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On the Role of Link Adaptation in Next Generation Multiple Access

NGMA Workshop

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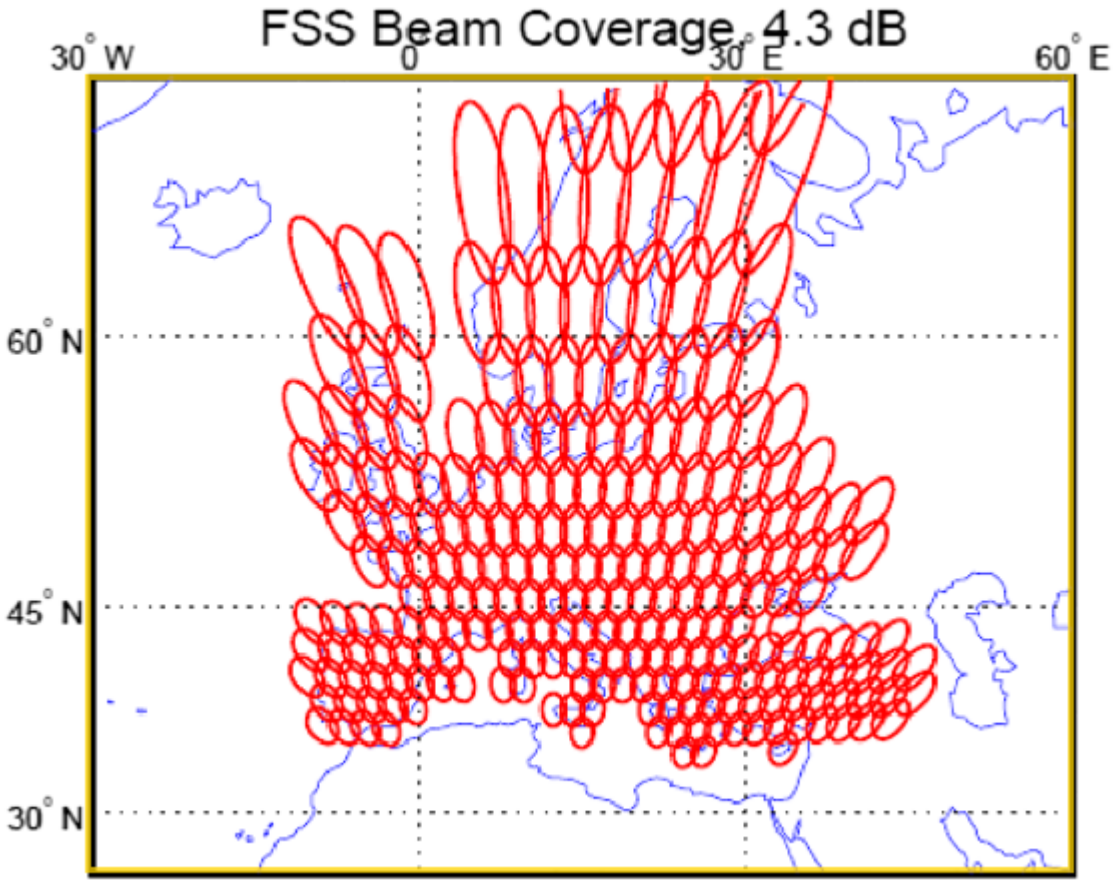
A motivation case:
linear precoding for multibeam satellites



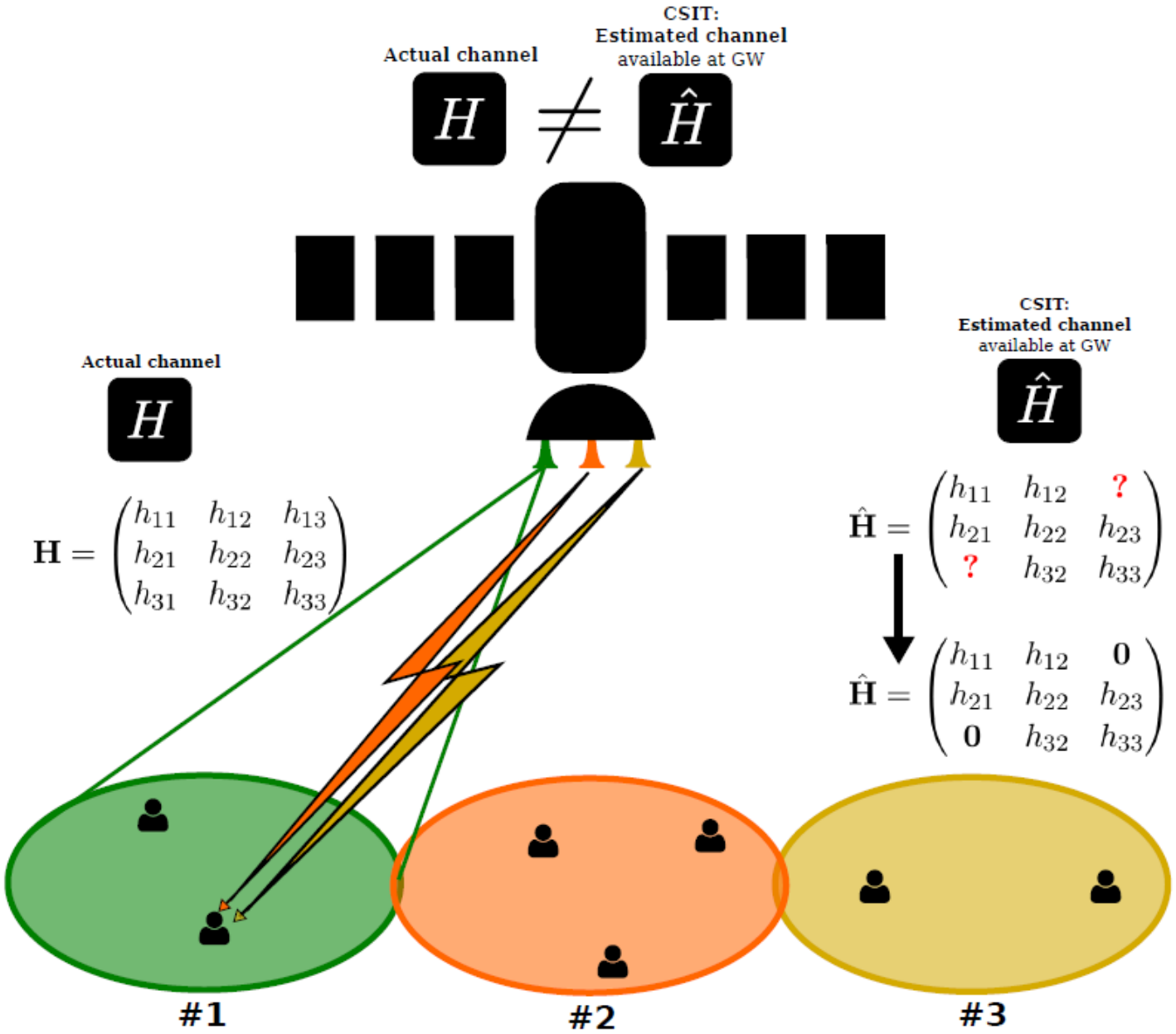
Input-output → $y = Hx + n$

Linear precoding → $x = Ws$

Imperfect channel → information $W = \text{Function of } \hat{H}$

Tato, A., Andrenacci, S., Lagunas, E., Chatzinotas, S., and Mosquera, C.
"Link adaptation and SINR errors in practical multicast multibeam satellite systems with linear precoding."
International Journal of Satellite Communications and Networking, **2022**.

Channel State Information at the Transmitter (CSIT) is not perfect: nullification effect



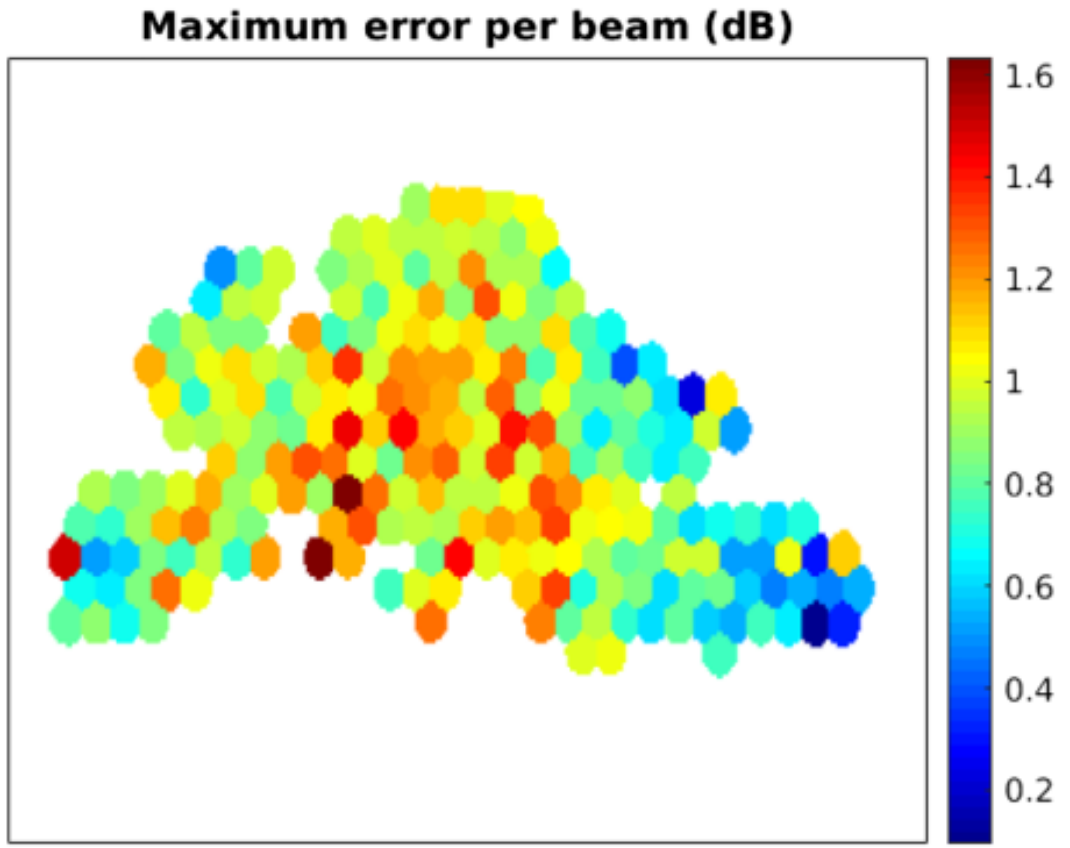
Performance is not accurately predicted

$$\widehat{\mathsf{sinr}}_k = \frac{|\hat{\boldsymbol{h}}_k^H \boldsymbol{w}_k|^2}{\sum_{j \neq k} |\hat{\boldsymbol{h}}_k^H \boldsymbol{w}_j|^2 + \sigma_n^2}$$

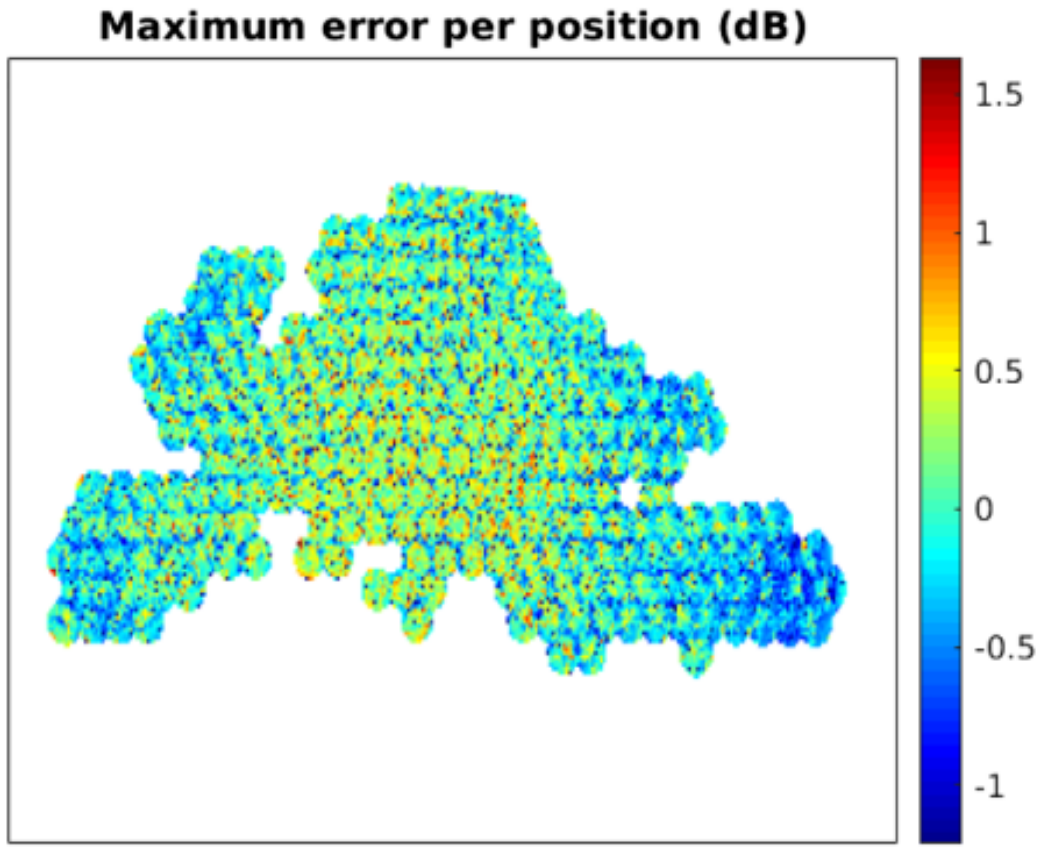
kth user

$$E_k = \widehat{\mathsf{SINR}}_k - \mathsf{SINR}_k \ (\mathrm{dB})$$

SINR Prediction Error

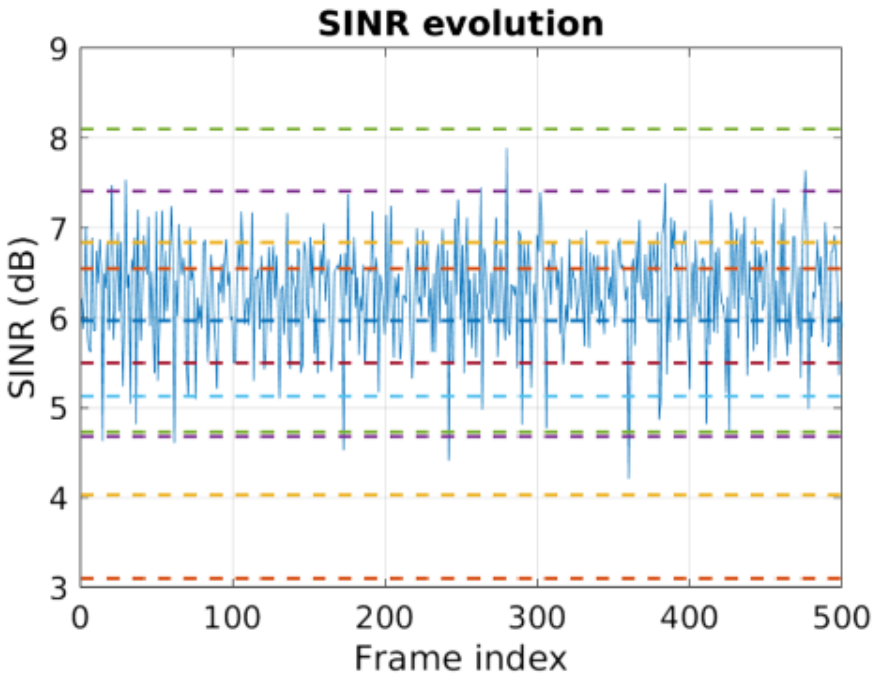


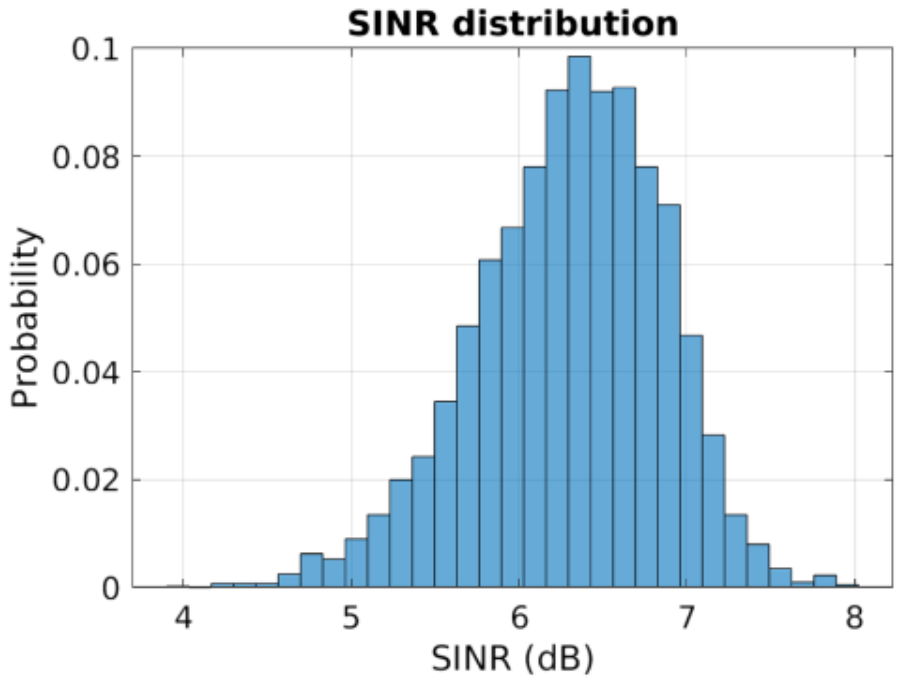
(A) Maximum error per beam.

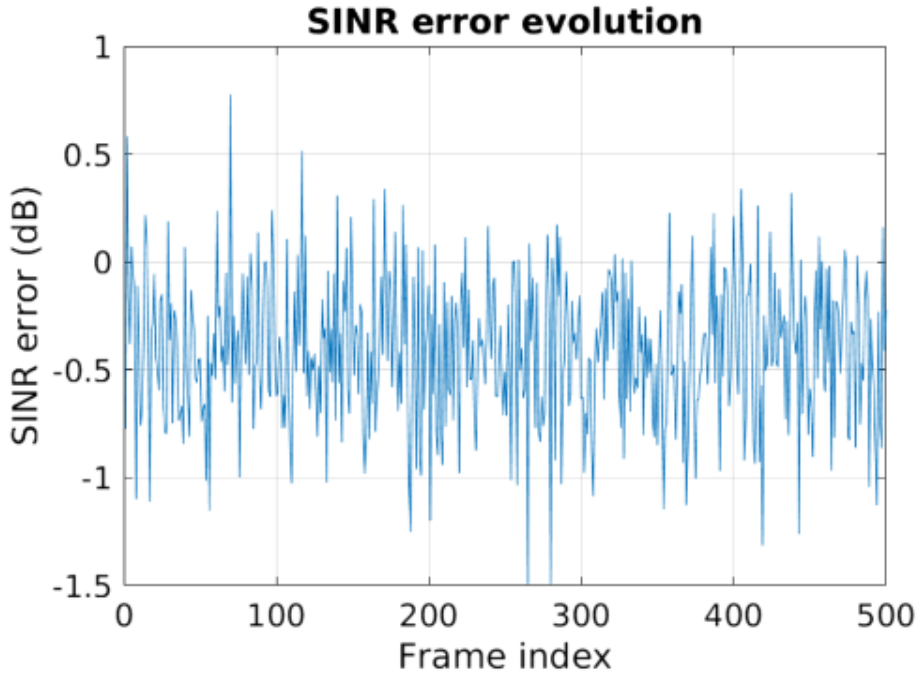


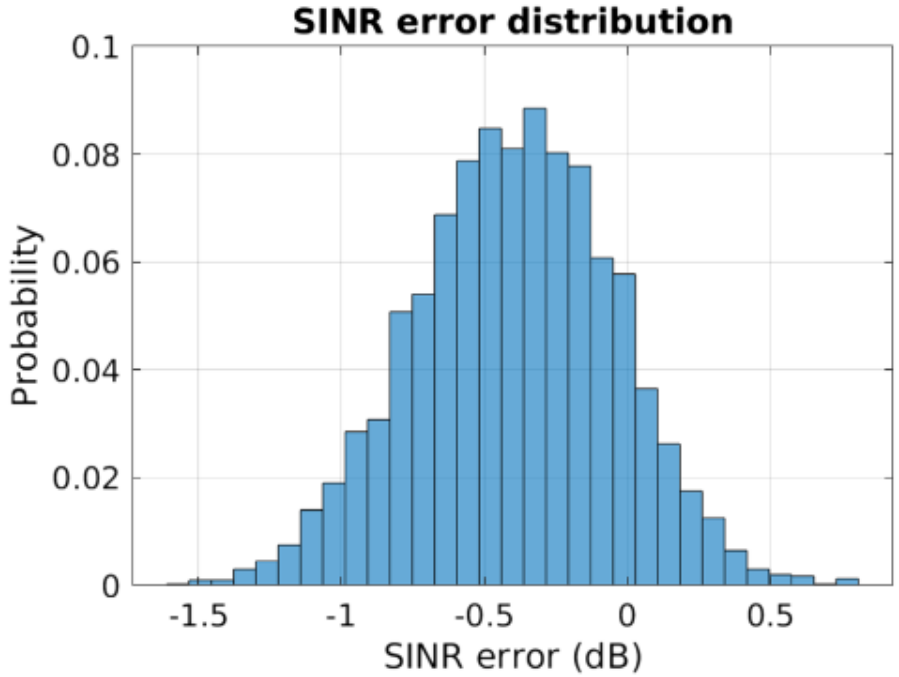
(B) Maximum error per position.

Time evolution for a fixed user









Modulation and Coding Scheme (MCS) Selection

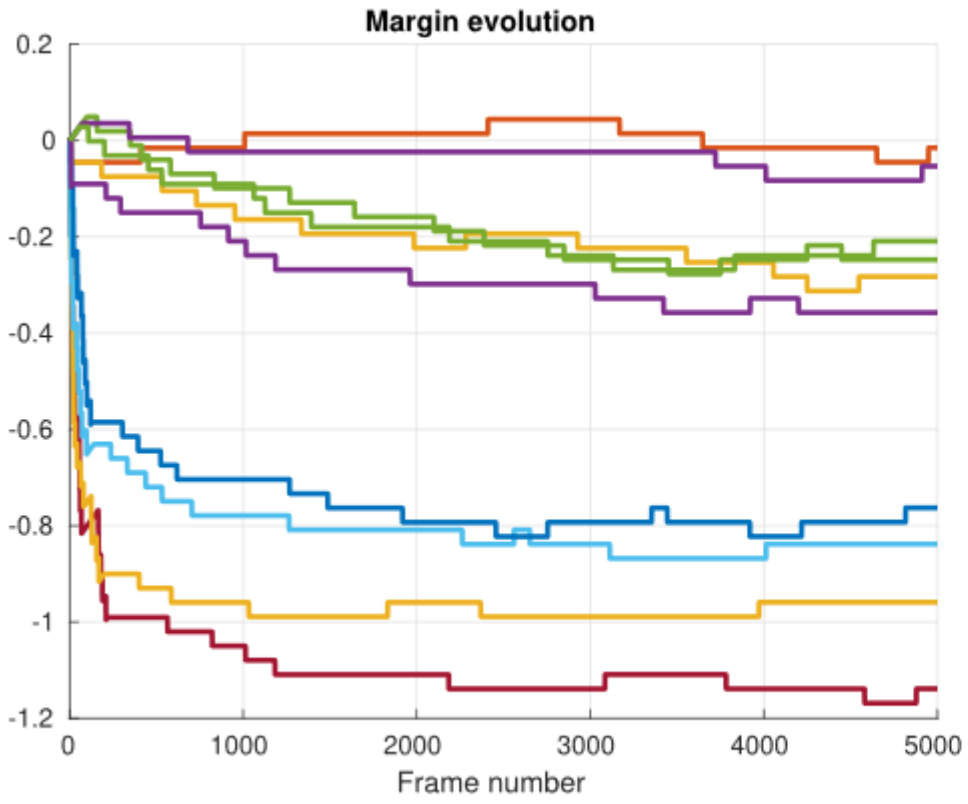
- **Look-Up-Table (LUT)** mapping SNR intervals to CQI values:

$$\mathrm{MCS} = \prod \left(\widehat{\mathrm{SINR}} + m \right)$$

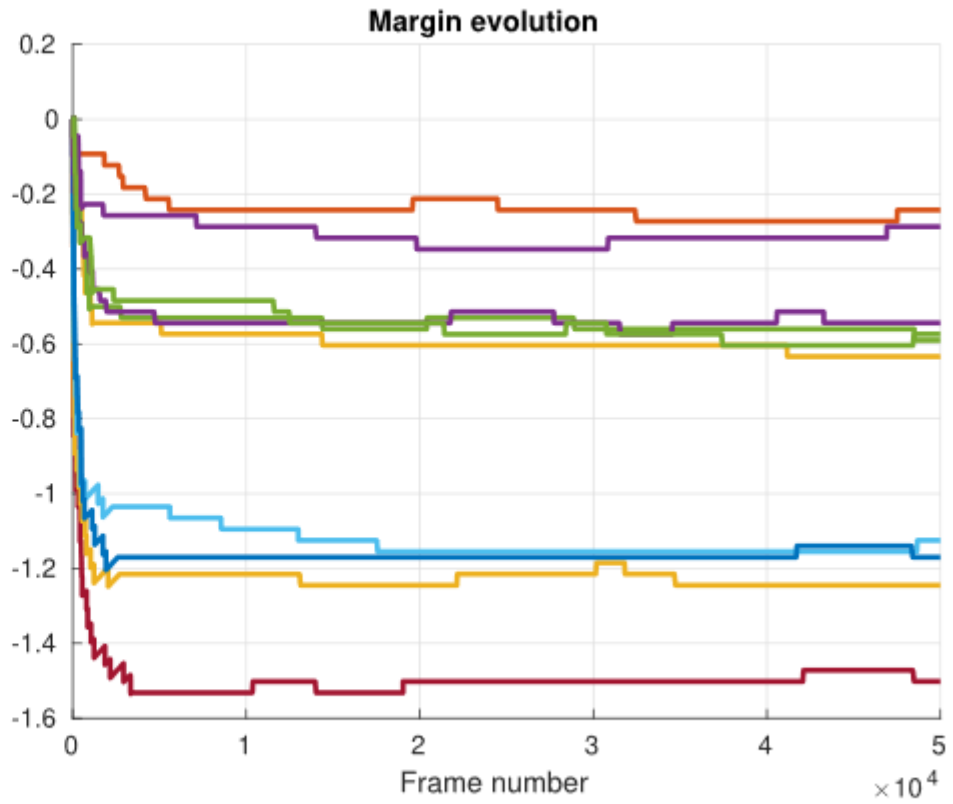
- **Margin** *m*: accounts for modeling uncertainty, partial or outdated CSIT
- Adjustment of margin becomes instrumental for high efficiency: **adaptive control**

Adaptive Control of Back-off Margin

- 10 users
- Feedback:
  - SINR
  - ACK/NAK



(A) Target FER 0.01



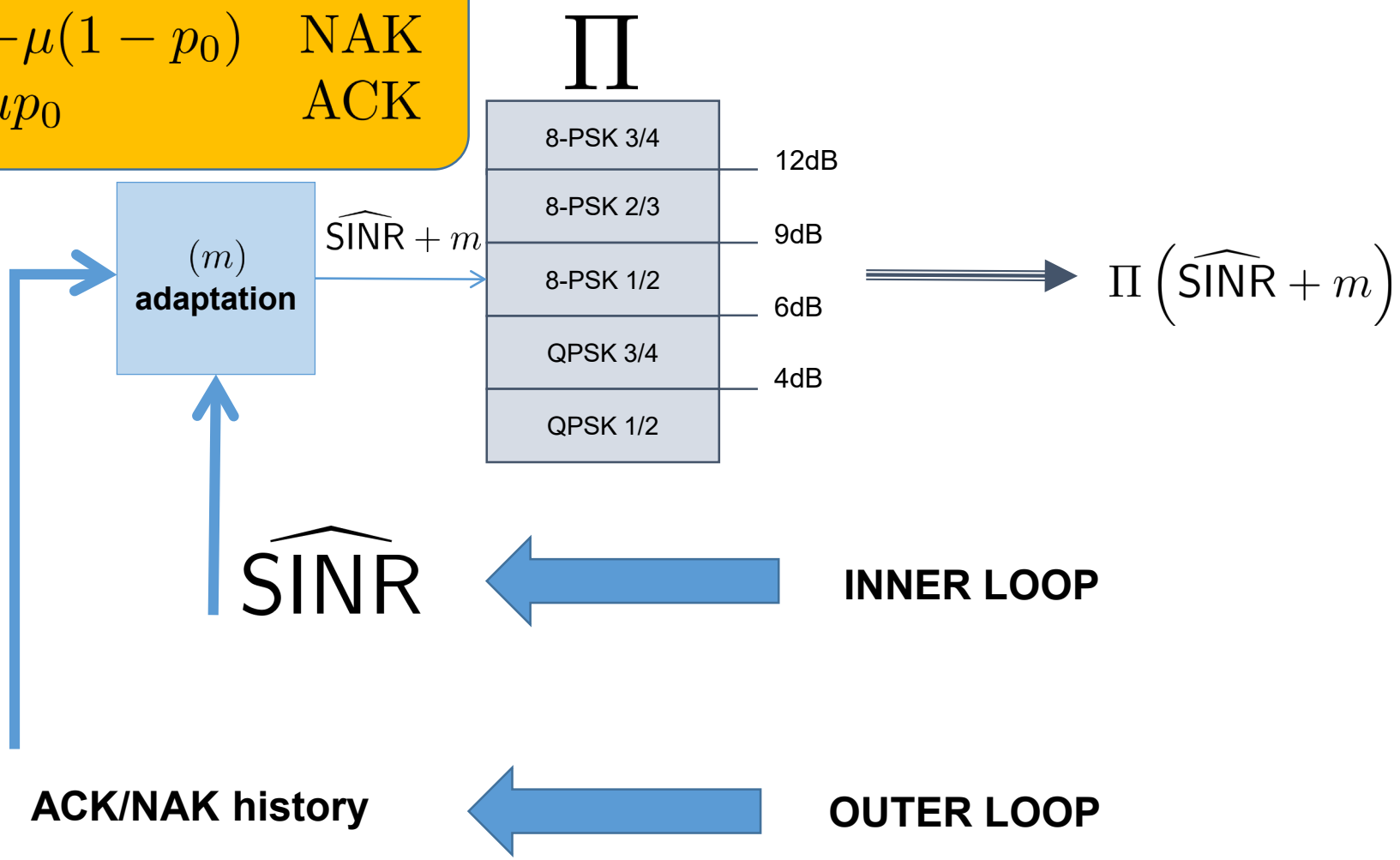
(B) Target FER 0.001

Next

1. **Adaptation loops**
2. **Rate splitting**
3. **Spatial modulation and NOMA**
4. **Conclusions**

OLLA: Outer/Inner Adaptation Loop

$$m_{i+1} - m_i = \begin{cases} -\mu(1-p_0) & \text{NAK} \\ \mu p_0 & \text{ACK} \end{cases}$$



Improvements and Recent Trends

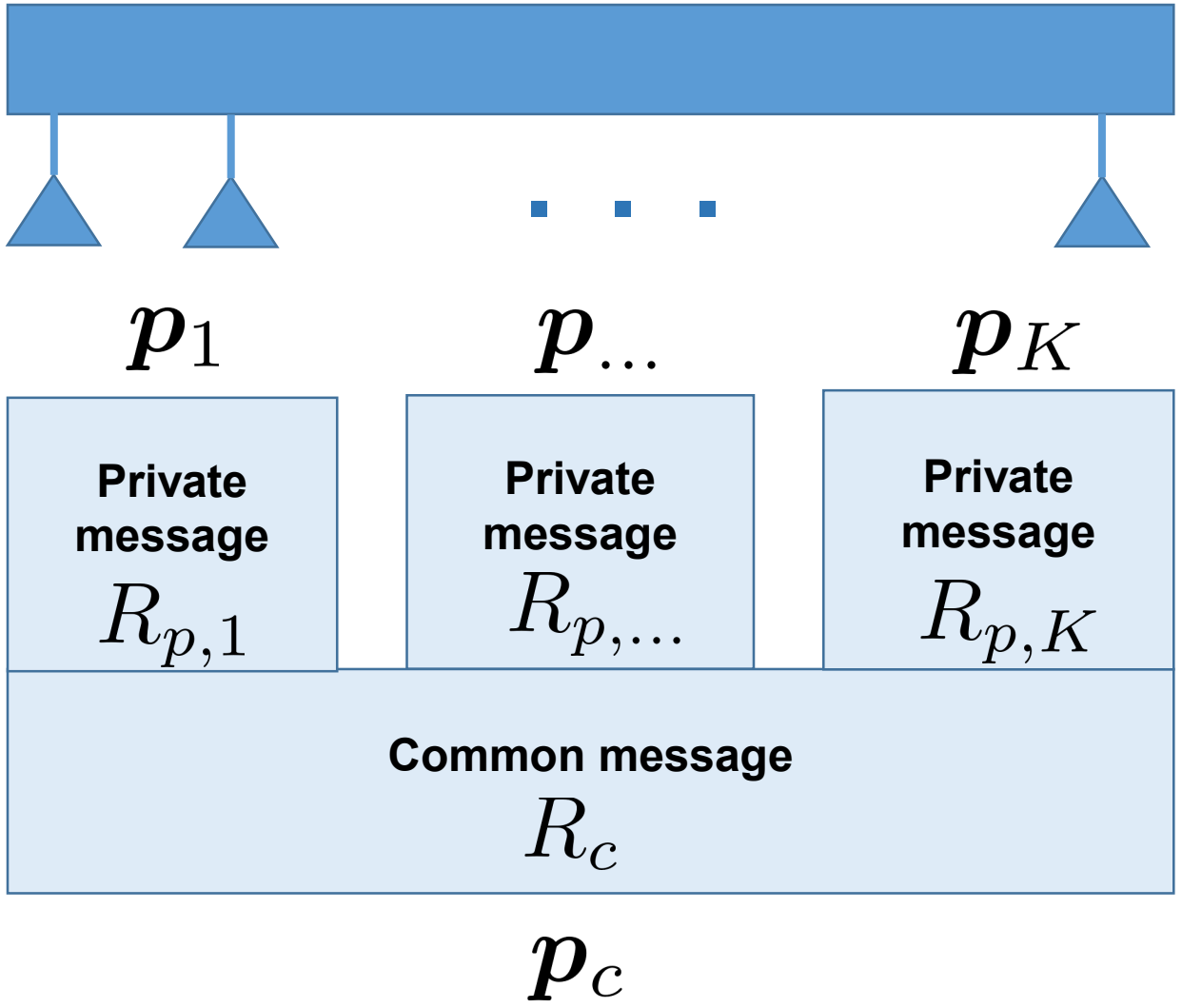
- Some refinements exist for faster convergence and lower variance, based, e.g., in **sequential hypothesis testing**
- **Reinforcement learning** blends naturally with OLLA, by exploiting the ACK/NACK feedback
- Exploration vs. Exploitation: **Multi-Armed Bandits**
- Different **Bayesian** flavors, e.g., Thomson sampling
- Most of these techniques apply to **single-user links**

V. Saxena, H. Tullberg and J. Jaldén, **"Reinforcement Learning for Efficient and Tuning-Free Link Adaptation,"** in *IEEE Transactions on Wireless Communications*, 2022

Rate Splitting (RS)

$$\widehat{\text{sinr}}_{p,k} = \frac{|\hat{\boldsymbol{h}}_k^H \boldsymbol{p}_k|^2}{\sum_{j \neq k} |\hat{\boldsymbol{h}}_k^H \boldsymbol{p}_j|^2 + \sigma_n^2}$$

$$\widehat{\text{sinr}}_{c,k} = \frac{|\hat{\boldsymbol{h}}_k^H \boldsymbol{p}_c|^2}{\sum_{j=1}^{K} |\hat{\boldsymbol{h}}_k^H \boldsymbol{p}_j|^2 + \sigma_n^2}$$



Two-level decoding

RS Back-off Margin

- Two-level decoding:

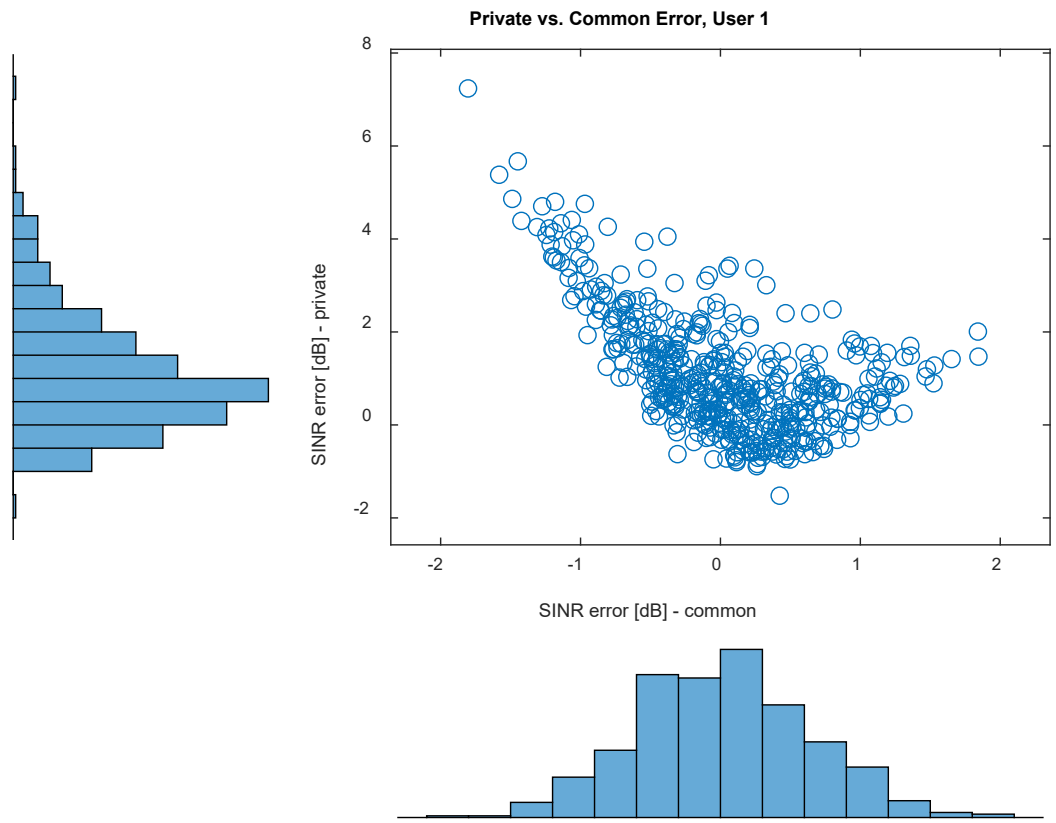
$$P_{outage} = \mathbb{P}\{(\mathsf{sinr}_{c,k} < 2^{R_c} - 1) \bigcup (\mathsf{sinr}_{p,k} < 2^{R_{p,k}} - 1)\}$$

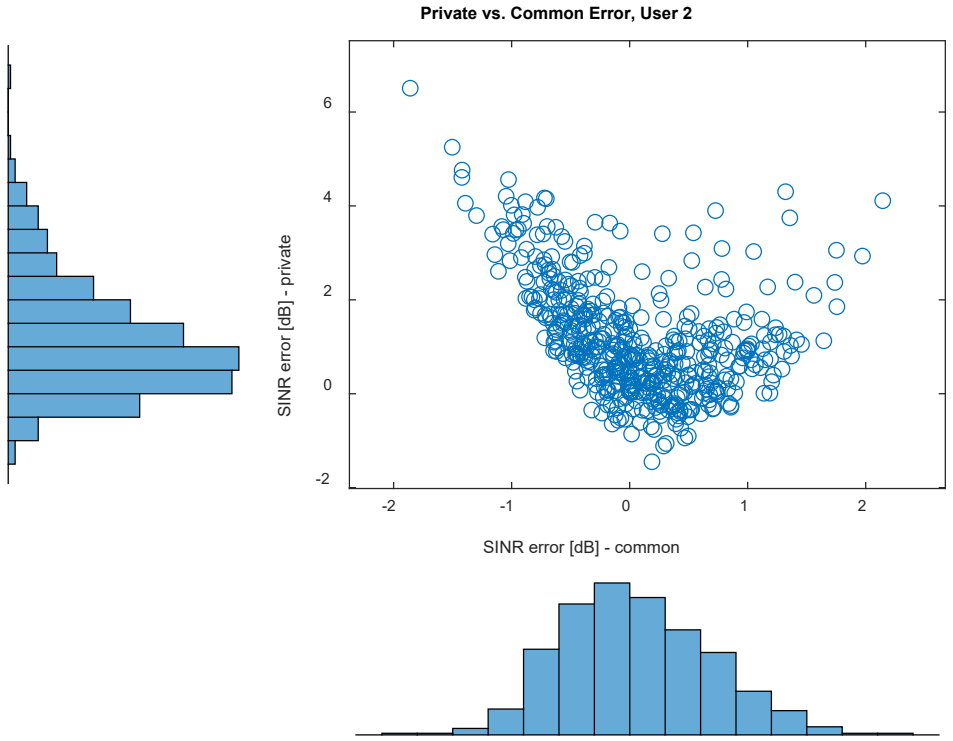
$$\max\left\{P_{outage}^{common}, P_{outage}^{private}\right\} < P_{outage} < 2\max\left\{P_{outage}^{common}, P_{outage}^{private}\right\}$$

- Margins should be adapted for each type of message

RS SINR Prediction Error (two users)

$\hat{\boldsymbol{h}}_1^H = [1, 1]$ $\quad$ SNR $= 20\text{dB}$ $\quad$ $\hat{\boldsymbol{h}}_2^H = [1, e^{j\pi/2}]$



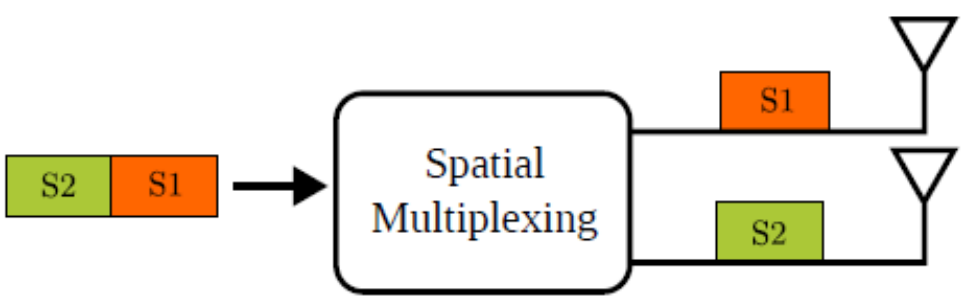


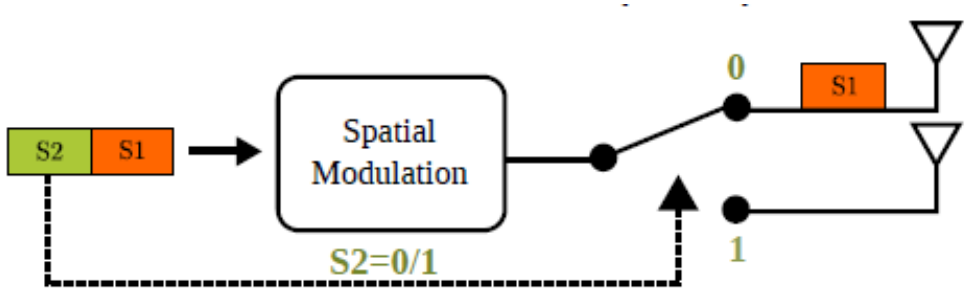
CSIT error: $\mathcal{CN}(0, 0.1)$

Code provided by Yijie (Lina) Mao, Shanghai Tech

Spatial Modulation

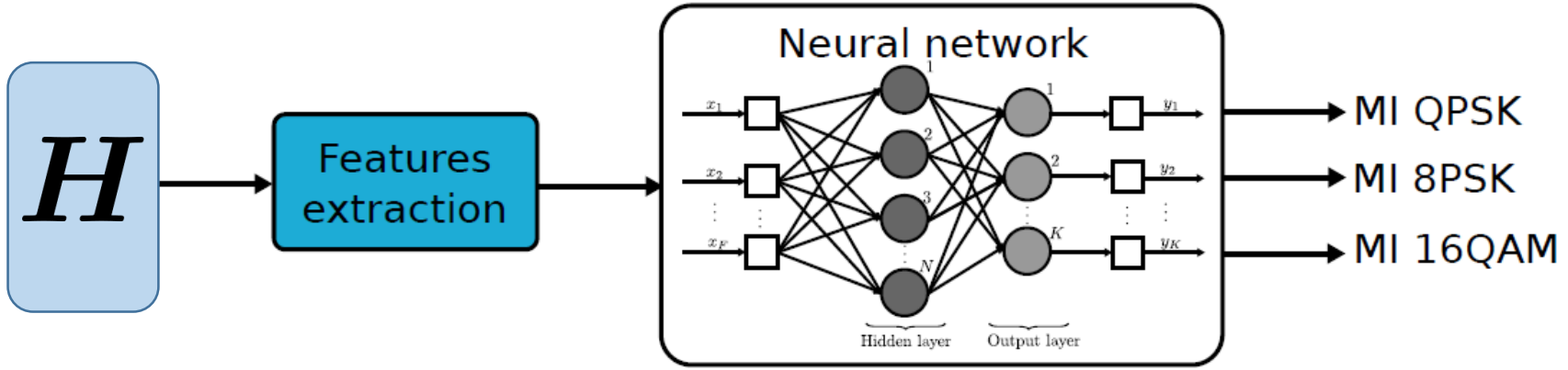
- Lower number of RF chains



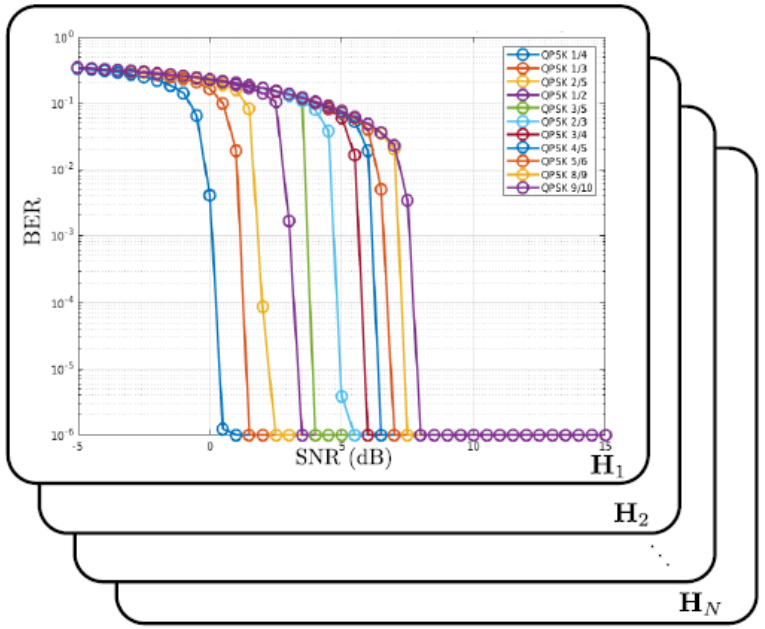


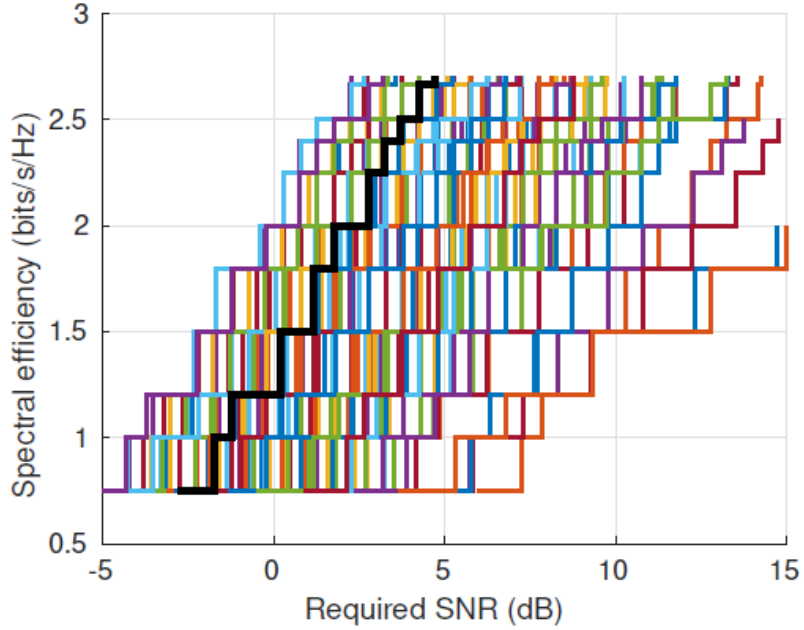
- Maximum achievable rate is a very complex function to evaluate

Model-Driven Deep Learning Evaluation of Achievable Rate



(1)

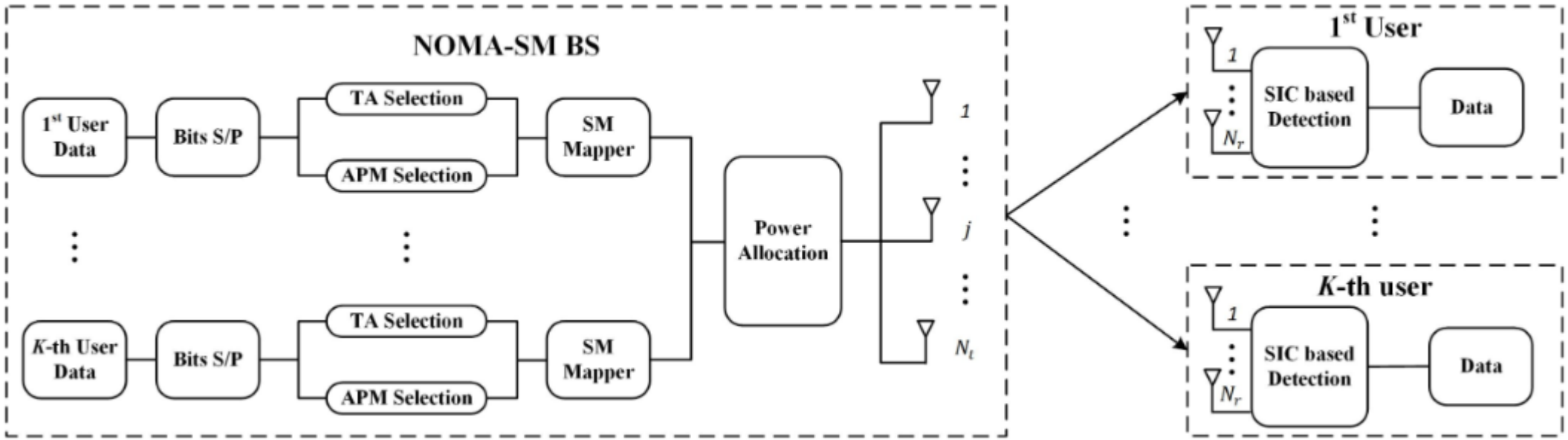




(2)

Spatial Modulation and NOMA

- Receivers: spatial index demodulation + SIC



Wang, Z., & Cao, J. **"NOMA-based spatial modulation"**, IEEE Access, **2017**

Conclusions

- Imperfect CSIT → unknown achievable rates
- Some novel modulation schemes → complex mapping between channel and achievable rates
- Link adaptation plays a major role to navigate through the channel limits

Contributions from:

- Anxo Tato, Eva Lagunas, Stefano Andrenacci, Symeon Chatzinotas, Yijie (Lina) Mao, Pol Henarejos, Ana Pérez-Neira

References

- Alberto Rico-Alvariño, Jesús Arnaú, and Carlos Mosquera. **"Link adaptation in mobile satellite links: schemes for different degrees of CSI knowledge."** International Journal of Satellite Communications and Networking, 2016.
- Tato, A., Andrenacci, S., Lagunas, E., Chatzinotas, S., and Mosquera, C. **“Link adaptation and SINR errors in practical multicast multibeam satellite systems with linear precoding.”** International Journal of Satellite Communications and Networking, 2022.
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- Mosquera, C., Noels, N., Ramírez, T., Caus, M., & Pastore, A. (2021). **“Space-Time Rate Splitting for the MISO BC with Magnitude CSIT”.** IEEE Transactions on Communications, 2021.
- Tato, Anxo, and Carlos Mosquera. "**Deep Learning Assisted Rate Adaptation in Spatial Modulation Links.**" 2019 16th International Symposium on Wireless Communication Systems (ISWCS). IEEE, 2019.