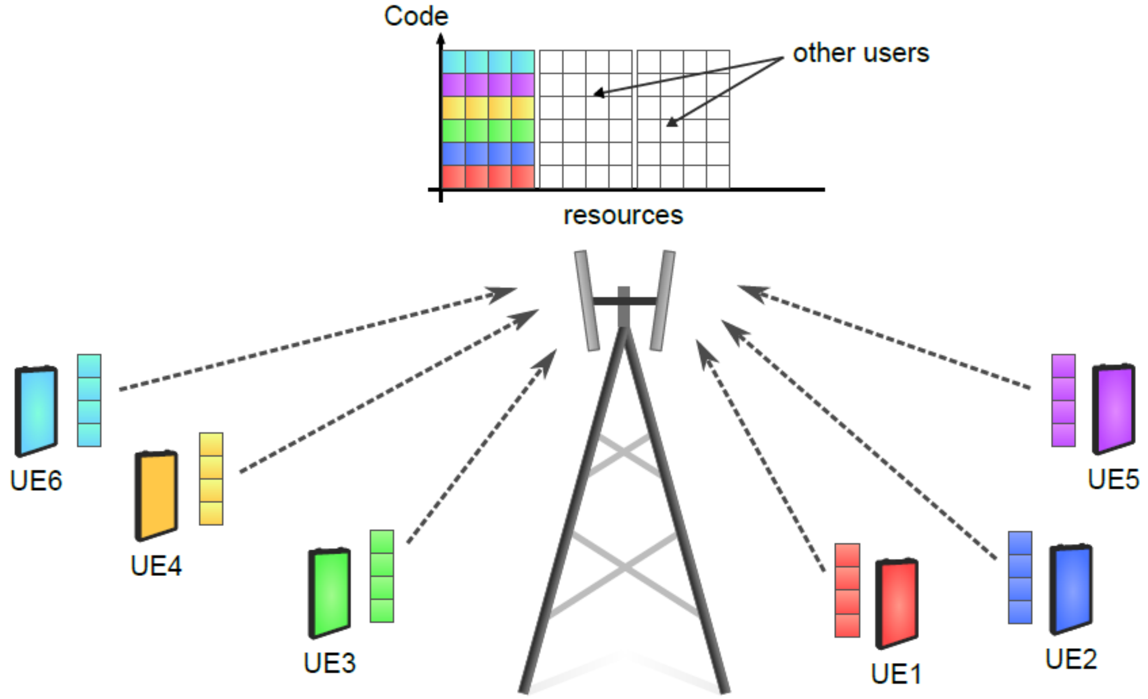
Let us consider a larger number of users
First classic OMA Uplink

- Superimposes users in the power-domain.
- User separability by successive interference cancellation.



Interesting Alternative is Code NOMA Grant free access with low latency

- Users with non-orthogonal signatures (bit or symbol-domain).
- High overloading capability and support for grant-free access.



Requires Code Book Design

- Non-sparse symbol-domain spreading offer
  - Low detection complexity with MMSE-SIC.
  - High overloading capability.
  - Support for grant-free access.
- For these schemes, the correlation between the spreading signatures plays a crucial role.
- The goal is to use a codebook with the lowest possible cross-correlation between its signatures.

$$X \in \mathbb{C}^{N \times M} = \left[\underline{x}_1 \quad \underline{x}_2 \quad \cdots \quad \underline{x}_M\right] ,$$

such that

$$X = \underset{X}{\operatorname{argmin}} \max_{\substack{i,j \\ i \neq j}} \left| \langle \underline{x}_i, \underline{x}_j \rangle \right| .$$

▷ We developed an algorithm for finding such codebooks.

- ▷ Starts with a random drop of points on a unit-norm hypersphere.
- ▷ On each point, magnitude of inner product hyperspheres are formed.
- ▷ The radius of those spheres increases slowly.
- ▷ Upon collision, the spheres repeal each other.

System Model

- The focus will be on the code-domain, since it offers low-complexity detection.
- Assumptions:
  - The uplink consists of K users.
  - Each user has a power constraint P_k.
  - Each symbol x_k is spread with a signature $\mathbf{s}_k$ of length L.
  - The spread signature is received by N_R antennas at the base station.
- Define $\mathbf{H}, \mathbf{S}, \mathbf{P}$ as follows

$$\mathbf{H} = \left[\mathbf{h}_1, \mathbf{h}_2, \ldots, \mathbf{h}_K\right], \ \mathbf{S} = \left[\mathbf{s}_1, \mathbf{s}_2, \ldots, \mathbf{s}_K\right], \ \mathbf{P} = \begin{bmatrix} P_1 & 0 & \ldots & 0 \\ 0 & P_2 & \ldots & 0 \\ \vdots & \vdots & \ddots & 0 \\ 0 & 0 & \ldots & P_K \end{bmatrix}.$$

- The received signal can be written as

$$\begin{aligned} \mathbf{y} &= (\mathbf{H} * \mathbf{S})\mathbf{P}^{1/2}\mathbf{x} + \mathbf{n} \\ &= \mathbf{G}\mathbf{P}^{1/2}\mathbf{x} + \mathbf{n}. \end{aligned}$$

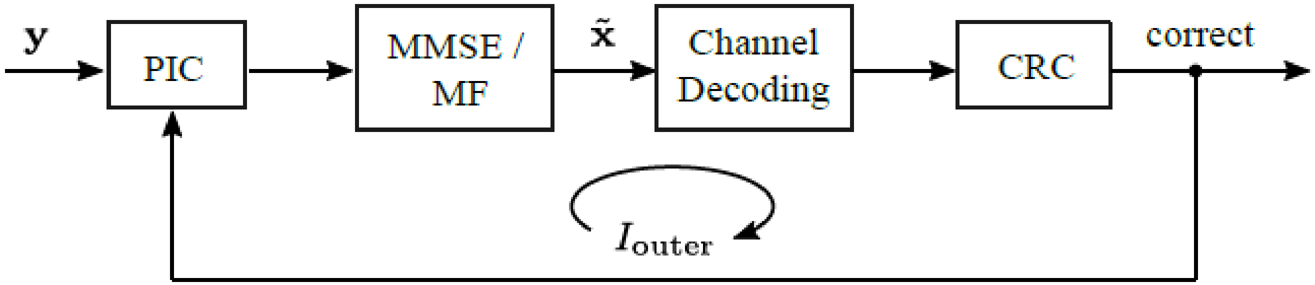
where $*$ denotes the Khatri-Rao product.

Detection

- The stacked received signal is given by

$$\mathbf{y} = \mathbf{B}\mathbf{x} + \mathbf{n}\,.$$

- Linear detectors
  - Matched Filter (MF).
  - Minimum Mean Squared Error (MMSE).
- Iterative (turbo) detectors
  - We consider hard parallel interference cancellation (PIC).
  - It has both low latency and complexity; requires few outer iterations I_{outer}.



Detection Performance

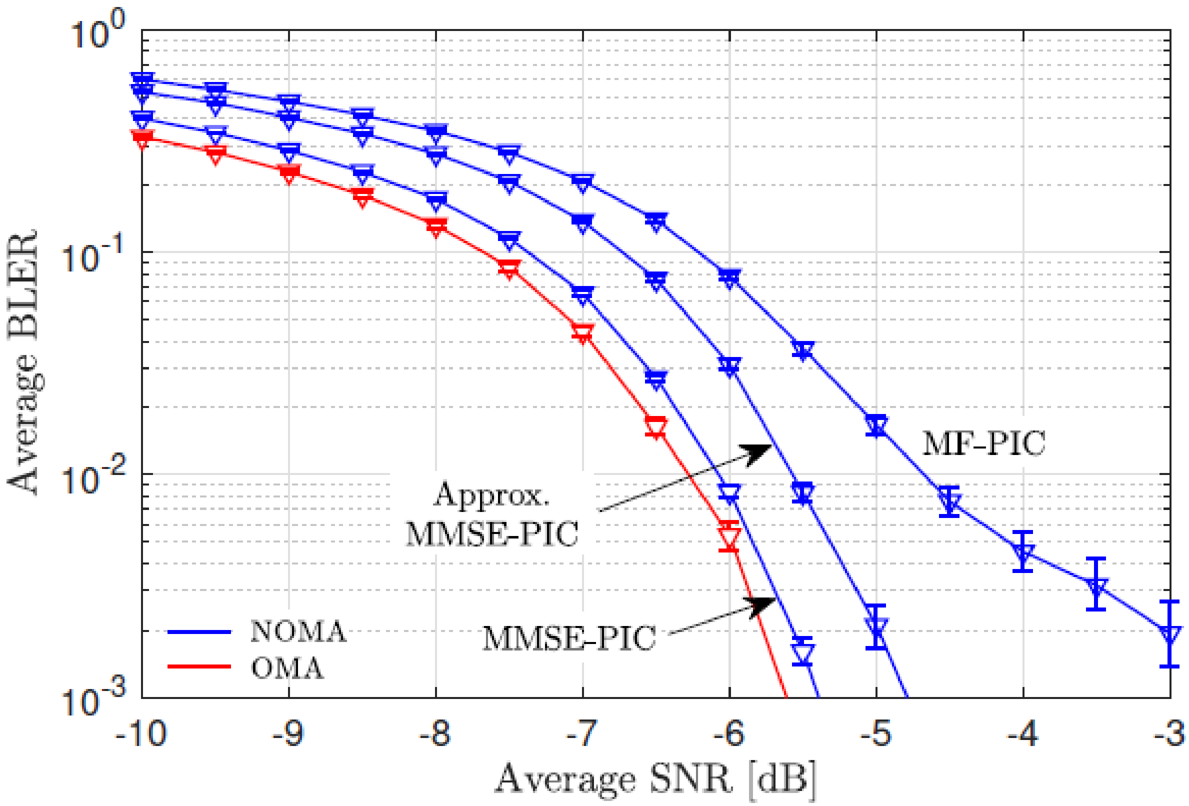
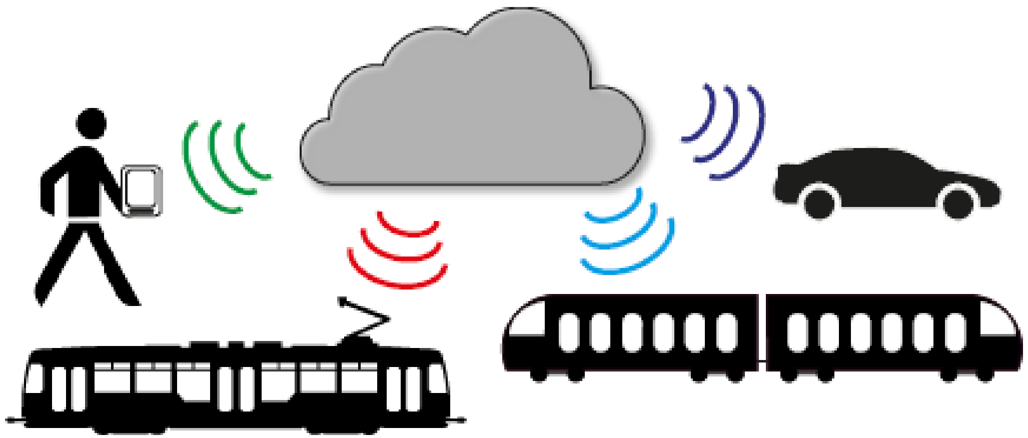


Figure: $N_R = 4, \sigma_e^2 = 10^{-2}$, w/ collisions, $I_{\text{outer}} = 6$.



ÖBB INFRA

Module 1:
PHY Enhancements
NOKIA

Module 2:
Innovative Technologies
A1

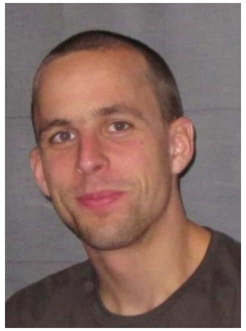
Module 3:
Network Architectures
KATHREIN

5G Research at the Institute of Telecommunications at TU Wien is pooled within the

Christian Doppler Laboratory for Dependable Wireless Connectivity for the Society in Motion

- Dependability: reliable and timely exchange of data packets even at high mobility
- Society in motion: focus on densely populated urban areas

Thanks to the CD-Lab Research Team



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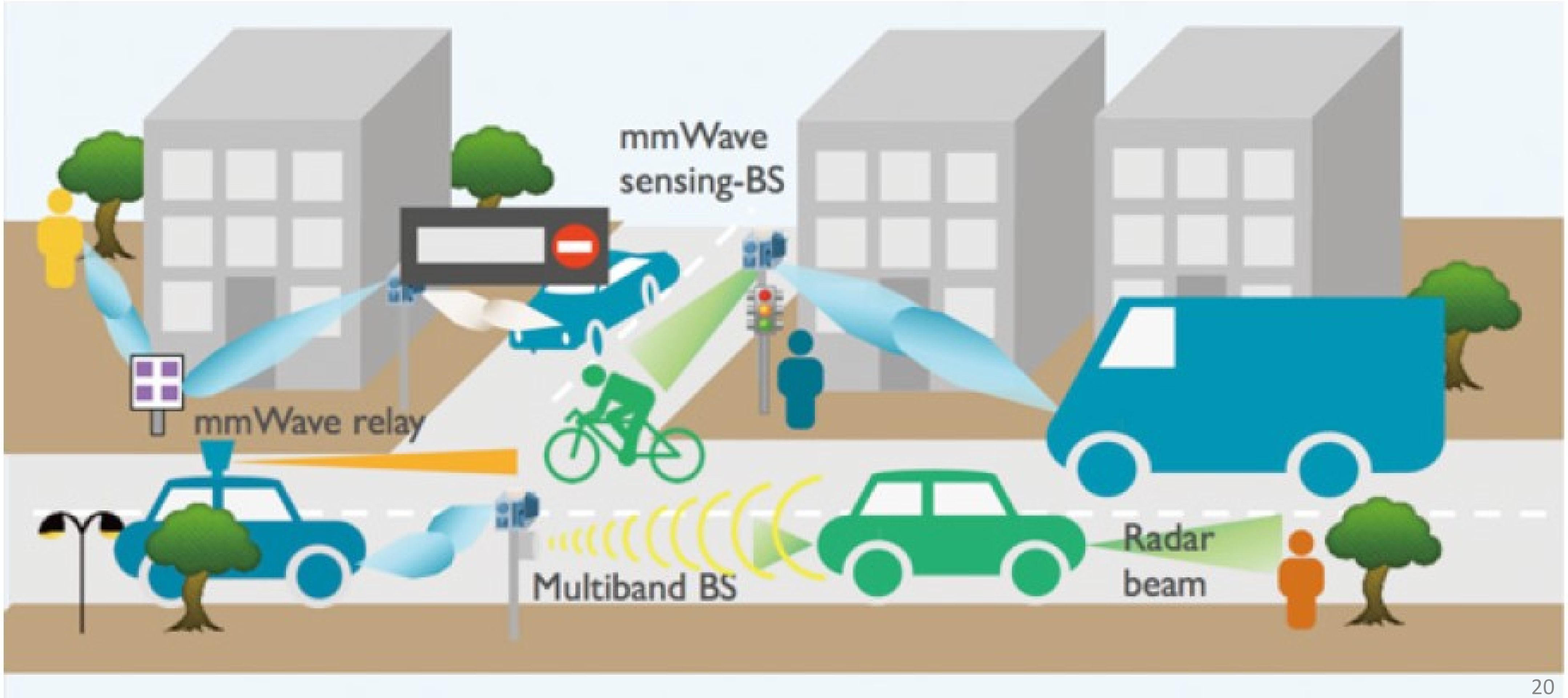
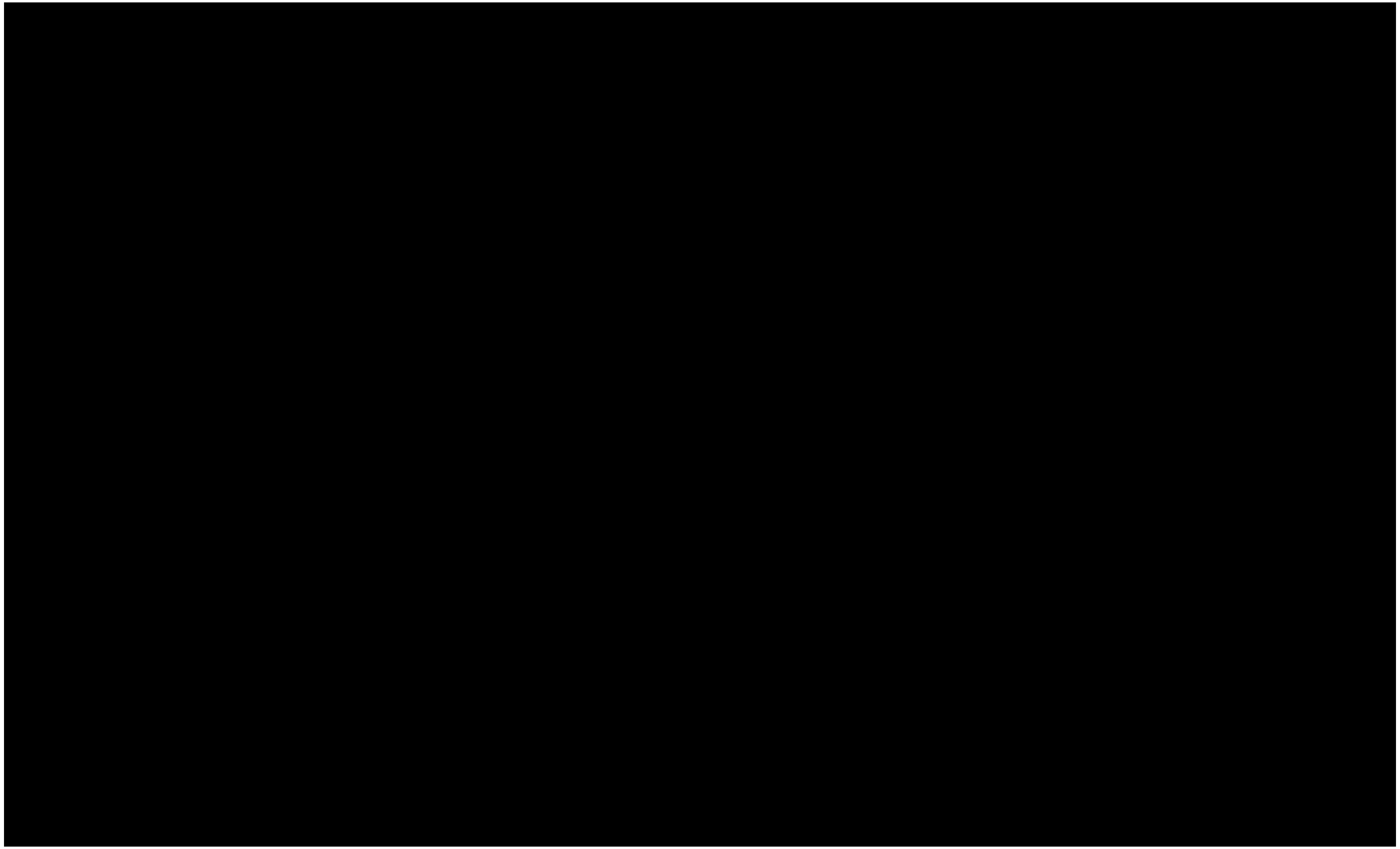
- Fjolla Ademaj, Martin Lerch, Ljiljana Marijanovic, Martin Müller, Ronald Nissel, Stefan Pratschner, Blanca Ramos-Elbal, Bashar Tahir, Martin Taranetz, Erich Zöchmann, Sebastian Caban, Robert Langwieser, Philipp Svoboda, Christoph Mecklenbräuker, Markus Rupp

MM Waves: Multiple Purpose



Dynamic channels at high frequencies?



Vienna Simulator Suite

- LTE 4G
  - DL Link Level
  - UL Link Level
  - DL System Level
- 5G
  - DL&UL Link Level (& side link)
  - DL&UL System Level
  - Soon also in TDD

- 1000s of users worldwide, ~30 companies (3GPP)

Conclusion

- In 20 years from now, the (wireless) world will look very different
- This calls for BIG changes in the way we like to consider communications
- The big open issues are
  - Security, security, security…
  - Decentralisation as fall back mode or default?
- Let‘s get started…

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