University of Bremen

Dept. of Communications Engineering

Equidistant Power Allocation for a service-based NOMA scheme

Mobilfunktagung 2023

Niklas Bulk, Alec Prinz, Carsten Bockelmann, Armin Dekorsy

May 9, 2023

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INDUSTRIAL RADIO LAB Germany

[1] Designed by macrovector / Freepik

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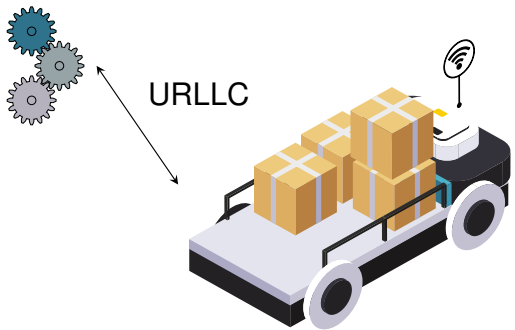
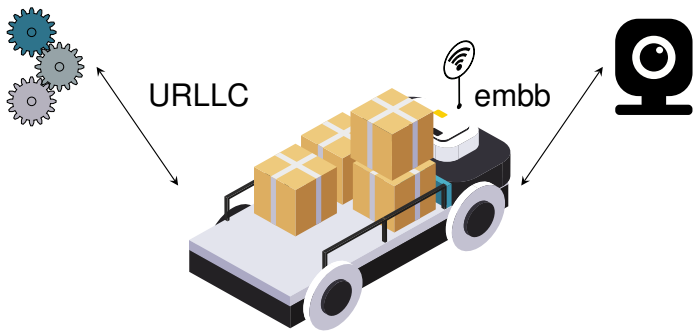
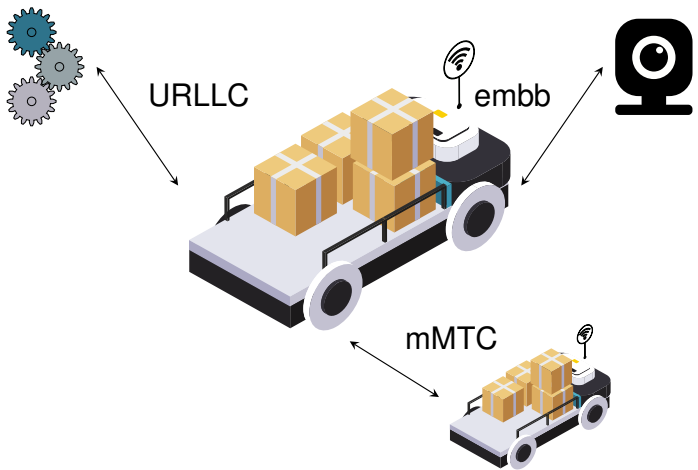

URLLC

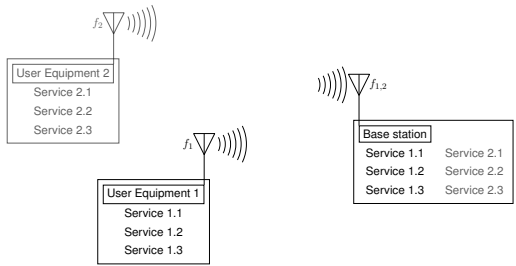

URLLC
embb


URLLC
embb
mMTC

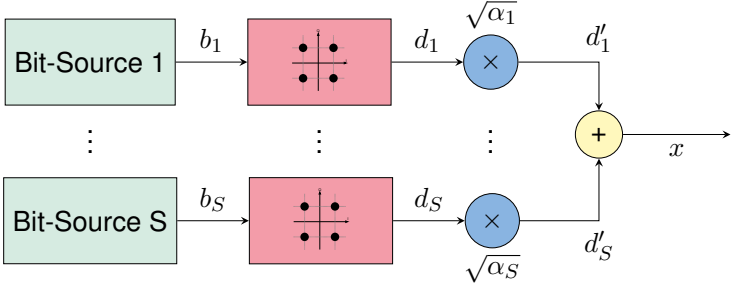
Industrial scenarios require:

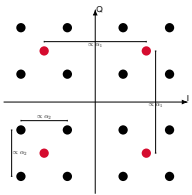
- massive connectivity
- low latency communication
- independent services

Multi-User/Single-Service → **Single-User/Multi-Service** NOMA system



NOMA-Transmitter



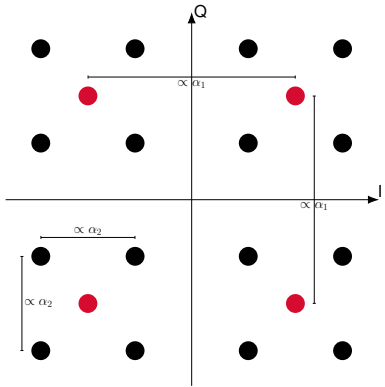


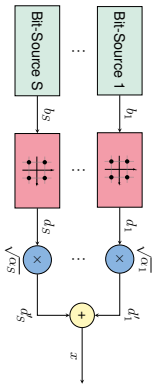
NOMA: 16-QAM

$$x = \sum_{s=1}^{S} \sqrt{\alpha_s \cdot P_{\text{total}}} \cdot d_s$$

$$\sum_{s=1}^{S} \alpha_s = 1$$

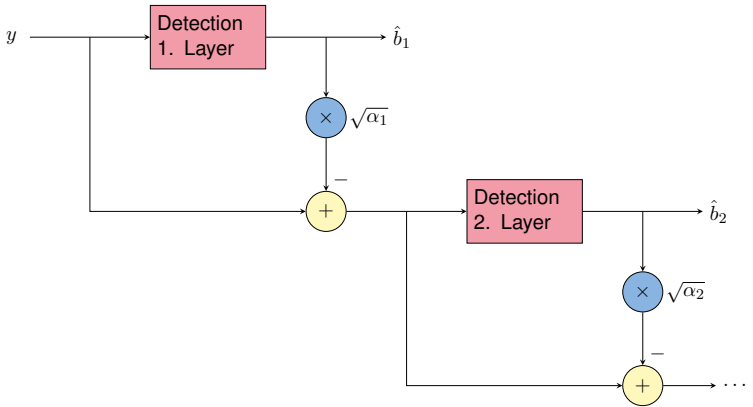
Hierarchical QAM





H-QAM: 4-QAM$\times$4-QAM = 16-QAM

Successive Interference Cancellation



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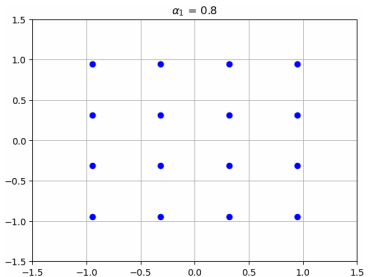

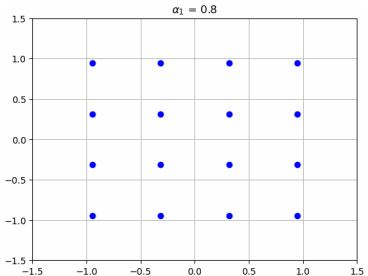

Objection

Find the best power allocation

In 1989 Forney and Wei[1] formulated the Constellation Figure of Merit:

$$\mathrm{CFM}(C) = \frac{d_{\min}^2}{P_{\mathrm{avg}}(C)}$$

[1] Multidimensional constellations. I. Introduction, figures of merit, and generalized cross constellations, Forney, G.D. and Wei, L.-F.

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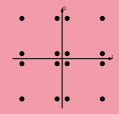
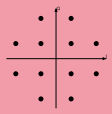
Geometric Shaping





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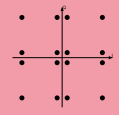
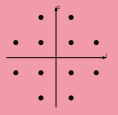
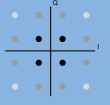




Probabilistic Shaping



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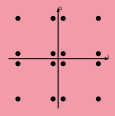
In 1989 Forney and Wei[1] formulated the Constellation Figure of Merit:

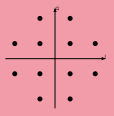
$$\mathrm{CFM}(C) = \frac{d^2_{\min}}{P_{\mathrm{avg}}(C)}$$

Observation

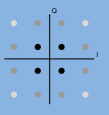
NOMA and Geometric Shaping are a good combination

Geometric Shaping





Probabilistic Shaping



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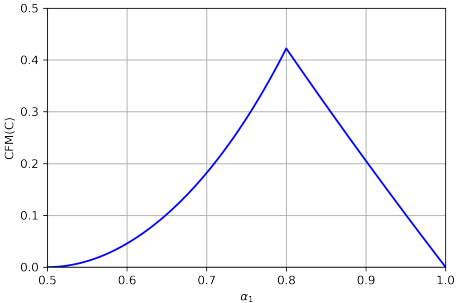
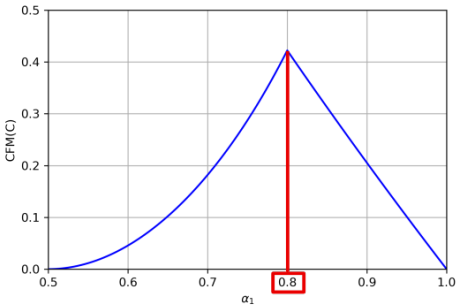
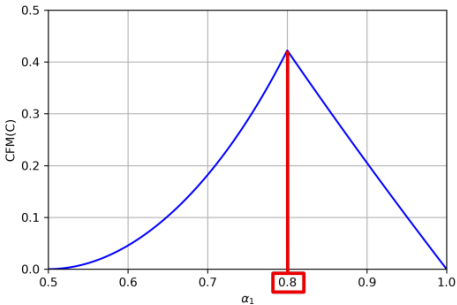
Constellation Figure of Merit

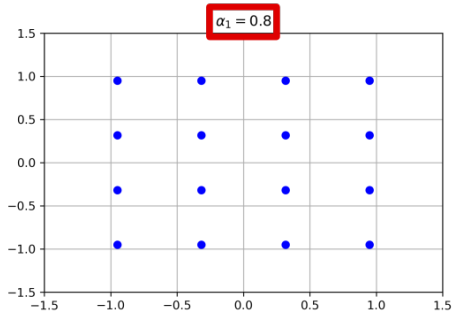


Constellation Figure of Merit

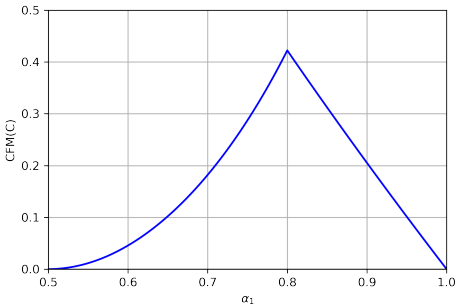


Constellation Figure of Merit





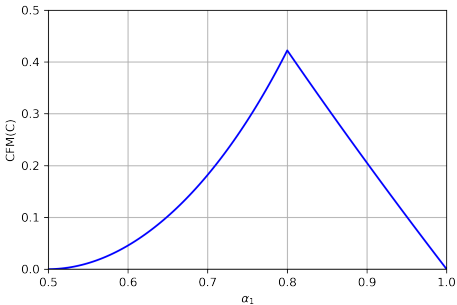
Constellation Figure of Merit



Observation

Based on CFM, choose power factors that lead to equidistant signal constellation

Constellation Figure of Merit



Observation

Based on CFM, choose power factors that lead to equidistant signal constellation

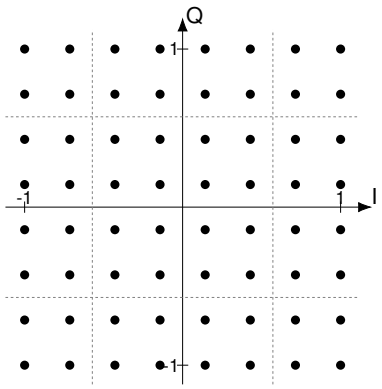
Solution

Equidistant Power Allocation for a service-based NOMA scheme

Example: 64-QAM$\times$QPSK

Service 1: 64-QAM

- 8$\times$8-ASK
- $\mathrm{RMS}_{8-\mathrm{ASK}} = \sqrt{21}$



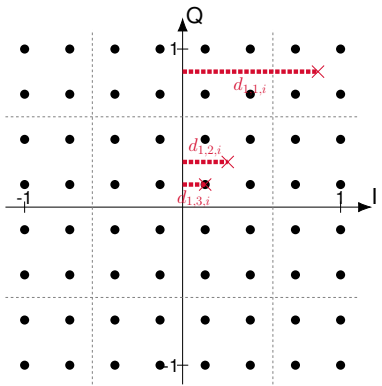
Service 1: 64-QAM

Example: 64-QAM×QPSK

Service 1: 64-QAM

- 8×8-ASK
- $\mathrm{RMS}_{8-\mathrm{ASK}} = \sqrt{21}$
- 3 distances per dimension

$$\mathbf{d}_1 = \begin{pmatrix} 4/\sqrt{21} \\ 2/\sqrt{21} \\ 1/\sqrt{21} \end{pmatrix}$$

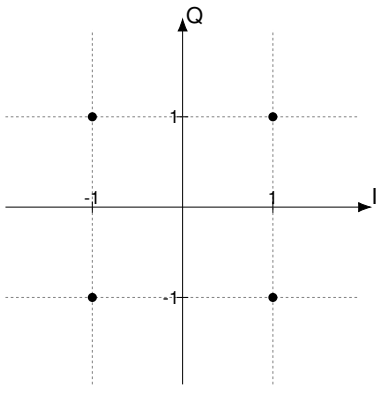


Service 1: 64-QAM

Example: 64-QAM$\times$QPSK

Service 2: 4-QAM

- 2$\times$2-ASK
- $\mathrm{RMS}_{2-\mathrm{ASK}} = 1$



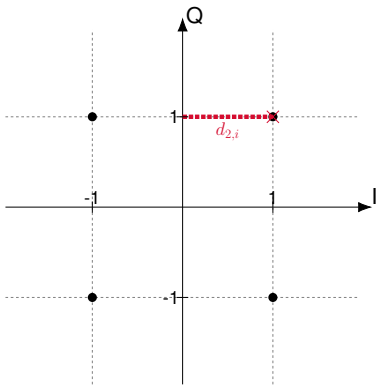
Service 2: 4-QAM

Example: 64-QAM×QPSK

Service 2: 4-QAM

- 2×2-ASK
- $\mathrm{RMS}_{2-\mathrm{ASK}} = 1$
- 1 distance per dimension

$$\mathbf{d}_2 = (1)$$



Service 2: 4-QAM

Example: 64-QAM$\times$QPSK

Distance Matrix

$$\rightarrow \mathbf{D} = \begin{bmatrix} \mathbf{d}_1 & 0 \\ 0 & \mathbf{d}_2 \end{bmatrix}$$

Example: 64-QAM$\times$QPSK

Distance Matrix

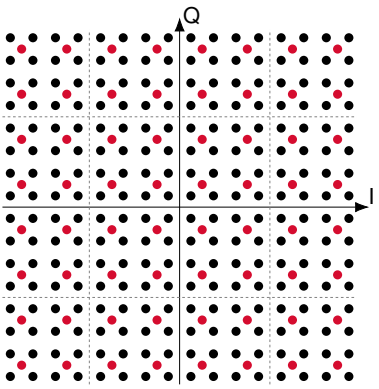
$$\rightarrow \mathbf{D} = \begin{bmatrix} \mathbf{d}_1 & 0 \\ 0 & \mathbf{d}_2 \end{bmatrix}$$

$$\rightarrow \mathbf{D} = \begin{bmatrix} 4/\sqrt{21} & 0 \\ 2/\sqrt{21} & 0 \\ 1/\sqrt{21} & 0 \\ 0 & 1 \end{bmatrix}$$

Example: 64-QAM$\times$QPSK

NOMA: 256-QAM

- 16$\times$16-ASK
- $\mathrm{RMS}_{16-\mathrm{ASK}} = \sqrt{85}$



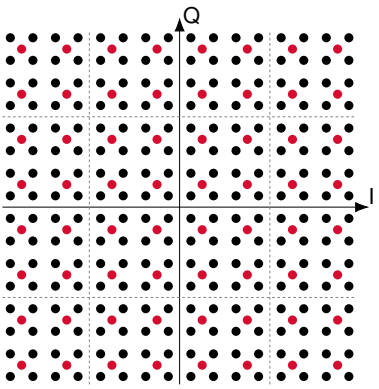
NOMA: 256-QAM

Example: 64-QAM$\times$QPSK

NOMA: 256-QAM

- 16$\times$16-ASK
- $\mathrm{RMS}_{16-\mathrm{ASK}} = \sqrt{85}$
- 4 distances per dimension

$$\mathbf{d}_{\mathrm{NOMA}} = \begin{pmatrix} 8/\sqrt{85} \\ 4/\sqrt{85} \\ 2/\sqrt{85} \\ 1/\sqrt{85} \end{pmatrix}$$



NOMA: 256-QAM

Example: 64-QAM$\times$QPSK

Initial

$$\mathbf{D} \cdot \boldsymbol{\alpha} = \mathbf{d}_{\mathrm{NOMA}}$$

Goal

$$\boldsymbol{\alpha} = ?$$

Example: 64-QAM$\times$QPSK

Initial

$$\mathbf{D} \cdot \boldsymbol{\alpha} = \mathbf{d}_{\mathrm{NOMA}}$$

Goal

$$\boldsymbol{\alpha} = ?$$

Challenge

- $\mathbf{D}$ is mostly rectangular
- $\mathbf{D}$ and $\mathbf{d}_{\mathrm{NOMA}}$ are overdetermined

Example: 64-QAM×QPSK

Initial

$$\mathbf{D} \cdot \boldsymbol{\alpha} = \mathbf{d}_{\mathrm{NOMA}}$$

Goal

$$\boldsymbol{\alpha} = \mathbf{D'}^{-1} \cdot \mathbf{d'}_{\mathrm{NOMA}}$$

Challenge

- $\mathbf{D}$ is mostly rectangular
- $\mathbf{D}$ and $\mathbf{d}_{\mathrm{NOMA}}$ are overdetermined

Reduction Matrix

$$\mathbf{D} \cdot \mathbf{R} = \mathbf{D'}$$

$$\mathbf{d}_{\mathrm{NOMA}} \cdot \mathbf{R} = \mathbf{d'}_{\mathrm{NOMA}}$$

Example: 64-QAM$\times$QPSK

Reduced Distance Matrix

$$\mathbf{D}' = \begin{bmatrix} 1/\sqrt{21} & 0 \\ 0 & 1 \end{bmatrix}$$

NOMA distance vector

$$\mathbf{d}'_{\mathrm{NOMA}} = \begin{pmatrix} 2/\sqrt{85} \\ 1/\sqrt{85} \end{pmatrix}$$

Example: 64-QAM×QPSK

Reduced Distance Matrix

$$\mathbf{D}' = \begin{bmatrix} 1/\sqrt{21} & 0 \\ 0 & 1 \end{bmatrix}$$

NOMA distance vector

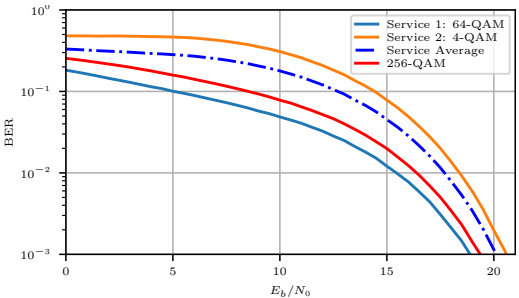
$$\mathbf{d}'_{\mathrm{NOMA}} = \begin{pmatrix} 2/\sqrt{85} \\ 1/\sqrt{85} \end{pmatrix}$$

Power allocation factor

$$\begin{pmatrix} \sqrt{\alpha_1} \\ \sqrt{\alpha_2} \end{pmatrix} = \begin{bmatrix} \sqrt{21} & 0 \\ 0 & 1 \end{bmatrix} \cdot \begin{pmatrix} 2/\sqrt{85} \\ 1/\sqrt{85} \end{pmatrix}$$

$$\begin{pmatrix} \sqrt{\alpha_1} \\ \sqrt{\alpha_2} \end{pmatrix} = \begin{pmatrix} 2\sqrt{21/85} \\ 1\sqrt{1/85} \end{pmatrix}$$

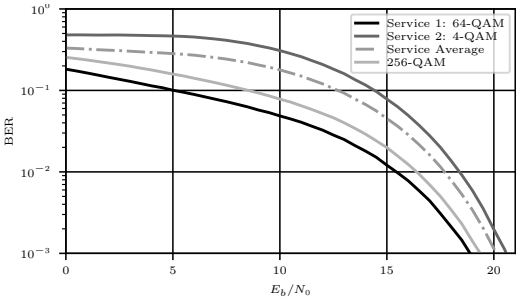
BER results



64-QAM $\times$ QPSK = 256-QAM, with

$\boldsymbol{\alpha} \approx \begin{pmatrix} 0.9882 & 0.0177 \end{pmatrix}^{\mathrm{T}}$

BER results



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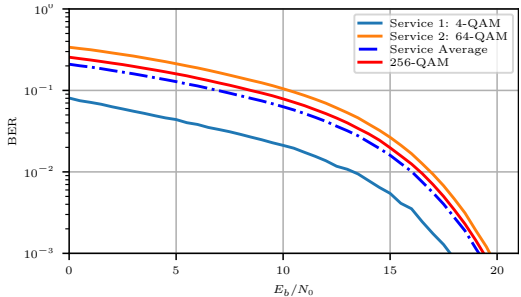
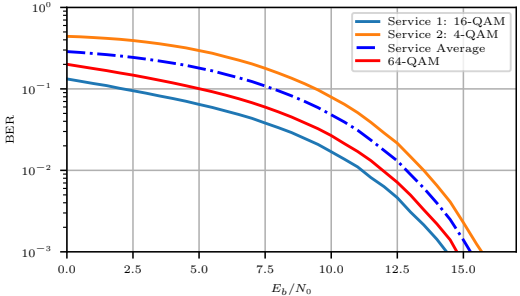


QPSK $\times$ 64-QAM = 256-QAM, with
$\boldsymbol{\alpha} \approx \begin{pmatrix} 0.7529 & 0.2471 \end{pmatrix}^{\mathrm{T}}$

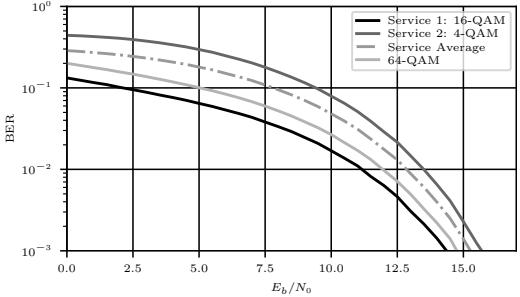
BER results



16-QAM $\times$ QPSK = 64-QAM, with

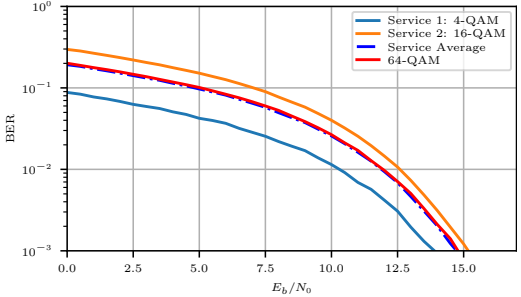
$$\boldsymbol{\alpha} \approx \begin{pmatrix} 0.9523 & 0.0476 \end{pmatrix}^{\mathrm{T}}$$

BER results



16-QAM $\times$ QPSK = 64-QAM, with

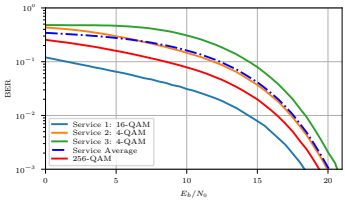
$\boldsymbol{\alpha} \approx \begin{pmatrix} 0.9523 & 0.0476 \end{pmatrix}^{\mathrm{T}}$



QPSK $\times$ 16-QAM = 64-QAM, with

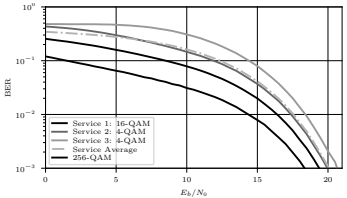
$\boldsymbol{\alpha} \approx \begin{pmatrix} 0.7619 & 0.2380 \end{pmatrix}^{\mathrm{T}}$

BER results

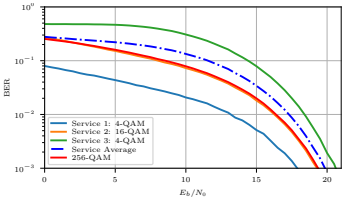


16-QAM×4-QAM×4-QAM

BER results

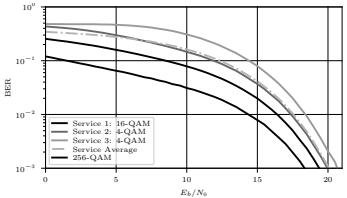


16-QAM×4-QAM×4-QAM

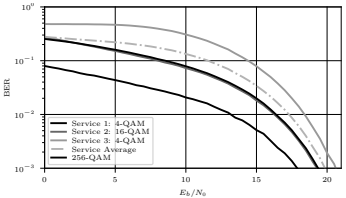


4-QAM×16-QAM×4-QAM

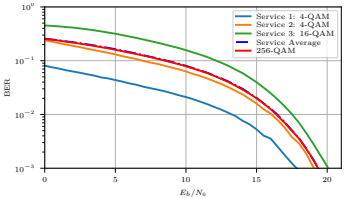
BER results



16-QAM×4-QAM×4-QAM



4-QAM×16-QAM×4-QAM



4-QAM×4-QAM×16-QAM

Results

- Allocate the highest power to the lowest modulation
- Equidistant power allocation maximizes CFM
- General power allocation algorithm for N services

Results

- Allocate the highest power to the lowest modulation
- Equidistant power allocation maximizes CFM
- General power allocation algorithm for N services

Outlook

- Including probabilistic shaping
- Machine Learning Concept to optimize the joint CFM
- Including 5G LDPC Frames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https://industrial-radio-lab.eu/ird23/

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