PEPR NF-PERSEUS

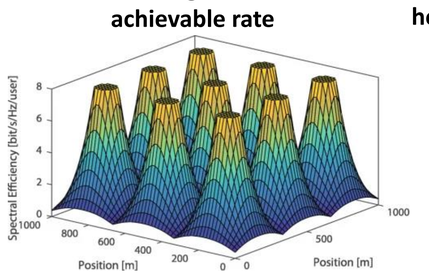
Antoine Durant - CEA-LETI

Study of cell-free massive MIMO under hardware impairments for low-energy consumption networks

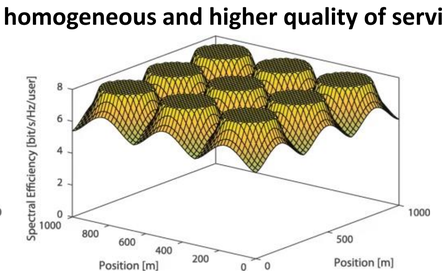
A shift in paradigm : Cell-Free massive MIMO

Traditional cellular networks have **limited performance** :
→ Signal power is proportional with **distance to the access point** (AP)
→ Densification is not a solution due to **inter-cell interferences**

Small cells : high variations in achievable rate



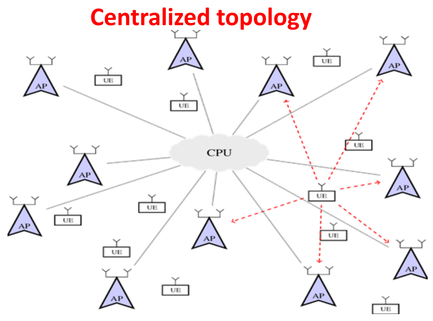
Cell-Free : cooperation allow for homogeneous and higher quality of service



Challenges :

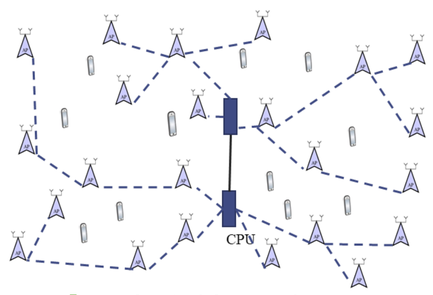
- How to provide high spectral efficiency while :
1) Dealing with many users (UE) and access point (AP) **= Scalability**
2) Having fewer antennas per AP compared to mMIMO **= Few degrees of freedom**

Centralized topology



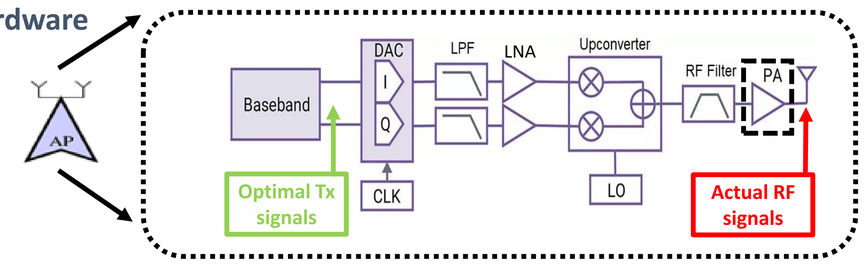
- **High computational complexity**
- **Need for high capacity fronthaul links**

Segmented serial topology



- **Local or Serial processing**
- **Easy deployement** (radio stripes)
- **Segmented fronthaul**

Problem : Cell-Free mMIMO is **economically attractive** only **with low-cost and energy efficient hardware**



Methodology

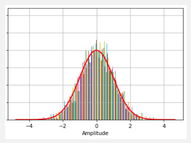
Evaluation of the performance in CF-mMIMO systems :

$$\mathrm{SINR}_{k,m} = \frac{|\mathrm{DS}_{k,m}|^2}{E\{|\mathrm{BU}_{k,m}|^2\} + \sum_{t=1,t\neq k}^{K} E\{|\mathrm{MUI}_{k,t,m}|^2\} + E\{|\mathrm{HWI}_{k,m}|^2\} + E\{|\mathrm{NO}_{k,m}|^2\}}$$

Useful Signal — Precoding uncertainty — Multi-user interference — Hardware impairment — Noise

Modelling of the hardware-induced impairments (HWI)

x = OFDM signals



Bussgang Theorem

x → Non-linear distortions → y

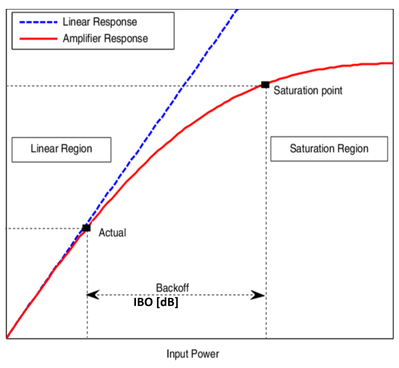
$$y = K_0\, x + d$$

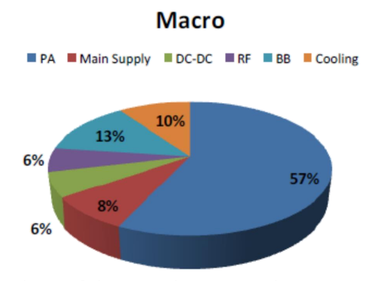
Scaled input ($K0x$) + uncorrelated distortion (d)

$$K_0 = \frac{E\{yx^*\}}{E\{|x|^2\}} \qquad \sigma_d^2 = E\{|d|^2\} = E\{|y|^2\} - K_0 E\{|x|^2\}$$

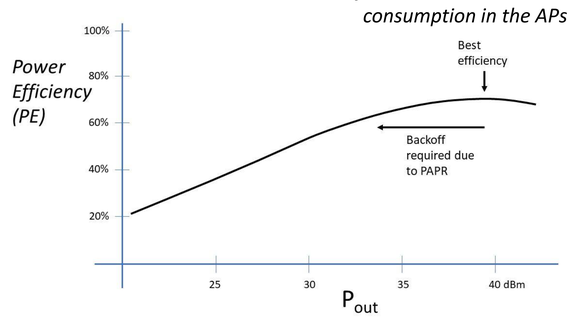
Focus on power amplifiers (PA)

PAs are more efficient near saturation
+ High energy efficiency
- More distortions on the signals



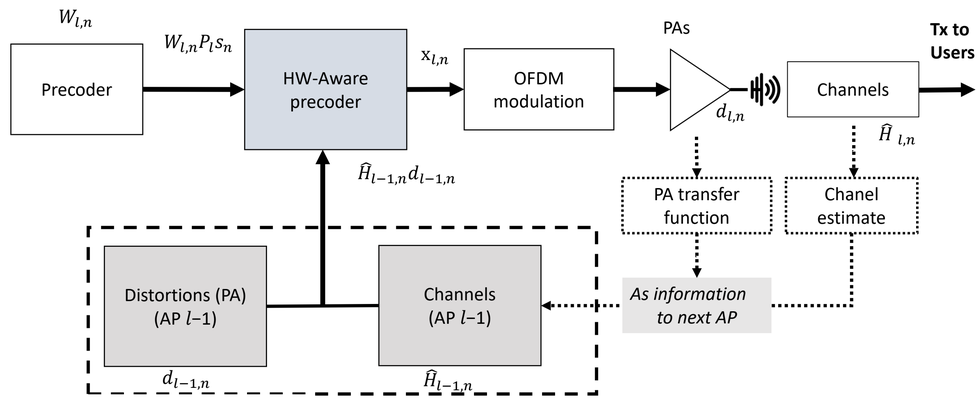


Share of the contributions to the energy consumption in the APs



Results and contributions

Main contribution : Sequential hardware-aware precoding for OFDM cell-free mMIMO systems with serial fronthaul



CDF of the spectral efficiency : M = 8, IBO = 4 dB, K = 7

Median SE against IBO for M = 8, K = 7

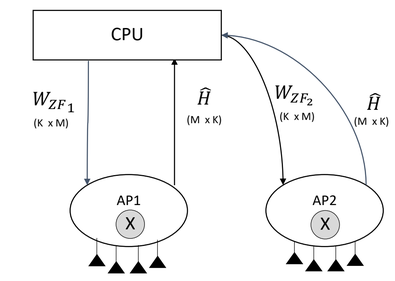
Complexity (nb op.) vs number of users K

- **Serial processing:** distortions and channel information are shared to each successive APs in the fronthaul with a constant size (scalability criteria respected)
- **Over-the-air distortion cancellation :** The users receive destructive contributions for the HWI while maintaining the precoded useful signal unaltered
- **Closed form solution :** Derived for two spatial multiplexing approach : FZF (ful-pilot zero forcing) and PZF (partial zero-forcing)
- **Complexity analysis :** carried for the proposed solution vs other PAPR reduction technics

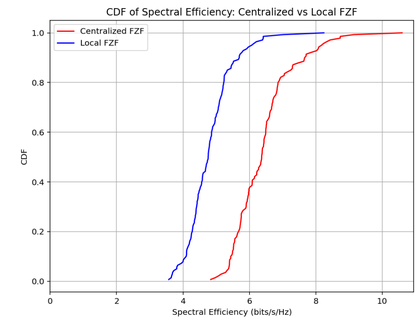
Advancements & Perspectives (3rd Year)

Under progress work including :

- Development of a high-performance **centralized processing scheme** optimized for 2 objectives :
  → Reducing the size of the shared information
  → Reducing the computational complexity with focus on scalability



Centralized processing requires to collect the local information at the CPU and return the solution to each APs



Centralized precoding schemes have higher achievable performance compared to local precoding

- Development of a machine learning based solution with compensation of the HWI

Publications

3 Conference papers and 1 submitted journal article (under review)

1. A. Durant, A. Mabrouk, R. Zayani “Sequential HW-Aware Precoding: Over-the-air cancellation of HWI in Downlink Cell-Free Massive MIMO with Serial Fronthaul” in IEEE transaction on communication, 2025, [Submitted, available on arxiv,org]
2. A. Durant, R. Zayani, D.Demmer "Sequential Hardware-aware Precoding for CF-mMIMO-OFDM with serial fronthaul" in IEEE WCNC 2024
3. A. Durant, R. Zayani, A. Mabrouk, D. Demmer "Inband and Out-of-Band Performance Evaluation of Downlink CF-mMIMO-OFDM under low-resolution DACs" in IEEE WCNC 2024
4. A. Durant, R. Zayani, “Distributed Precoding for Mitigating Hardware Impairments in Cell-free massive MIMO with Sequential Fronthaul” in 2024 58th Asilomar Conference on Signals, Systems, and Computers