Link Adaptation and Carriers Detection Errors in Multibeam Satellite Systems with Linear Precoding

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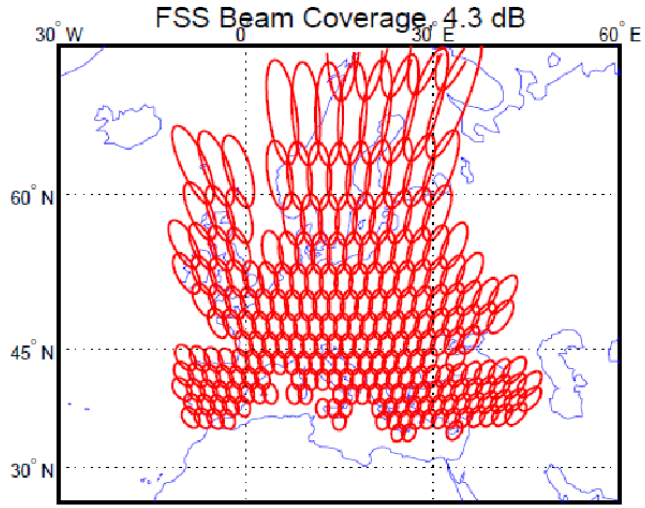
Introduction

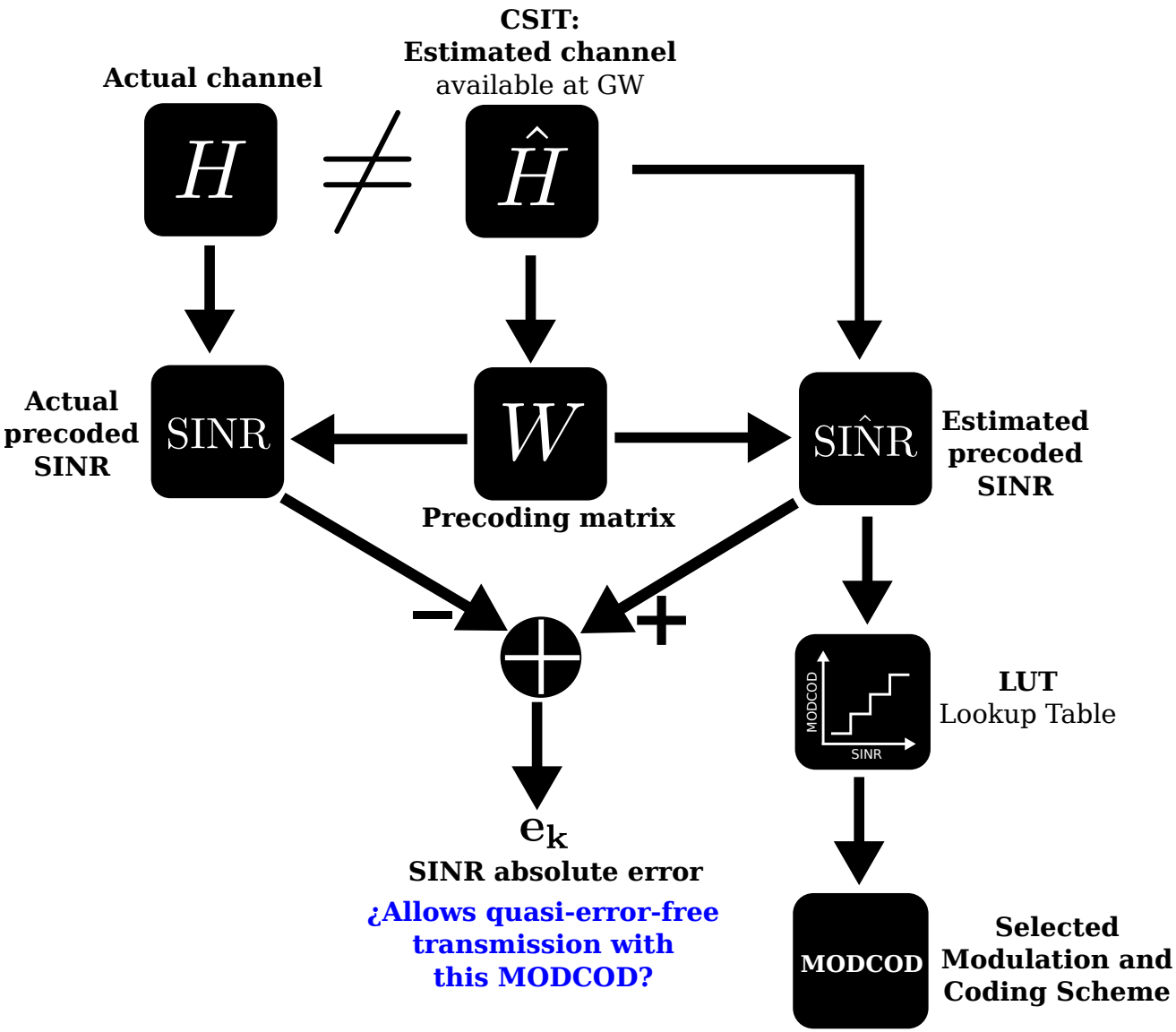
- High Throughput Satellite (HTS) at Ka-band
  - Multibeam satellite + Linear Precoding + Link Adaptation



Full Frequency reuse, 245 beams

- Imperfect Channel State Information at the Transmitter (CSIT)
  - Carriers detection errors = Nullification
- Unicast
- Random interbeam scheduling

Introduction

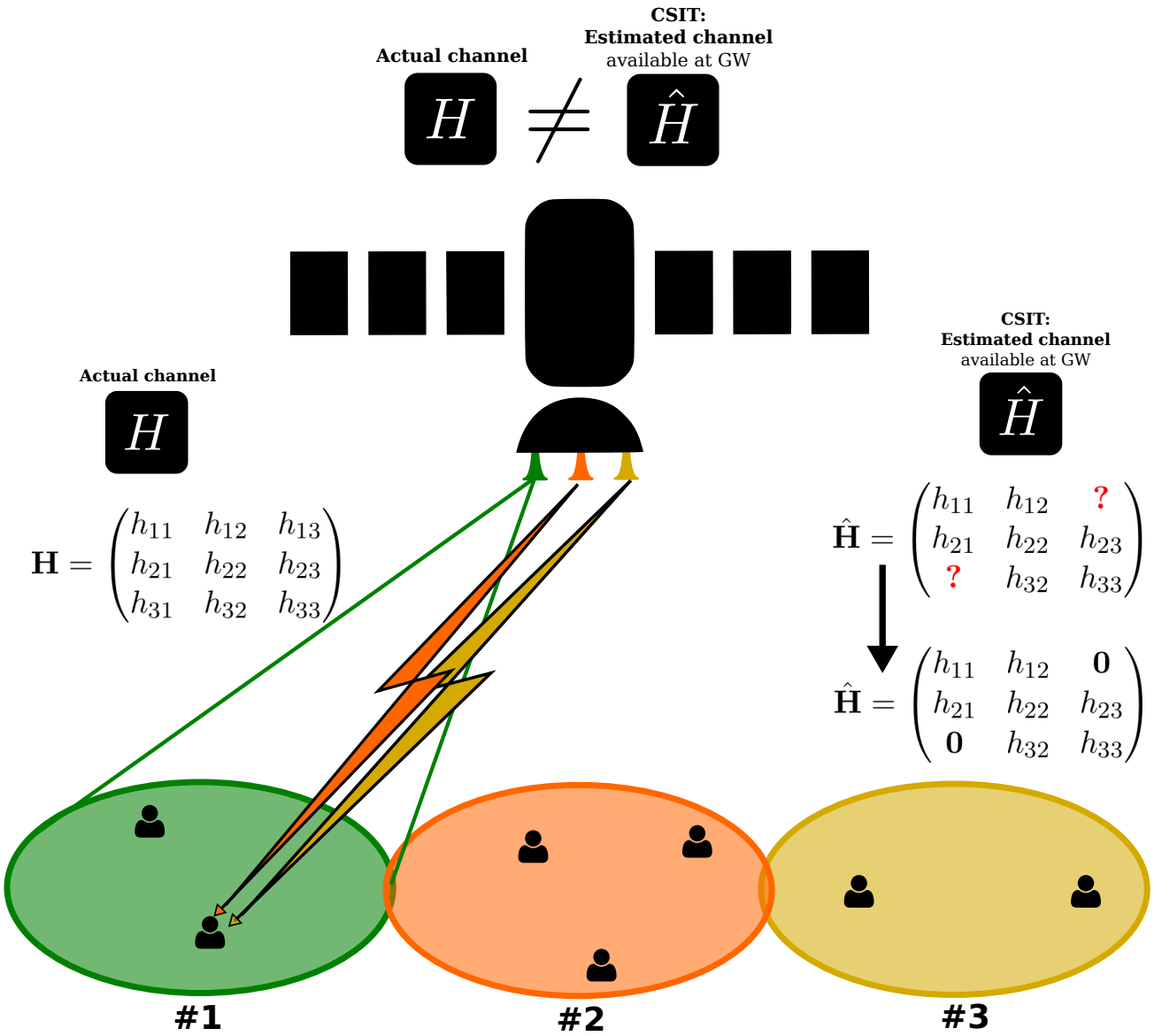


System model

- Signal model:
$$\mathbf{y} = \mathbf{H}\mathbf{x} + \mathbf{n} = \mathbf{H}\mathbf{W}\mathbf{s} + \mathbf{n}$$
- Channel model:
ESA's 245 beams radiation pattern
- $\hat{\mathbf{H}}$: Imperfect CSIT due to...
  - Nullification
  - Gaussian estimation errors
- Linear Precoding: MMSE with Sum Power Constraint (SPC)

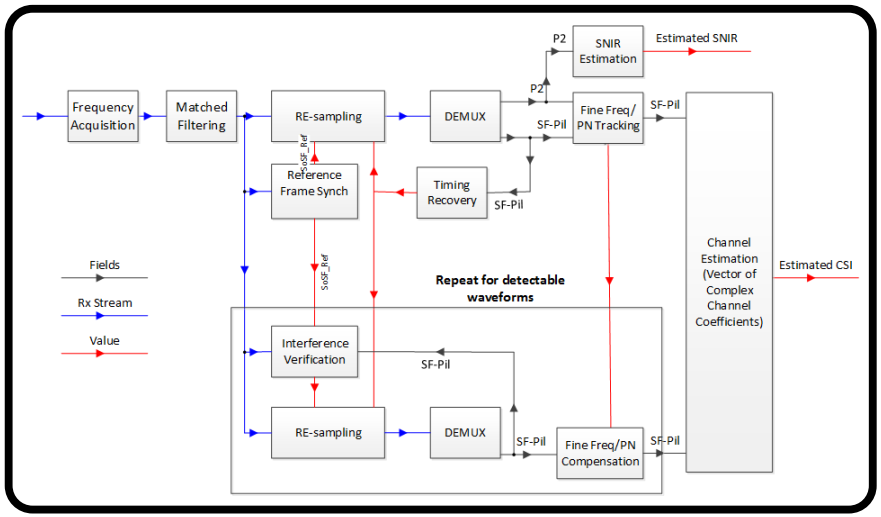
$$\mathbf{W} = \eta \cdot \hat{\mathbf{H}}^H \left(\hat{\mathbf{H}}\hat{\mathbf{H}}^H + \frac{1}{\mathsf{snr}} \mathbf{I}_N \right)^{-1} \tag{1}$$

Nullification effect

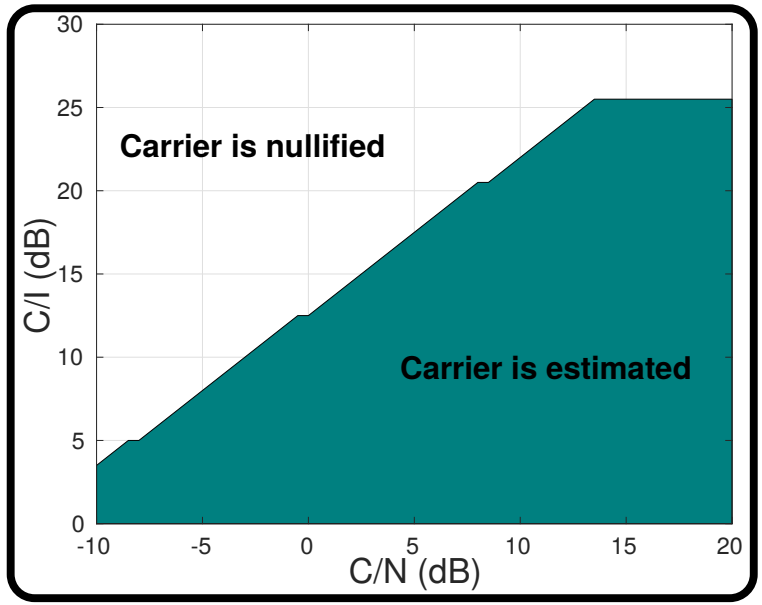


Nullification description

- Estimation of CSI coefficients:
  - **Asynchronous systems** $\rightarrow$ I/C ≈ -15 dB
  - **Synchronous systems:** $\rightarrow$ I/N ≈ -15 dB
  - **Real system:**

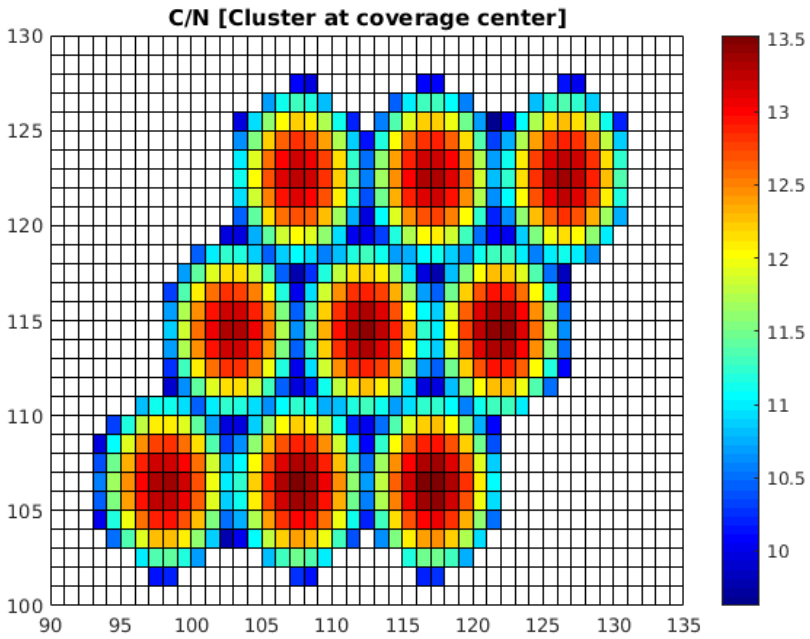


Architecture of the receiver for CSI detection and estimation

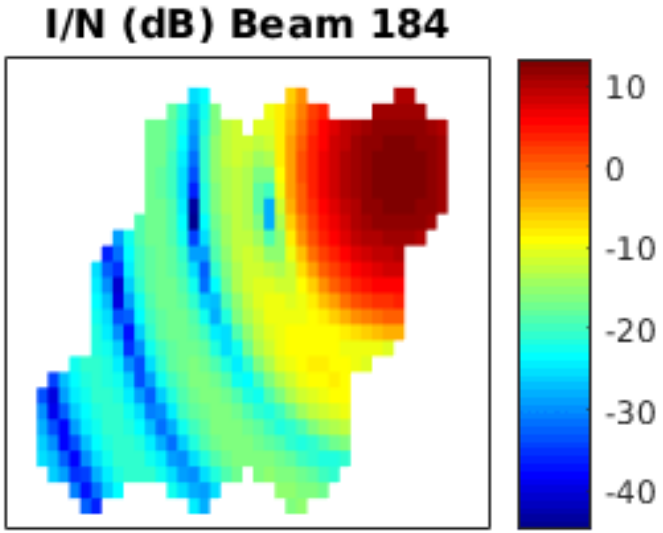


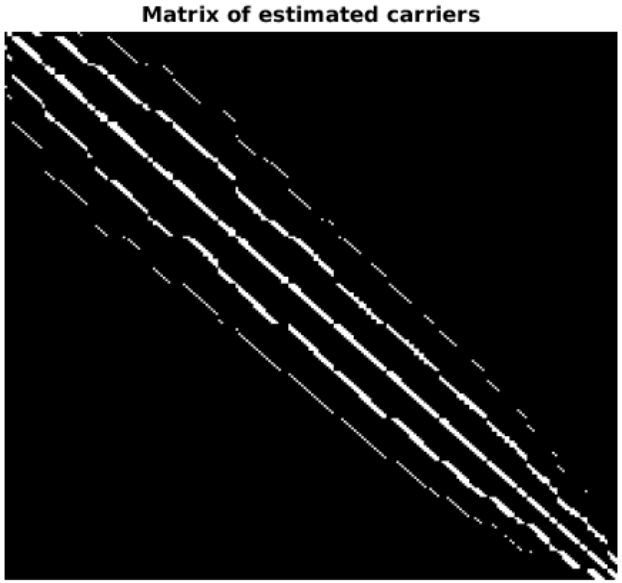
CSI estimation performance

Example of nullification



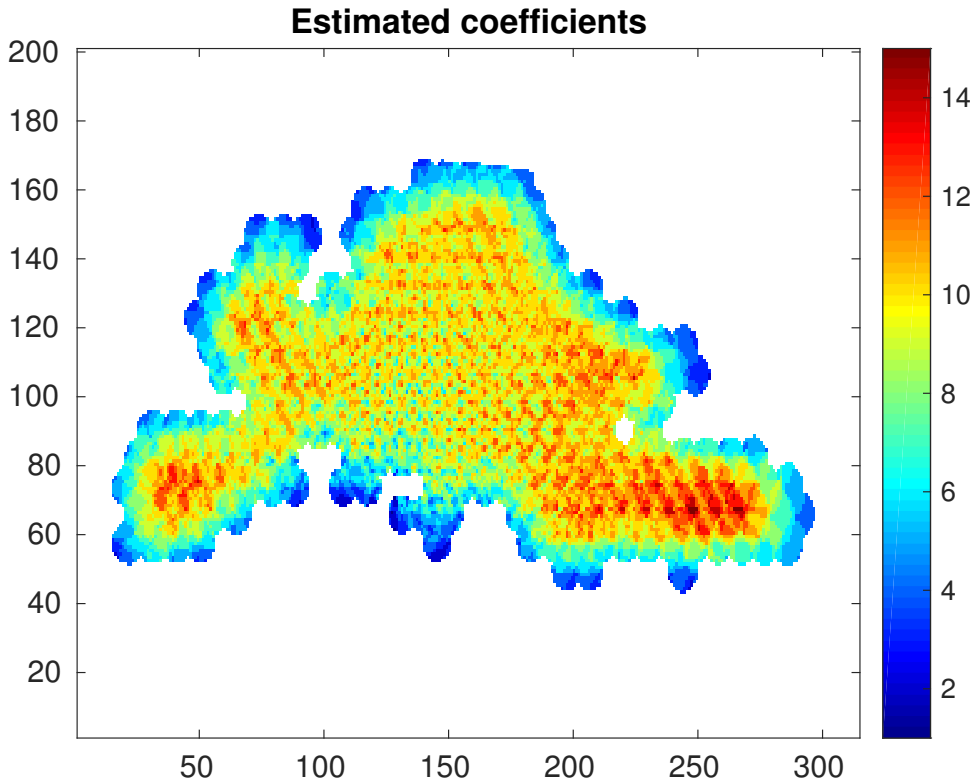
Carrier to Noise in a subset of 9 beams





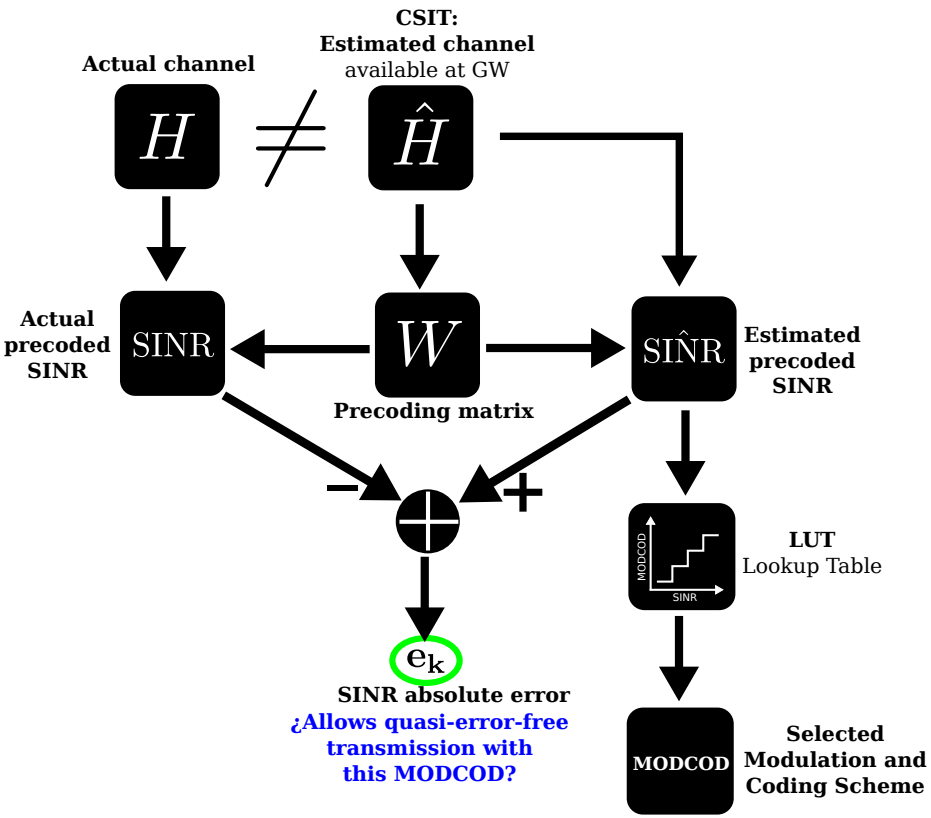
Number of estimated channel coefficients

- Total number of coefficients per channel vector = **245**
- DVB-S2X standard allows to report up to **32** coefficients
- Number of estimated coefficients with nullification: **1-15**



Results with real nullification

SINR absolute error due to nullification



- **SINR calculated by the GW**

$$\hat{\mathsf{sinr}}_k = \frac{|\hat{\mathbf{h}}_k^{\perp}\mathbf{w}_k|^2}{\sum_{j\neq k}|\hat{\mathbf{h}}_k^{\perp}\mathbf{w}_j|^2 + N_0}$$

- **Actual user SINR**

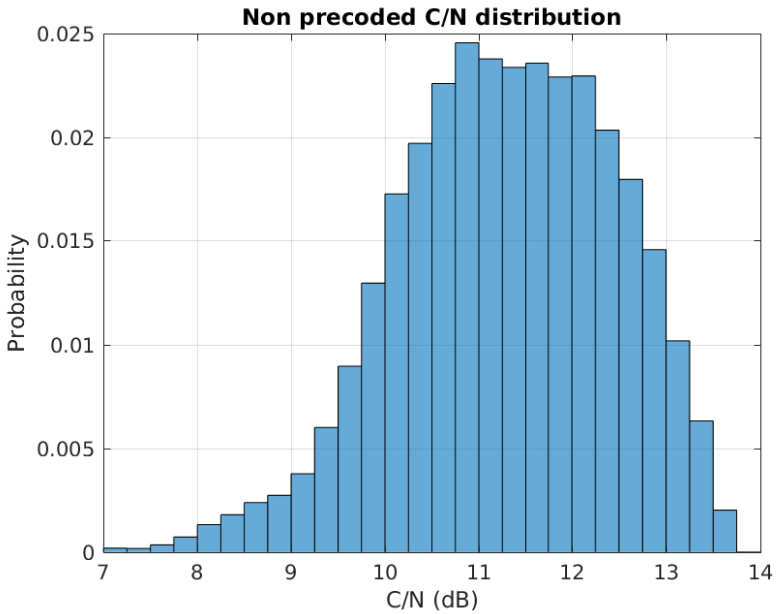
$$\mathsf{sinr}_k = \frac{|\mathbf{h}_k^{\perp}\mathbf{w}_k|^2}{\sum_{j\neq k}|\mathbf{h}_k^{\perp}\mathbf{w}_j|^2 + N_0}$$

- **SINR absolute error in dB**

$$e_k = 10\log_{10}\hat{\mathsf{sinr}}_k - 10\log_{10}\mathsf{sinr}_k$$

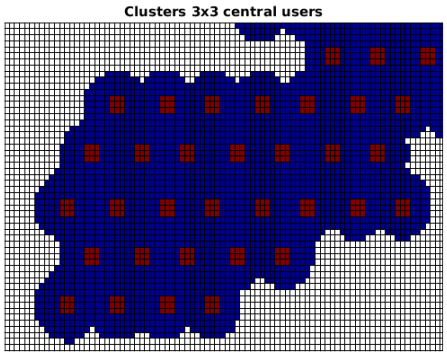
System parameters

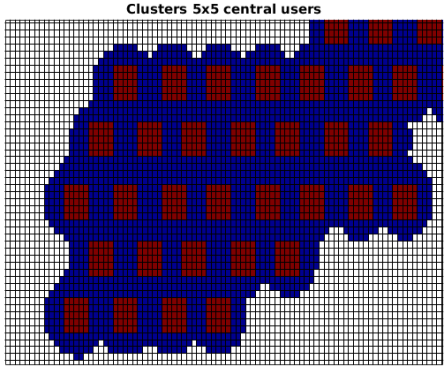
Parameter	Value
Satellite orbit	GEO
Downlink frequency	Ka-band (20 GHz)
Number of beams	245
Color scheme	Full frequency reuse
Fading	No fading

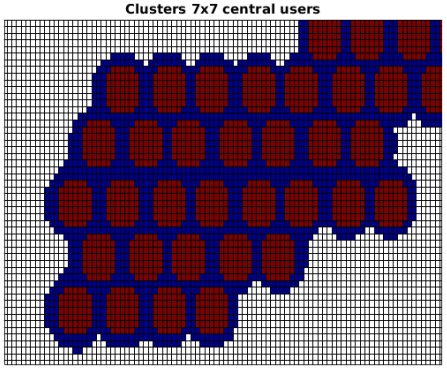


Interbeam scheduling

- **Unicast**: only one user served per beam in each frame
- **Interbeam scheduling:** Users selecting user randomly among...
  - central positions of the beam within a radius of 2/6, 3/6 or 4/6 of the total beam radius
  - all beam positions

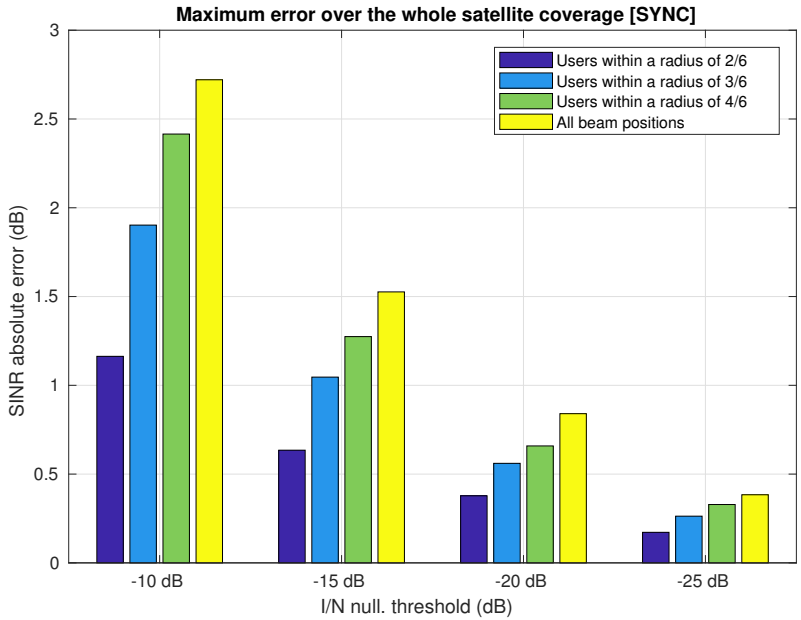




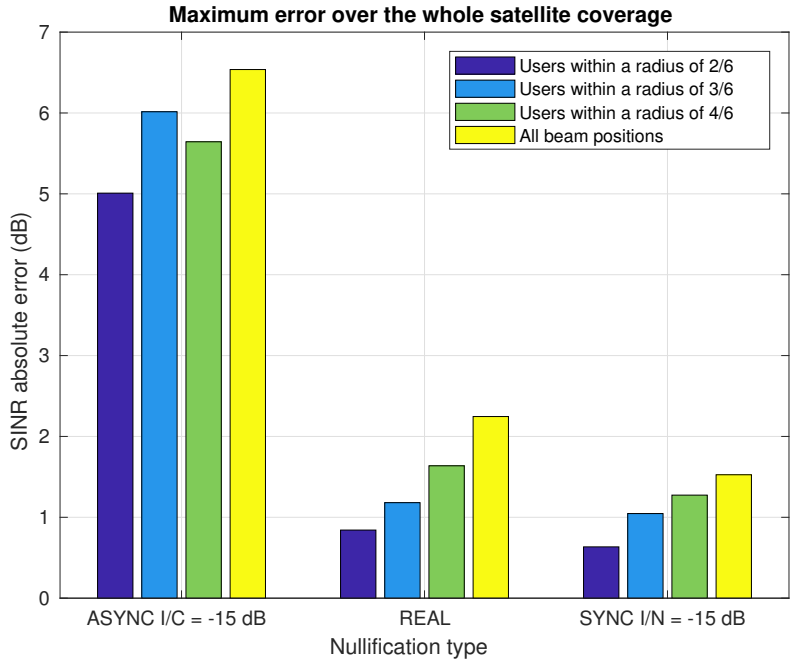


Maximum of the SINR absolute error (global results)

- Synchronous nullification

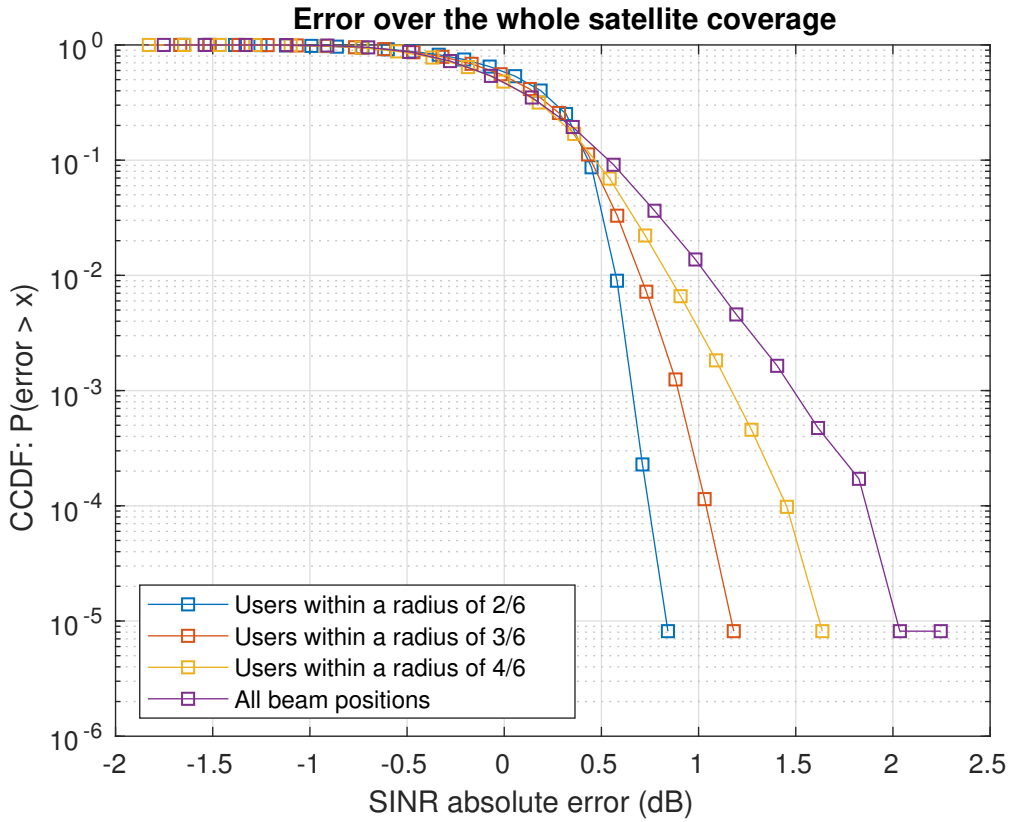


- Comparison different nullifications



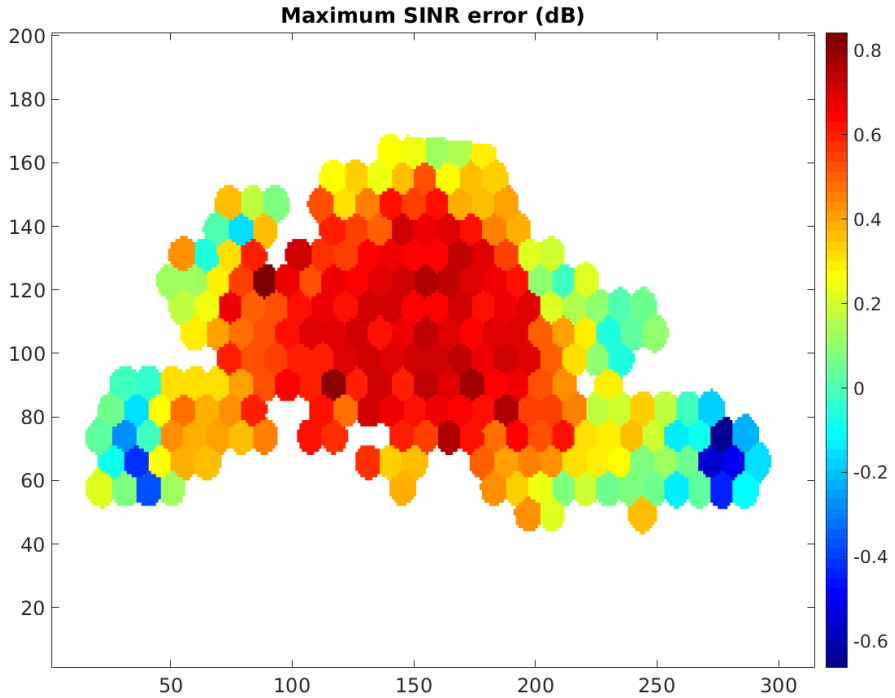
Complementary CDF of the error

- Margin required to guarantee a given Frame Error Rate (FER) in all the coverage



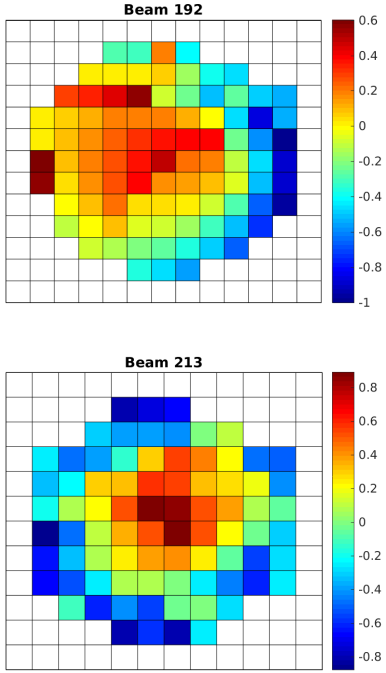
- High capacity losses due to the required large margins!

Geographical distribution of the error



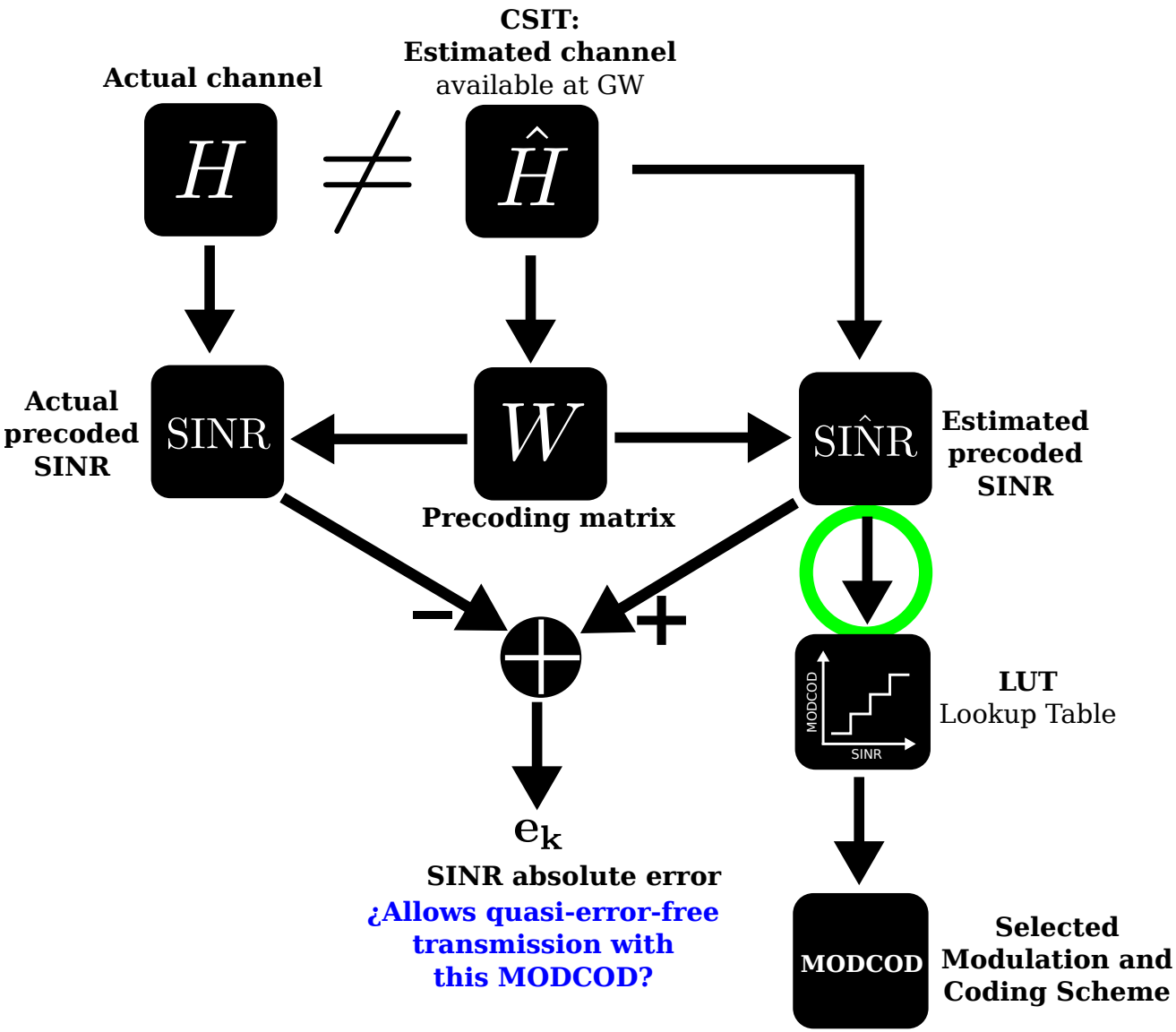
Map of the SINR maximum error per beam over 1,000 realizations with MMSE-SPC precoder, real nullification and scheduling users from inner circle of radius 2/6

Maximum error per position when in the rest of the beams a random user is scheduled from the 3x3 central users



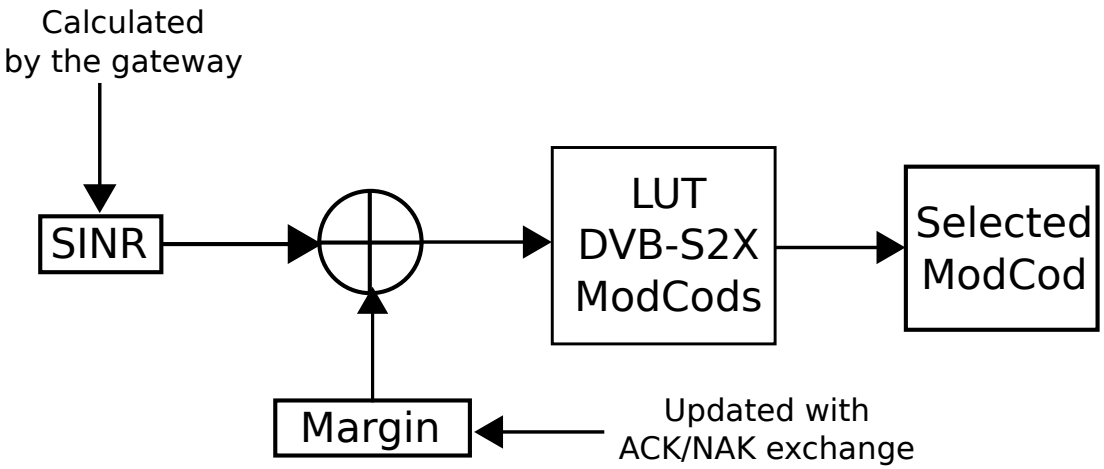
- Best solution: independent margin per user to avoid performance loss of worst-case margin.

Countermeasure: link adaptation with adaptive margin



Countermeasure: link adaptation with adaptive margin

- Add to the SINR calculated by the gateway an adaptive margin, independent for each user, updated with its ACK/NAK exchange
  - Note: these are not used for retransmission purposes



  - ACK: Margin $\leftarrow$Margin + Δ_{ACK}
  - NAK: Margin $\leftarrow$Margin - Δ_{NAK}
    - $\frac{\Delta_{\mathrm{ACK}}}{\Delta_{\mathrm{NAK}}} = \frac{p_0}{1-p_0}$, p_0 = Target FER (Typically 1E-5)

Simulation results

- **Scenario:**
  - Continuous transmission of frames to 10 users located in 10 non-neighbour beams scattered over all Europe.
  - **Target FER**: $p_0 = 10^{-3}, 10^{-4}, 10^{-5}$

- **Results:**
  - **Without adaptive margin**
    - FER $\gg$ Target value p_0
  - **With adaptive marging**
    - Experimental FER of users is within $90 - 110\%$ of the target FER Avoiding the performance loss of a global fixed margin.

Thanks for your attention!

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