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.

Power

UE1

Frequency

UE2

Discards UE1 part

Discards UE2 part

UE1

UE2
New NOMA System:

- Now consider the Power NOMA case.
How does it work?

- The transmission is basically a superposition.

```
UE1 Bits  →  UE1 Mapper  →  √1 - β
          ↓          ↓          
        UE2 Bits  →  UE2 Mapper  →  √β

Composite constellation (non-uniform 16-QAM)
```
Three power ratios are defined for each combination of the QAM mappings of NearUE and FarUE.

<table>
<thead>
<tr>
<th>MUSTIdx</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>00</td>
<td>No MUST</td>
</tr>
<tr>
<td>01</td>
<td>MUST, power ratio 1</td>
</tr>
<tr>
<td>10</td>
<td>MUST, power ratio 2</td>
</tr>
<tr>
<td>11</td>
<td>MUST, power ratio 3</td>
</tr>
</tbody>
</table>

The scheduler controls the power allocation using those three power ratios.
Consider the OMA system

- UE1 PL = 90 dB
- UE2 PL = 90 dB
- UE3 PL = 110 dB
NOMA Example

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

- 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.

$$X \in \mathbb{C}^{N \times M} = [x_1 \ x_2 \ ... \ x_M],$$

such that

$$X = \arg\min_X \max_{i \neq j} |\langle x_i, x_j \rangle|.$$

- 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 $s_k$ of length $L$.
  - The spread signature is received by $N_R$ antennas at the base station.
- Define $H, S, P$ as follows

\[
H = [h_1, h_2, \ldots, h_K], \quad S = [s_1, s_2, \ldots, s_K], \quad P = \begin{bmatrix}
P_1 & 0 & \cdots & 0 \\
0 & P_2 & \cdots & 0 \\
\vdots & \vdots & \ddots & 0 \\
0 & 0 & \cdots & P_K
\end{bmatrix}
\]

- The received signal can be written as

\[
y = (H \ast S)P^{1/2}x + n = GP^{1/2}x + n,
\]

where $\ast$ denotes the Khatri-Rao product.
Detection

- The stacked received signal is given by
  \[ y = Bx + n. \]

- 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 \( I_{\text{outer}} \).
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 \(\rightarrow\) 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.

\[ T_i = \frac{1}{|S_i|} \sum_{k \in S_i} |y_k| - \frac{1}{N} \sum_{k=1}^{N} |y_k| \cdot \]

Active patterns = \{1, 6, 11, 12\}
To detect the presence of a user, the possible patterns are sensed.

\[ T_i = \frac{1}{|S_i|} \sum_{k \in S_i} |y_k| - \frac{1}{N} \sum_{k=1}^{N} |y_k|. \]

Active patterns = \{2, 6, 13, 14\}
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.
<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td># active devices $K$</td>
<td>4</td>
</tr>
<tr>
<td># patterns</td>
<td>16</td>
</tr>
<tr>
<td>Expansion factor $L$</td>
<td>4</td>
</tr>
<tr>
<td>Center frequency</td>
<td>5.9 GHz</td>
</tr>
<tr>
<td>Subcarrier spacing</td>
<td>15 kHz</td>
</tr>
<tr>
<td>Allocated subcarriers</td>
<td>72</td>
</tr>
<tr>
<td>Transmission duration</td>
<td>2 slots (14 OFDM symbols)</td>
</tr>
<tr>
<td>Average SNR</td>
<td>15 dB</td>
</tr>
<tr>
<td>Channel model</td>
<td>TDL-C with Jakes Doppler spectrum</td>
</tr>
<tr>
<td>RMS delay spread</td>
<td>100 ns</td>
</tr>
<tr>
<td>Relative velocity</td>
<td>50 km/h</td>
</tr>
<tr>
<td>Neural network</td>
<td>4 hidden layers (fully connected), 16 nodes each</td>
</tr>
<tr>
<td>Dataset</td>
<td>7500 frames for training, 2500 for validation</td>
</tr>
</tbody>
</table>
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%
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

- 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
Literature: Overview


• Stefan Schwarz and Markus Rupp, "Cellular Networks for a Society in Motion," Proc. of IWSSIP 2018, Maribor, Slovenia, June 2018.
Literature Overview


• 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.
Literature: High Speed Systems


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Literature: HetNets and Random Objects

- S. Schwarz: "Remote Radio Head Assignment and Beamforming in Dynamic Distributed Antenna Systems"; IEEE International Conference on Communications, Kansas City, USA; May 2018.
Literature: Trains and Cars


• I. Safiulin, S. Schwarz, T. Philosof, M. Rupp: "Latency and Resource Utilization Analysis for V2X Communication over LTE MBSFN Transmission"; ITG Workshop on Smart Antennas, München; 09.03.2016 - 11.03.2016.


• S. Schwarz, T. Philosof, M. Rupp: "Leakage-Based Multicast Transmit Beamforming"; IEEE International Conference on Communications (ICC2015), London, UK; 08.06.2015 - 12.06.2015; pp. 2405 - 2410.


Literature: LTE-MIMO


Literature: FD MIMO


• F. Ademaj, M. Müller, S. Schwarz, M. Rupp: "Modeling of Spatially Correlated Geometry-Based Stochastic Channels"; IEEE 86th Vehicular Technology Conference (VTC2017-Fall), Canada; 2017


Literature FD MIMO


Literature: 60GHz


- E. Zöchmann, K. Guan, M. Rupp: "Two-Ray Models in mmWave Communications"; "IEEE International Workshop on Signal Processing Advances in Wireless Communications (SPAWC 2017),


Literature 60GHz


Literature: NOMA & Coding

- 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.


Literature: NOMA and Coding


