Wireless Communications of the Future

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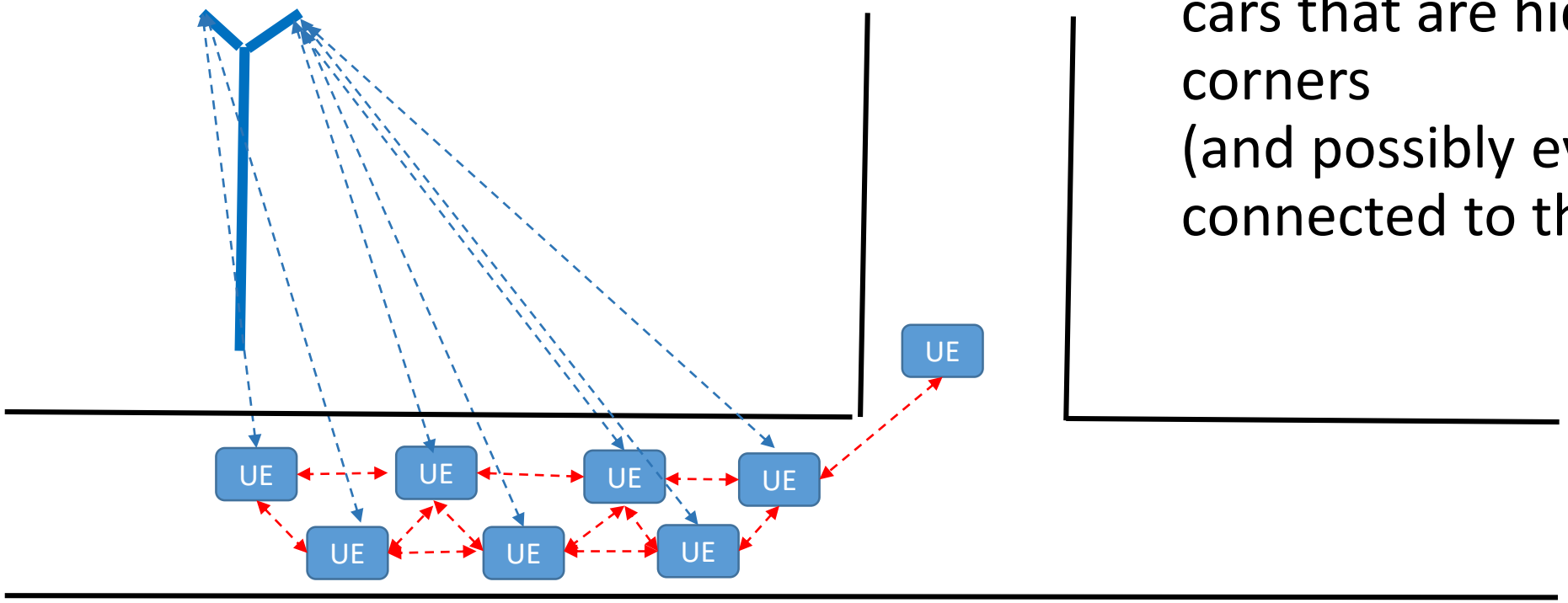
Autonomous Moving Systems: A new Challenge

- 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**

Situation: Today and in the Near Future

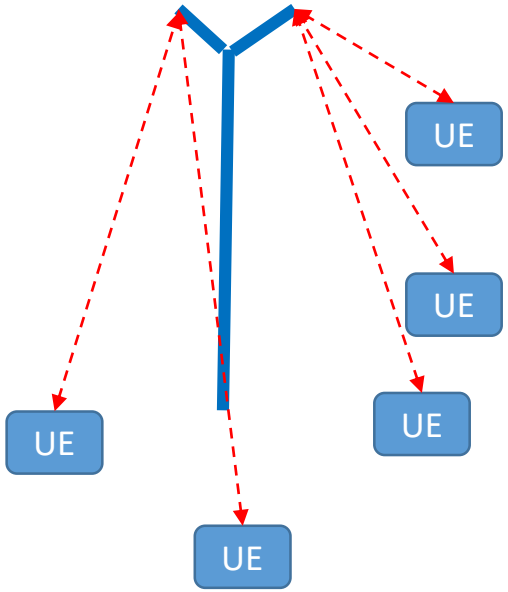
Potential Solution: NOMA Techniques

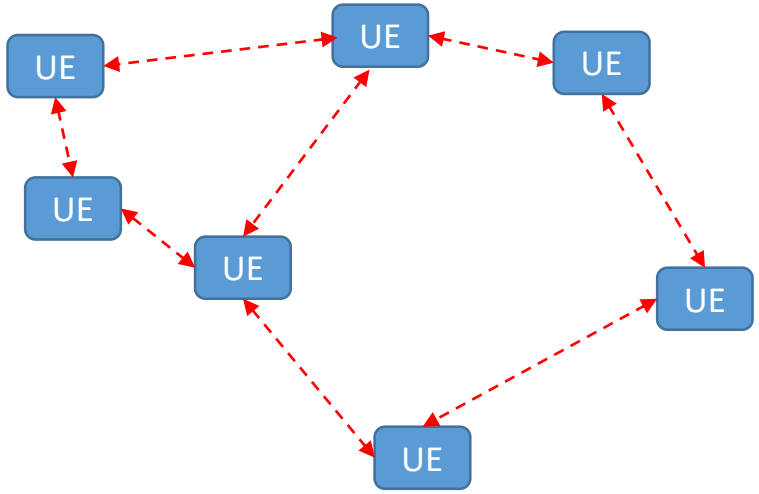


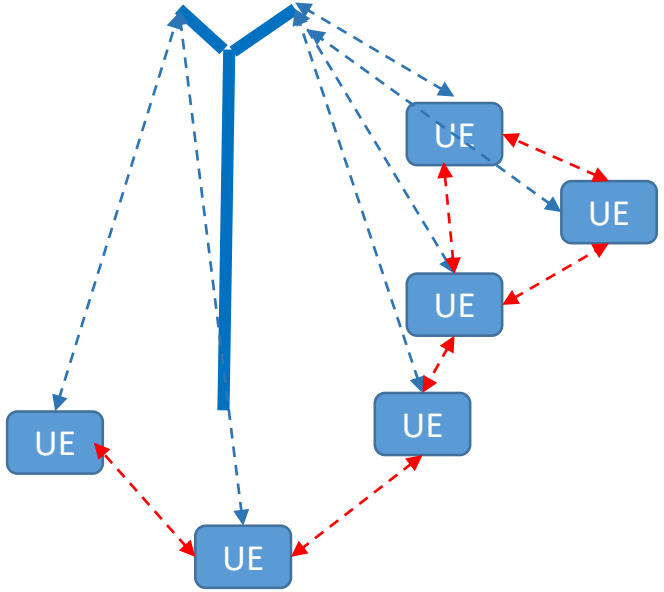
- In cities they may detect cars that are hidden by corners
  (and possibly even not connected to the BS)

Classic networks are

- either centralized
- or adhoc → hybrid

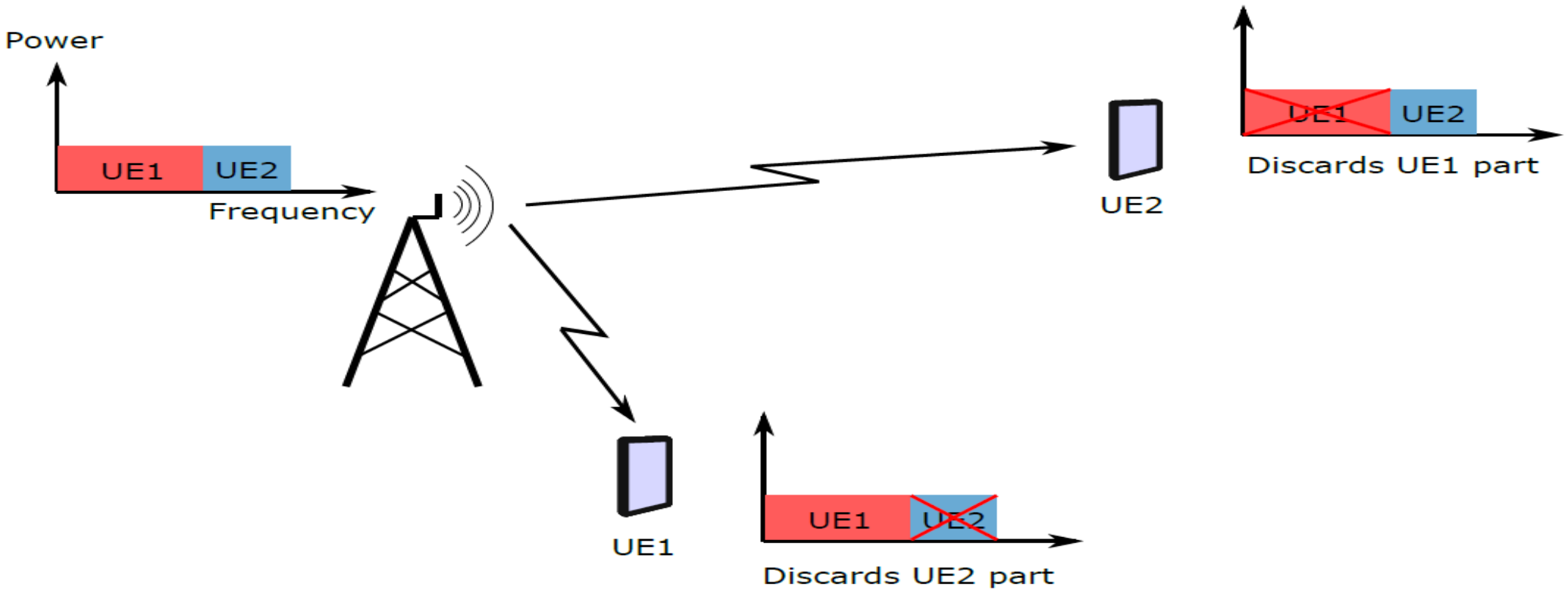






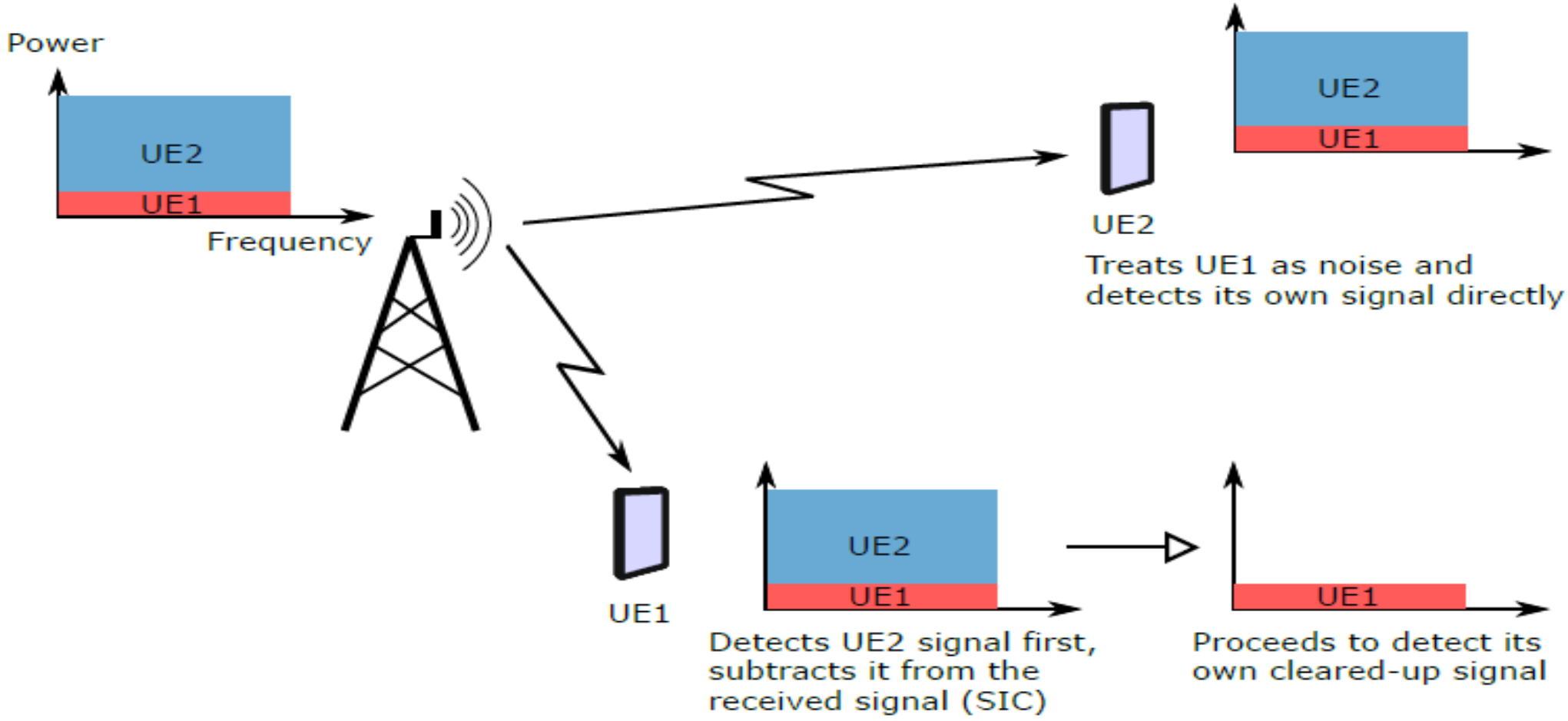
Classic OMA System:

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



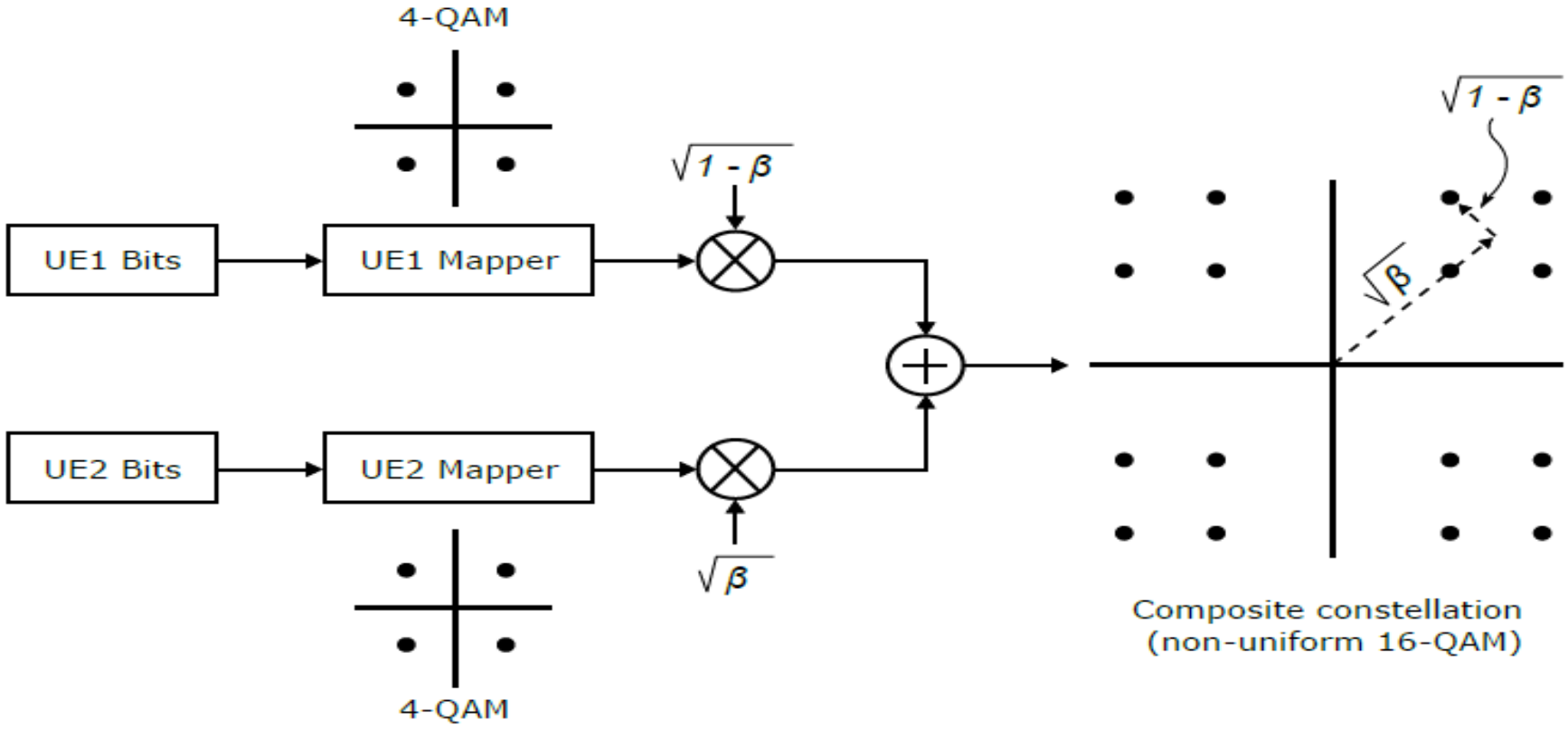
New NOMA System:

- 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

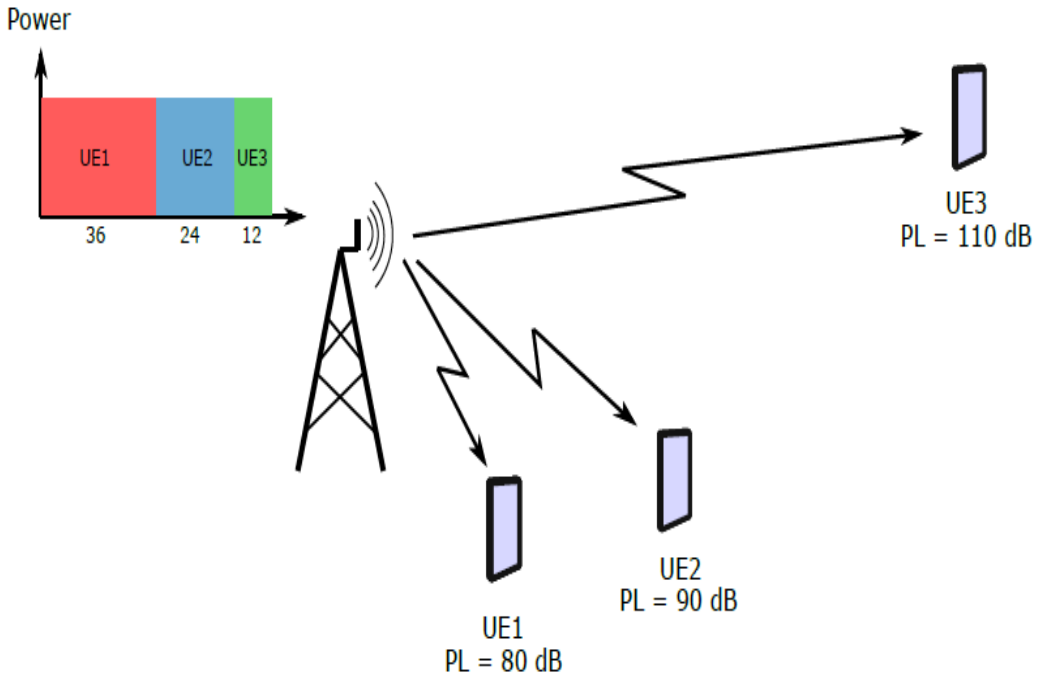
- Three power ratios are defined for each combination of the QAM mappings of NearUE and FarUE.

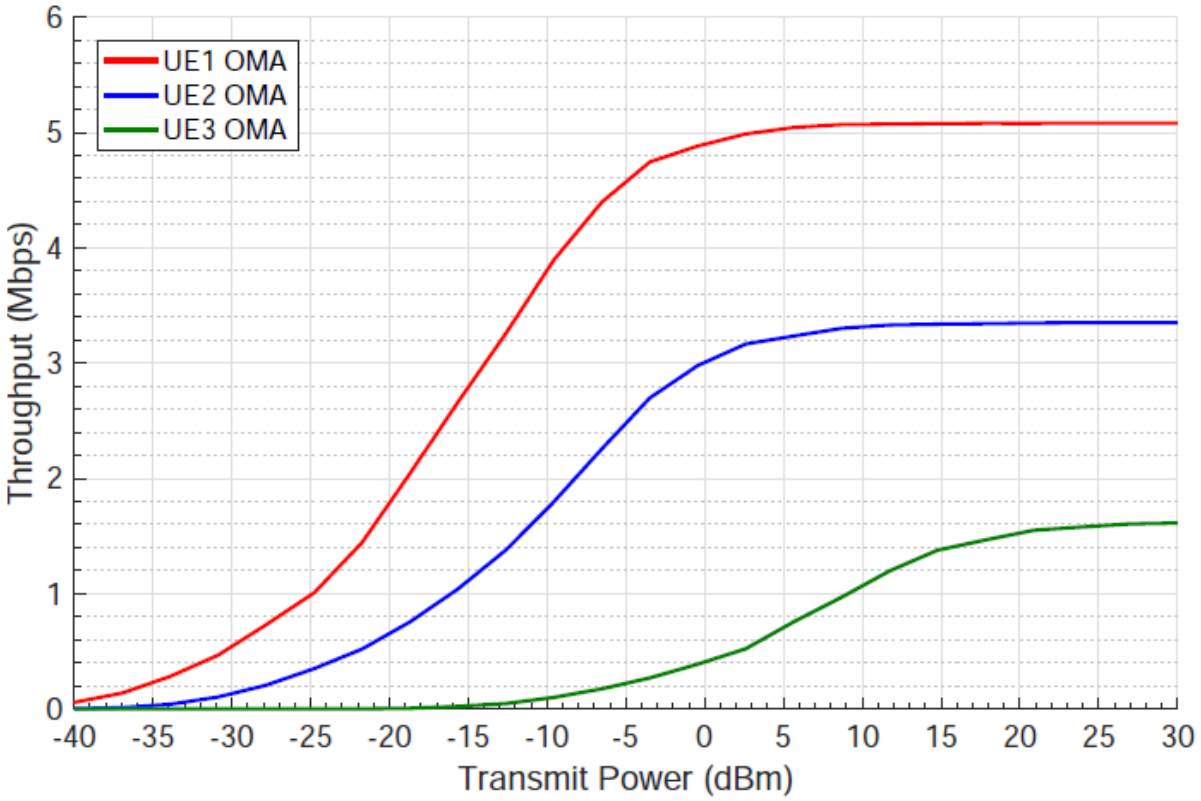
MUSTIdx	Value
00	No MUST
01	MUST, power ratio 1
10	MUST, power ratio 2
11	MUST, power ratio 3

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

NOMA Example

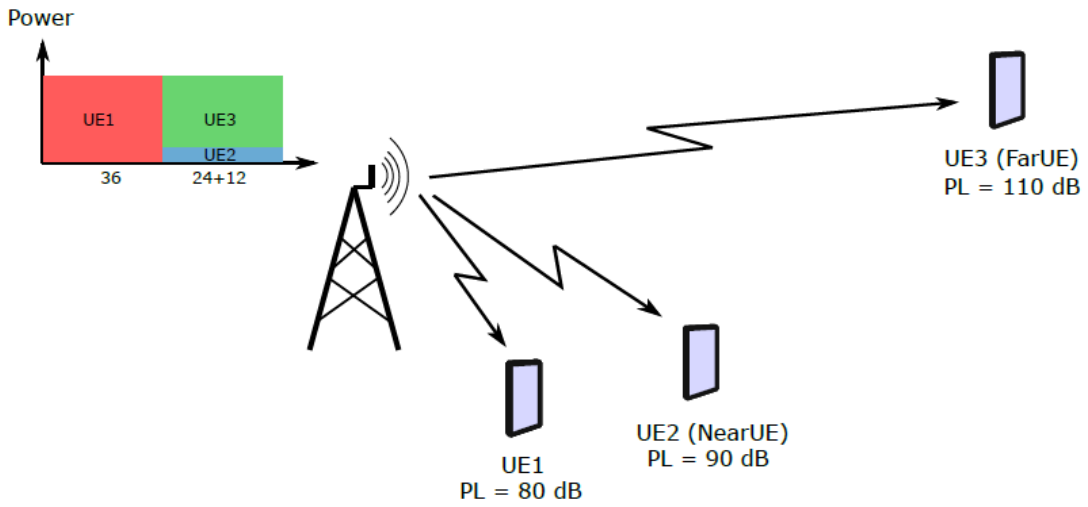
- Consider the OMA system

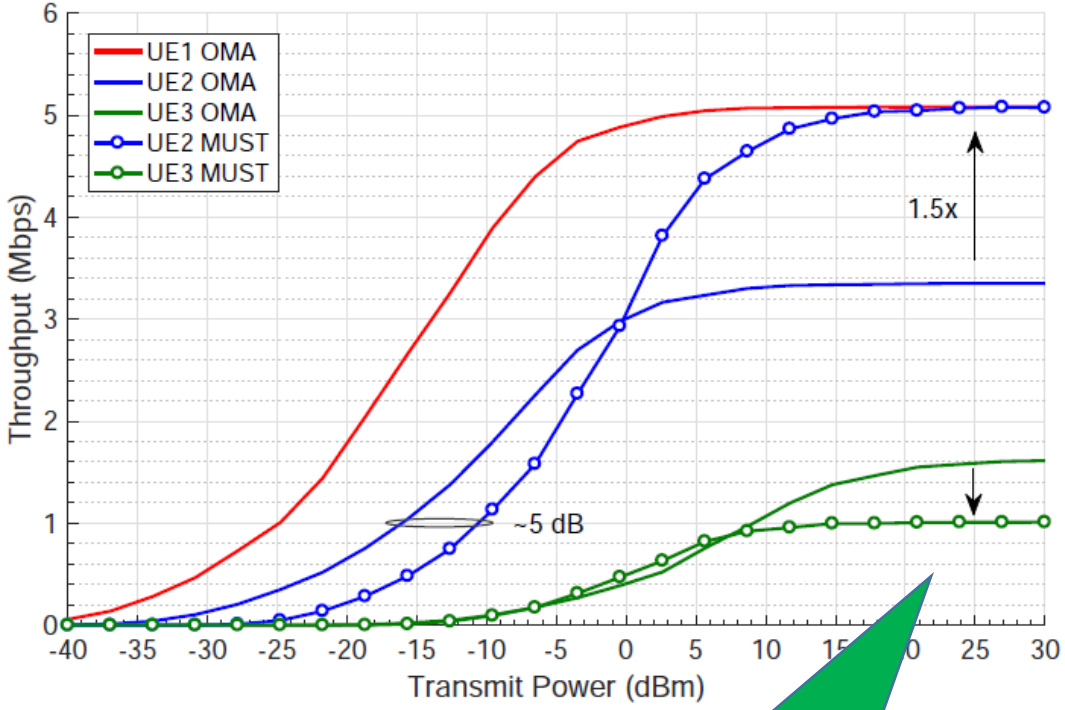




NOMA Example

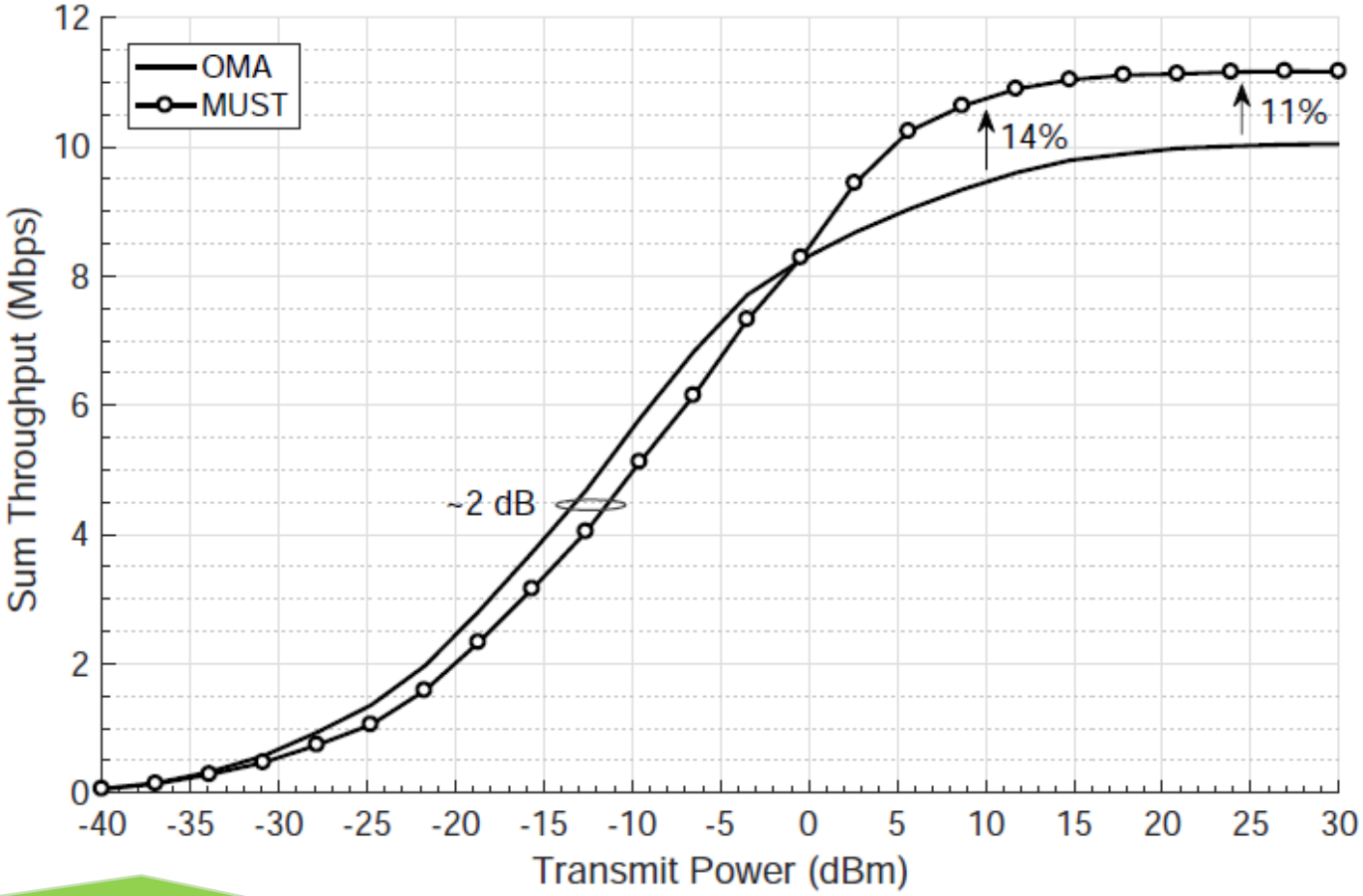
- Now consider the MUST system





Throughput of UE3 drops, as only 4QAM is allowed for in 3GPP

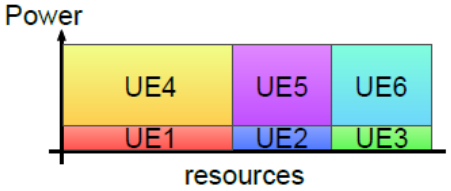
NOMA Example

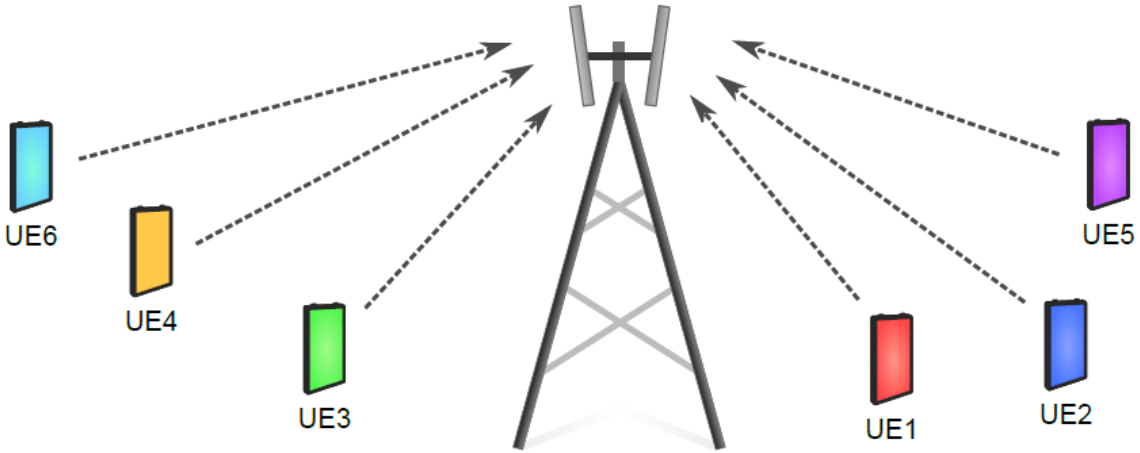


S. Pratschner, B. Tahir, L. Marijanovic, M. Mussbah, K. Kirev, R. Nissel, S. Schwarz, M. Rupp: "*Versatile mobile communications simulation: the Vienna 5G Link Level Simulator*"; EURASIP Journal on Wireless Communications and Networking, **2018** (2018), 1; 226 S.

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

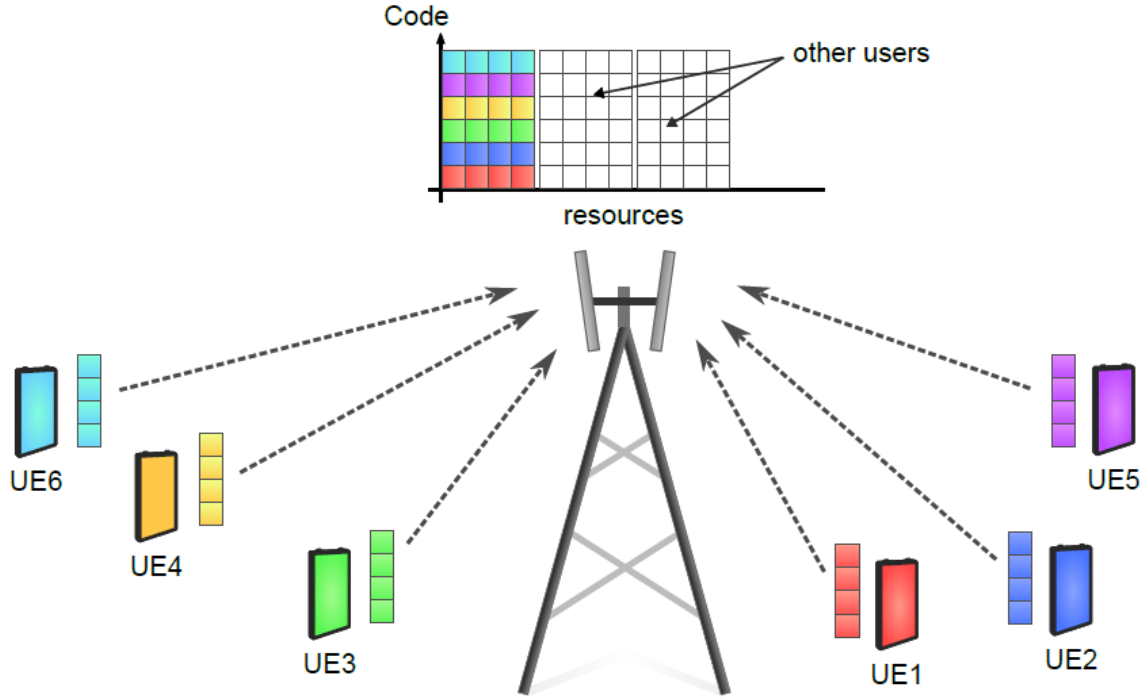
- Superimposes users in the power-domain.
- User separability by successive interference cancellation.





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

B. Tahir, S. Schwarz, M. Rupp: "*Constructing Grassmannian Frames by an Iterative Collision-Based Packing*"; IEEE Signal Processing Letters, **26** (2019), 7; S. 1056 - 1060.

- 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.

$$X \in \mathbb{C}^{N \times M} = \begin{bmatrix} \underline{x}_1 & \underline{x}_2 & \cdots & \underline{x}_M \end{bmatrix} ,$$

such that

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

- ▷ 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

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

- The received signal can be written as

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

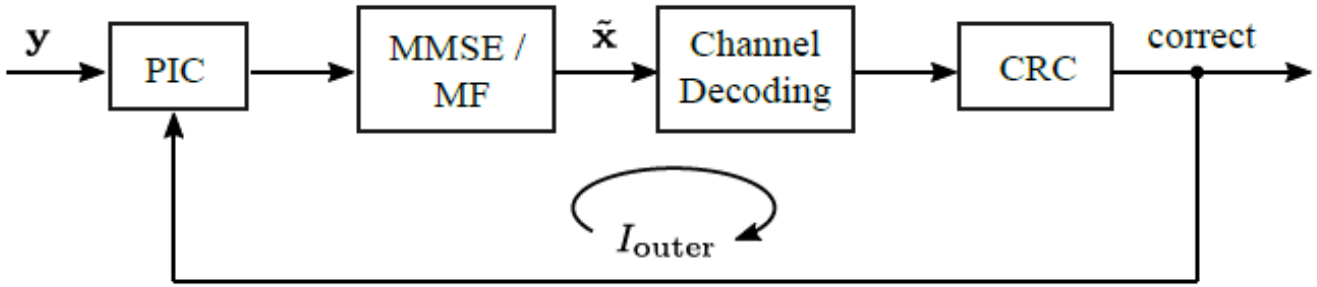
where $*$ denotes the Khatri-Rao product.

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

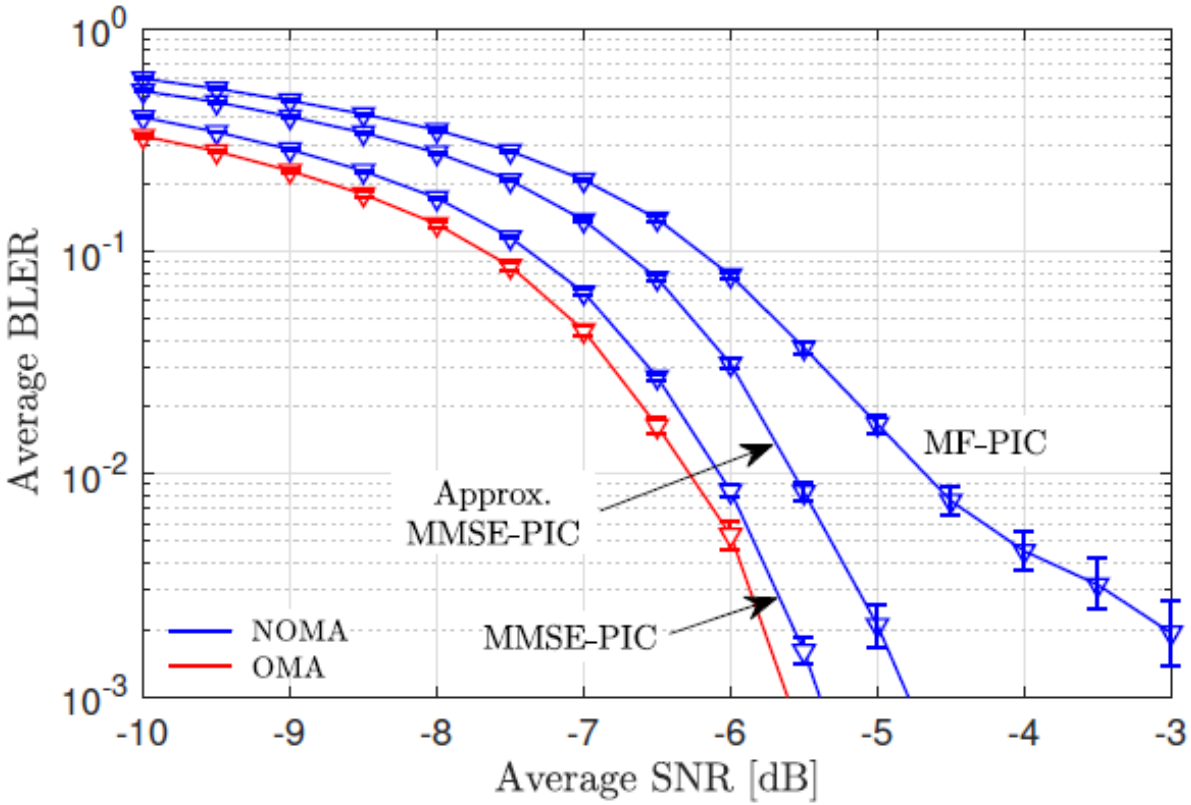


Figure: $N_R = 4, \sigma_e^2 = 10^{-2}$, w/ collisions, $I_{\text{outer}} = 6$.

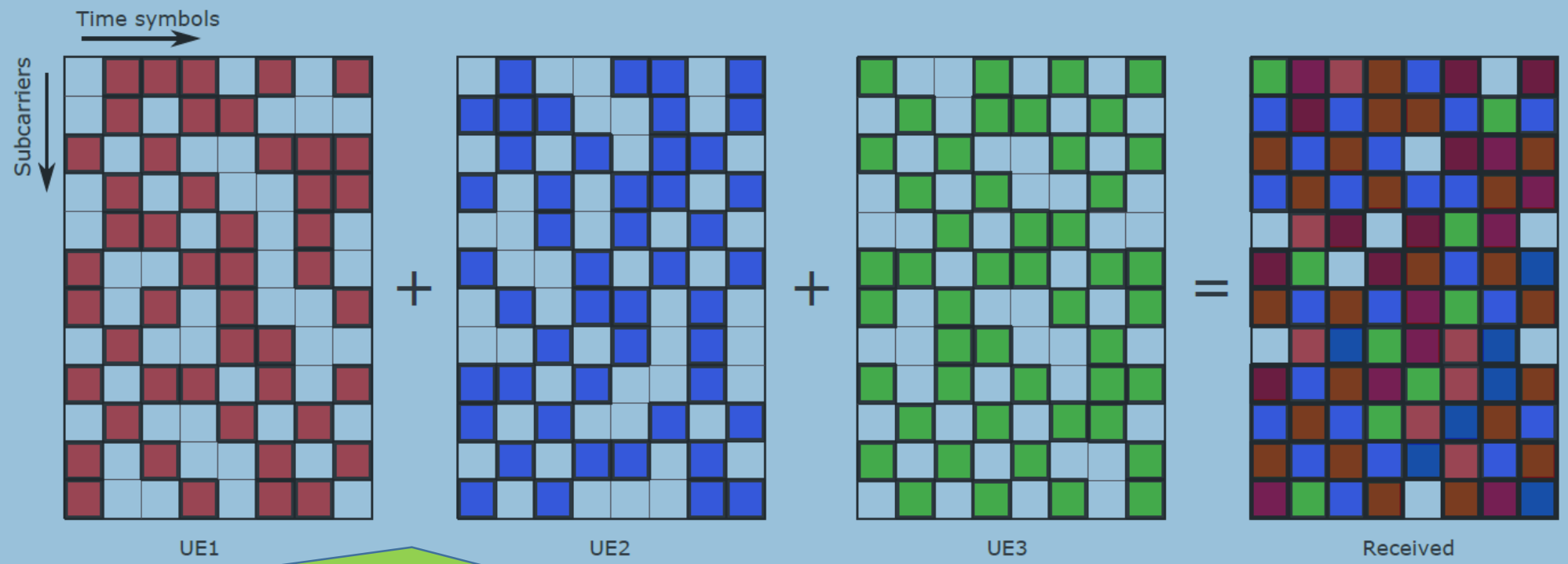
But How do we Find the Codes?

- Problems:
  - number of users a-priori unknown
  - Codes are supposed to be uncorrelated (little correlation)

- Solution:
  - Not possible to solve
  - Use random codes

Random Codes over Time-Frequency Grid

- Each UE maps its symbols in a spread manner onto the time-frequency grid.
- Interferers per RE is reduced automatically → per user detection.



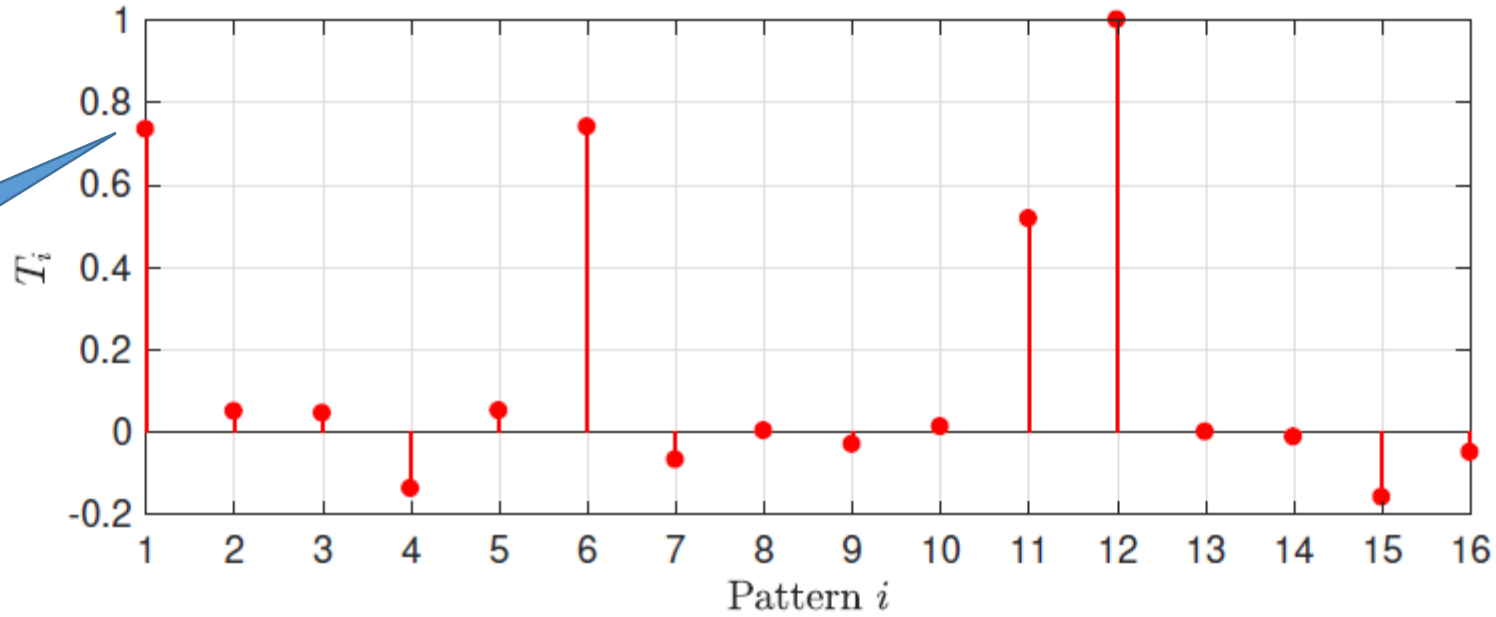
B.Tahir, S.Schwarz, M.Rupp: "Collision Resilient V2X Communication via Grant-Free NOMA, " submitted to VTC Fall 2020

- To detect the presence of a user, the possible patterns are sensed.

$$T_i = \frac{1}{|\mathcal{S}_i|} \sum_{k \in \mathcal{S}_i} |y_k| - \frac{1}{N} \sum_{k=1}^{N} |y_k| \,.$$

- Active patterns $= \{1, 6, 11, 12\}$

This one is easy!

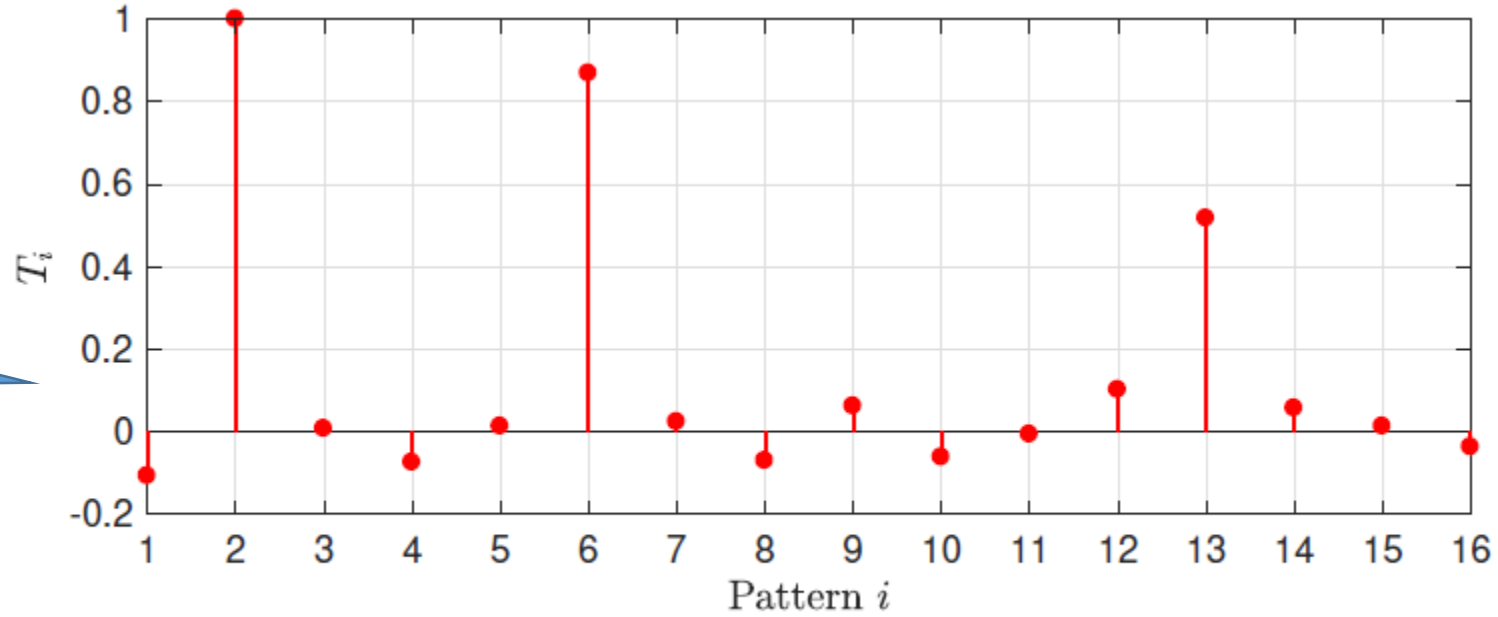


- To detect the presence of a user, the possible patterns are sensed.

$$T_i = \frac{1}{|\mathcal{S}_i|} \sum_{k \in \mathcal{S}_i} |y_k| - \frac{1}{N} \sum_{k=1}^{N} |y_k| \,.$$

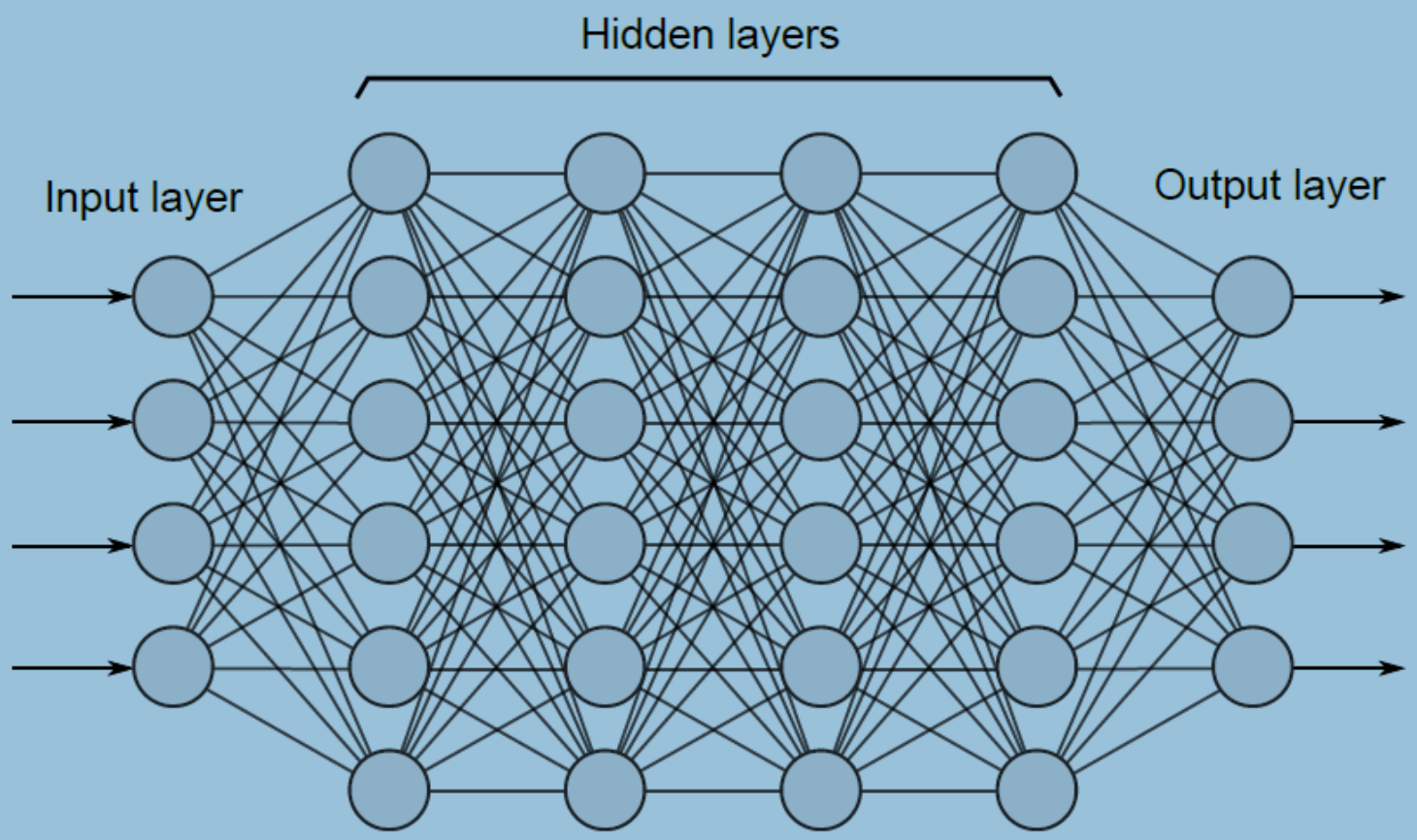
- Active patterns $= \{2, 6, 13, 14\}$

This one is tough!



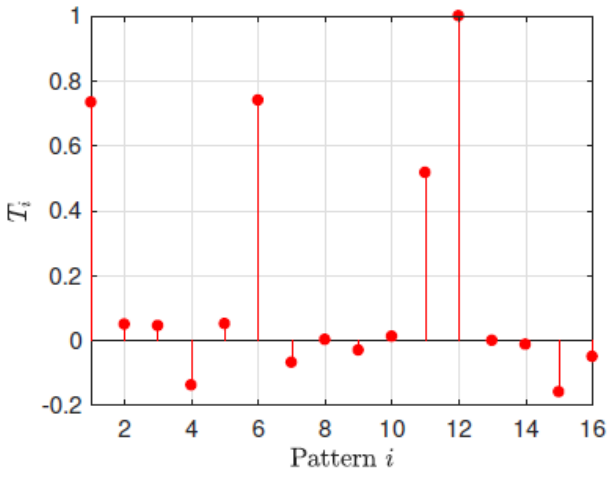
Idea: use Deep Learning Network

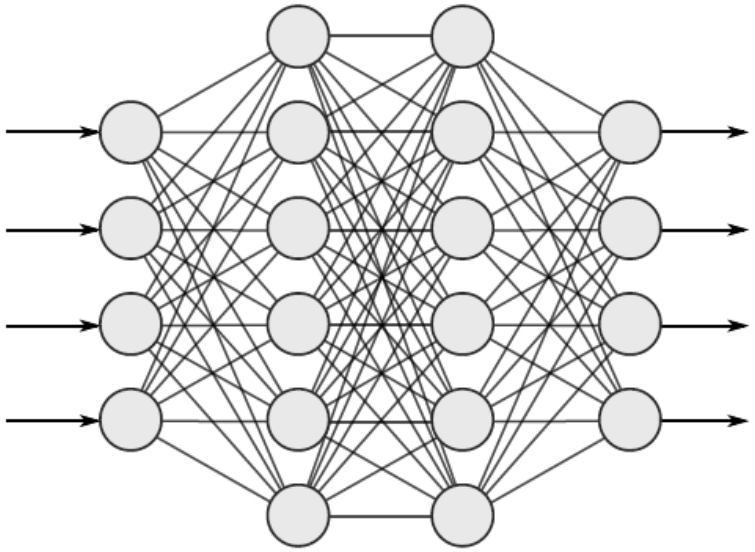
- Use a neural network to enhance the activity detection.

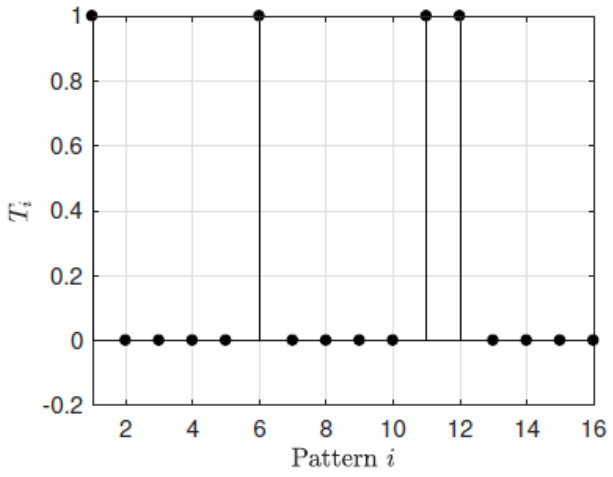


Training a Neural Network

- Find weights (by training) that minimize a certain cost function between the input and the output.
  - Iterative via stochastic gradient descent using many training samples.





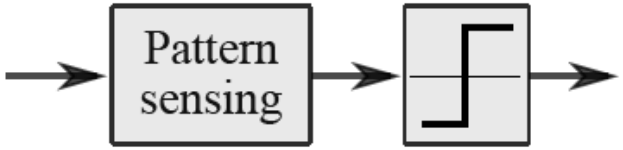


Parameter	Value
# active devices K	4
# patterns	16
Expansion factor L	4
Center frequency	5.9 GHz
Subcarrier spacing	15 kHz
Allocated subcarriers	72
Transmission duration	2 slots (14 OFDM symbols)
Average SNR	15 dB
Channel model	TDL-C with Jakes Doppler spectrum
RMS delay spread	100 ns
Relative velocity	50 km/h
Neural network	4 hidden layers (fully connected), 16 nodes each
Dataset	7500 frames for training, 2500 for validation

The Result

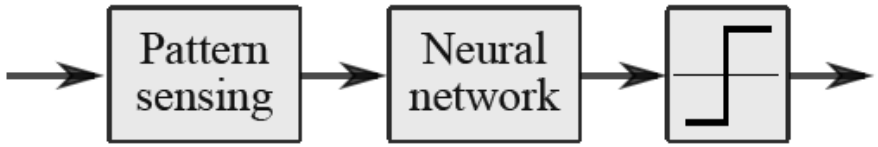
Success probability of detecting exactly the active patterns (no miss and no false alarm).

- **Sensing only**

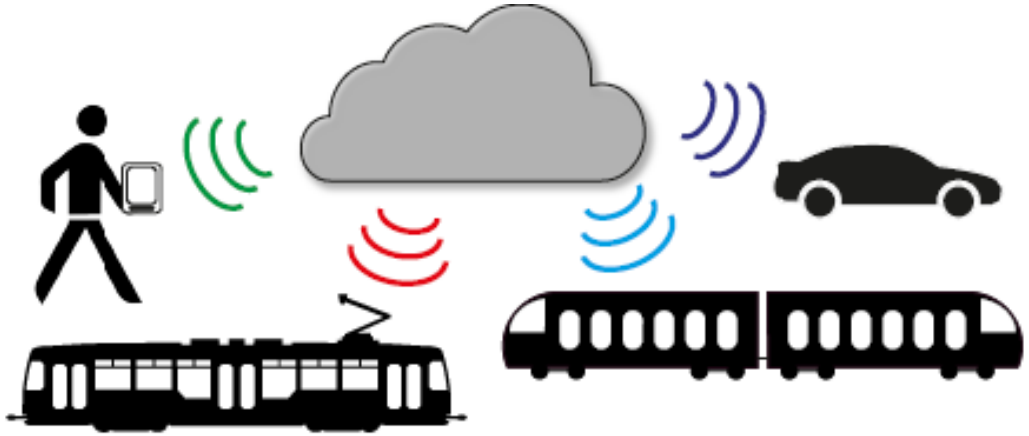


  - Success probability (thresholding): **9.8%**
  - Success probability (highest four): **11.4%**

- **Sensing + NN**



  - Success probability (thresholding): **96.1%**
  - Success probability (highest four): **97.1%**



ÖBB INFRA

Module 1:
PHY Enhancements
NOKIA

Module 2:
Innovative Technologies
A1

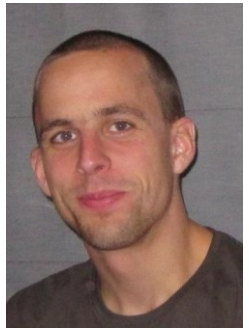
Module 3:
Network Architectures
KATHREIN

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

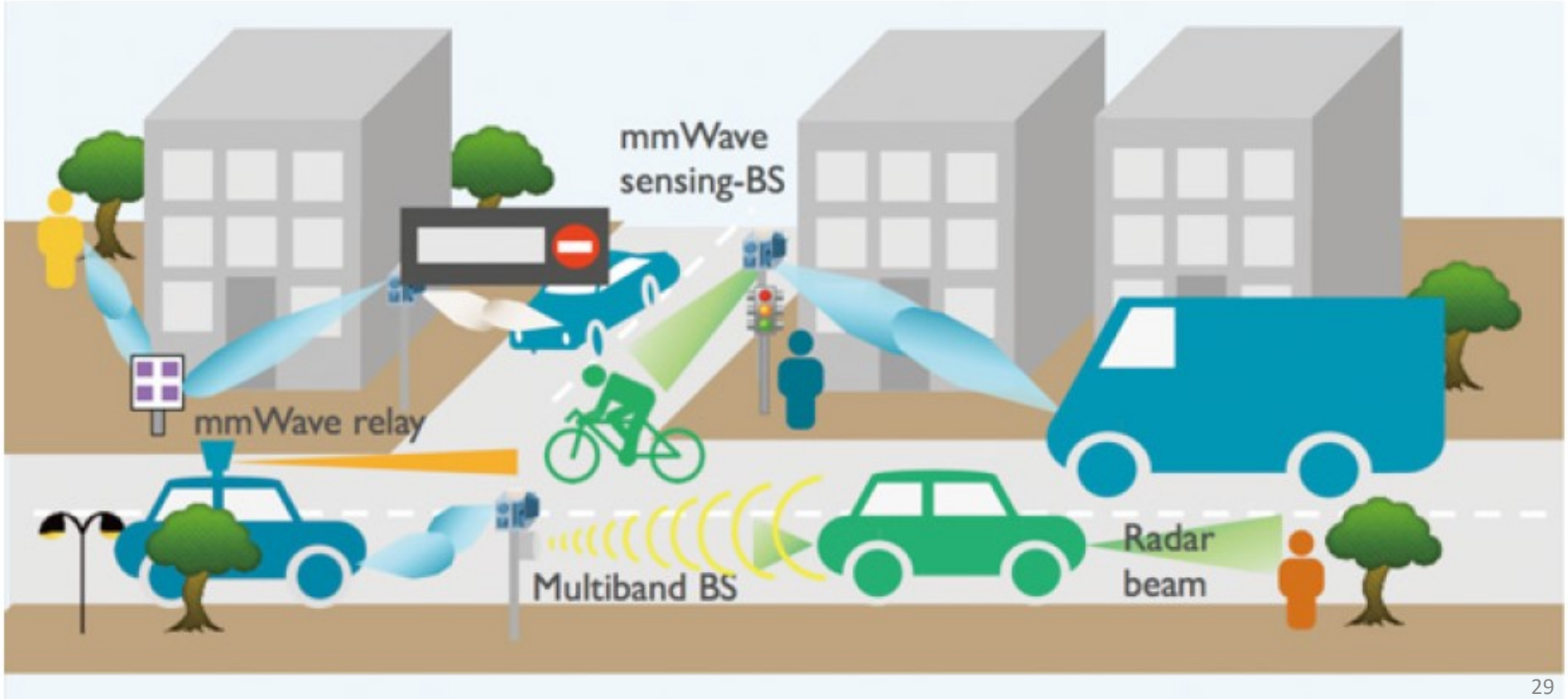
Thanks to the CD-Lab Research Team



Stefan Schwarz

- 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



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…

- Questions: markus.rupp@tuwien.ac.at

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