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Grant-Free Random Access of IoT devices in Massive MIMO with Partial CSI

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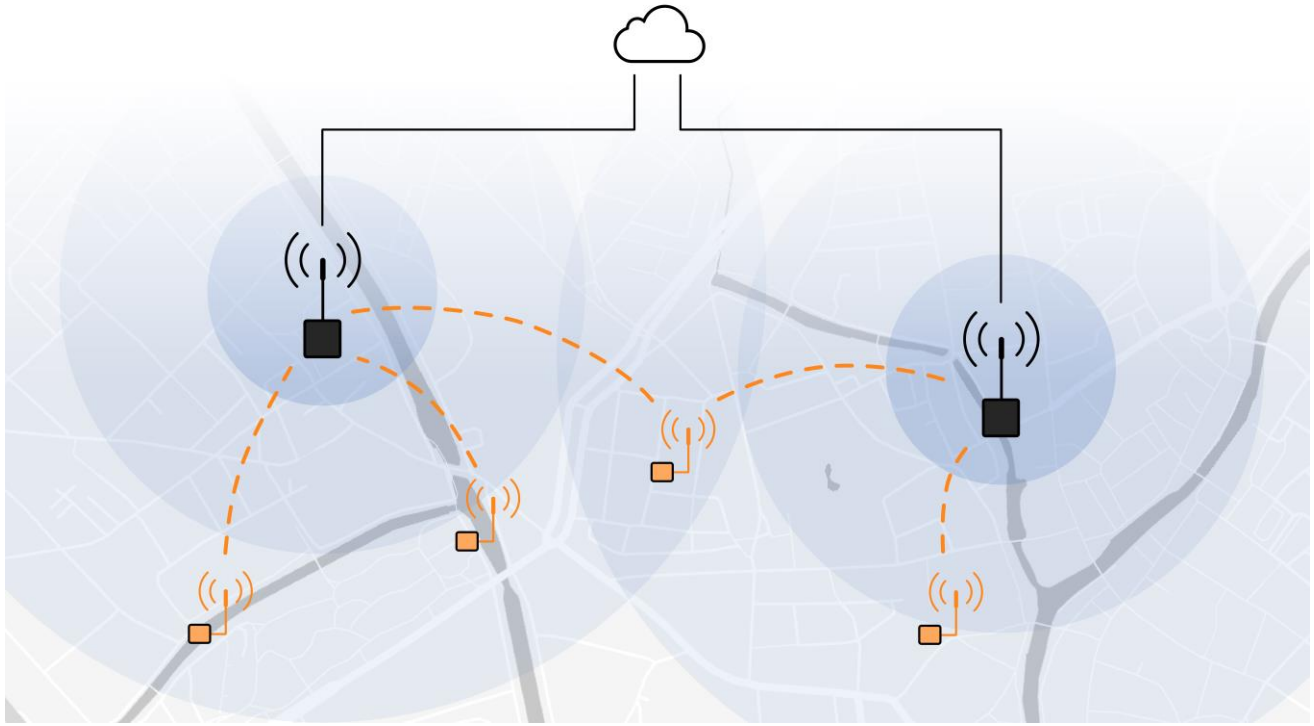
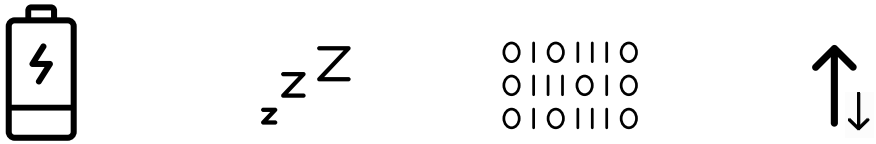
IEEE WCNC 2023

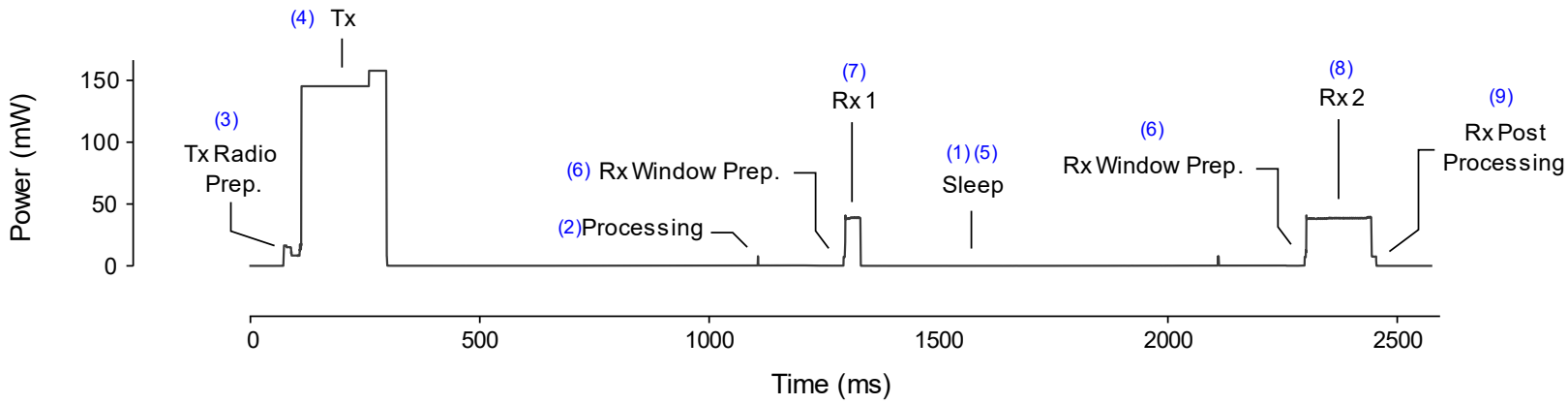
DRAMCO

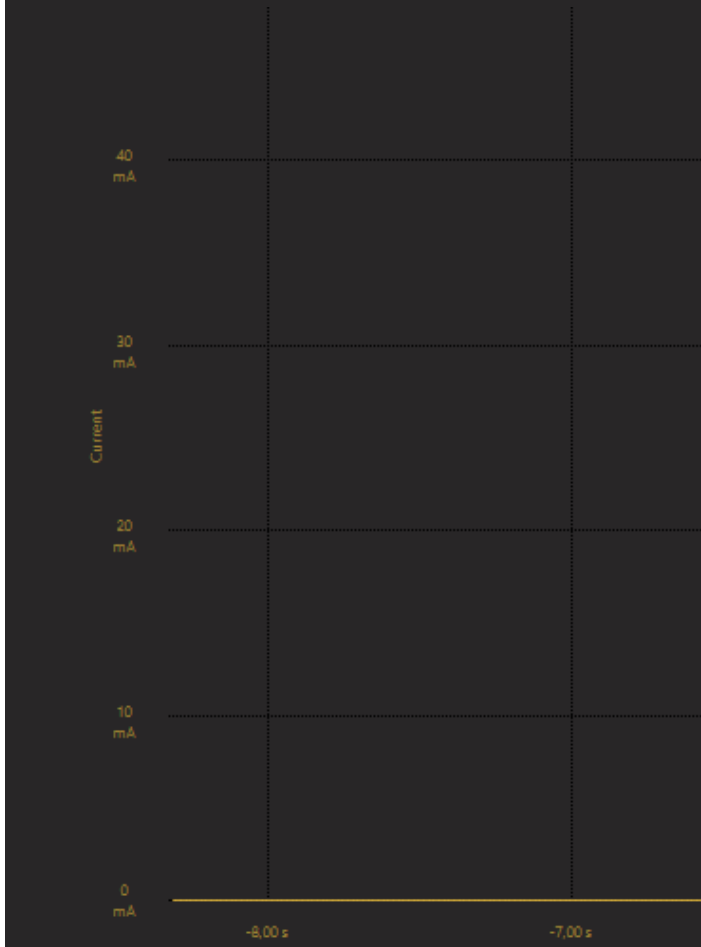
Our focus is on energy-constrained remote devices



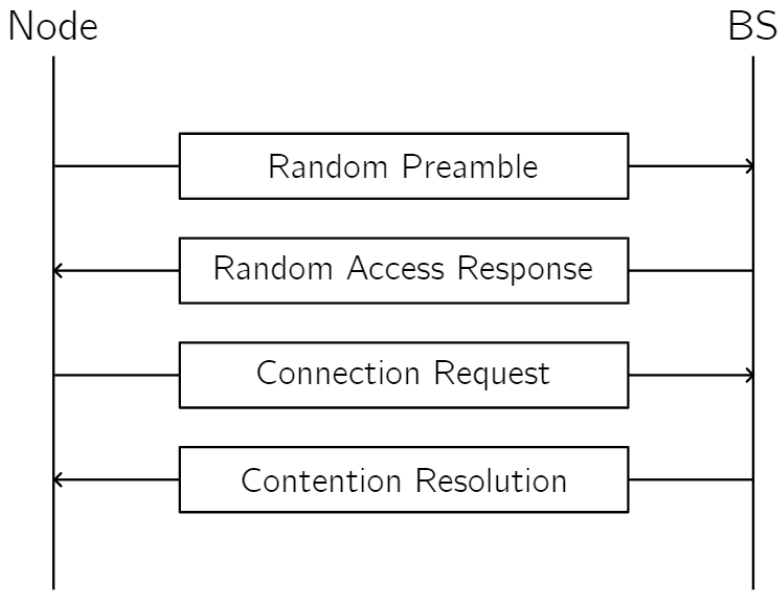


Simple multiple-access control

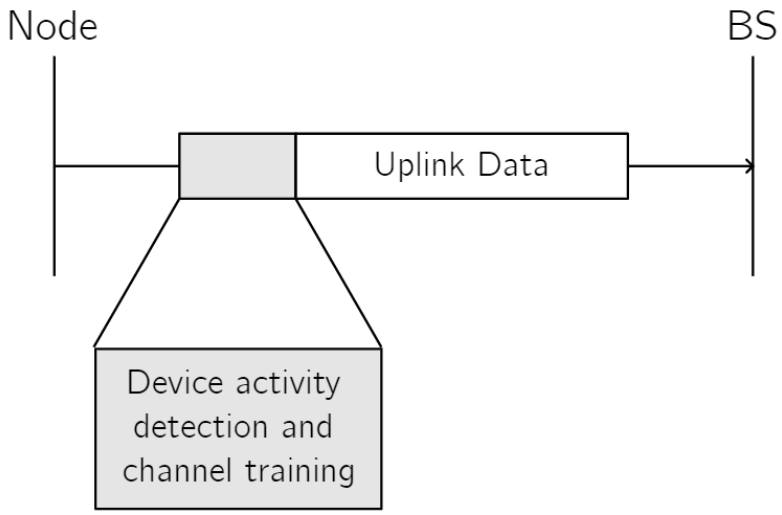




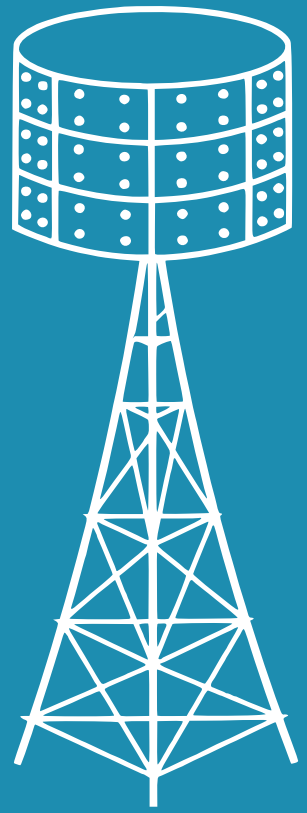
Grant-Based



Grant-Free



Exploiting



degree-of-freedom

static deployment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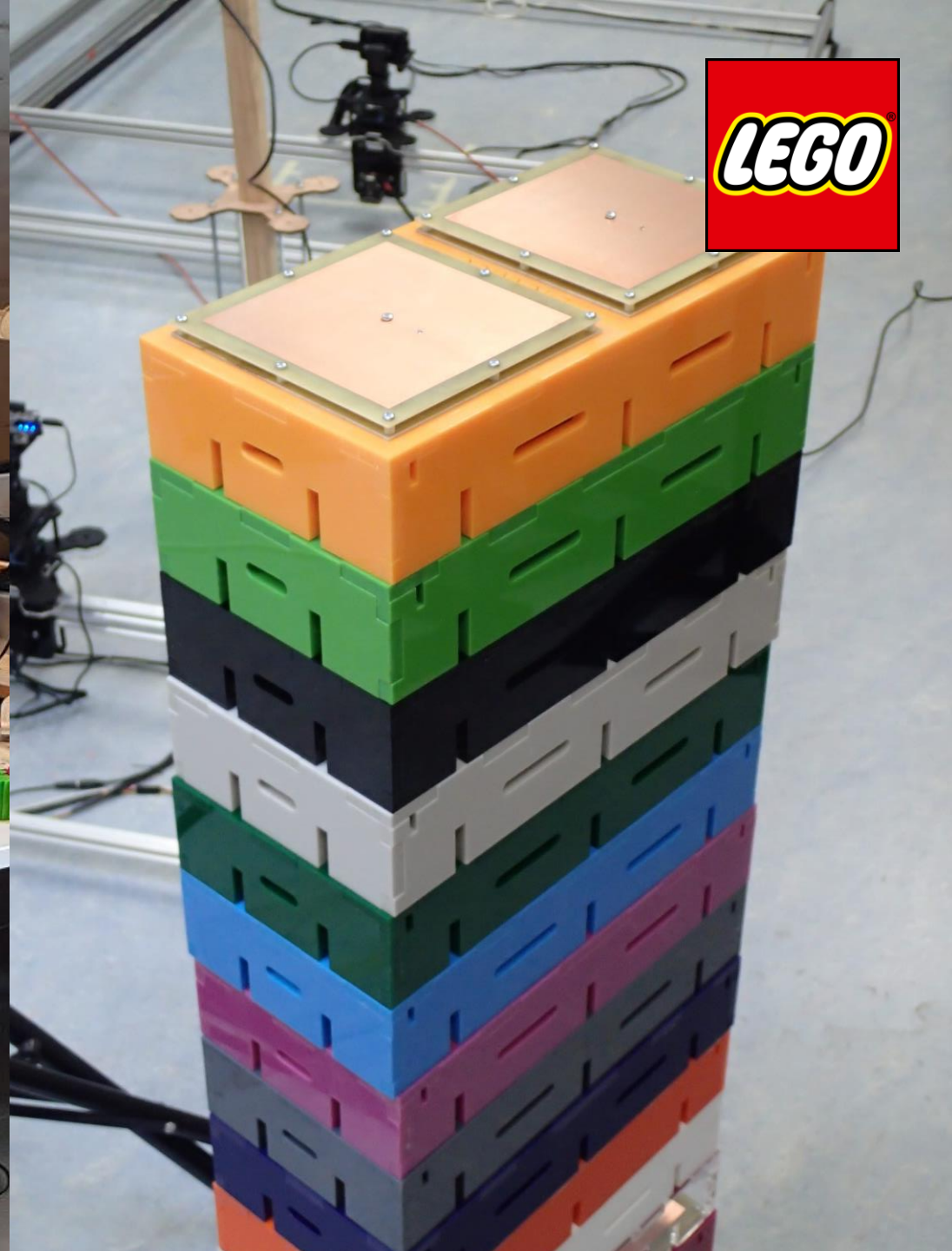
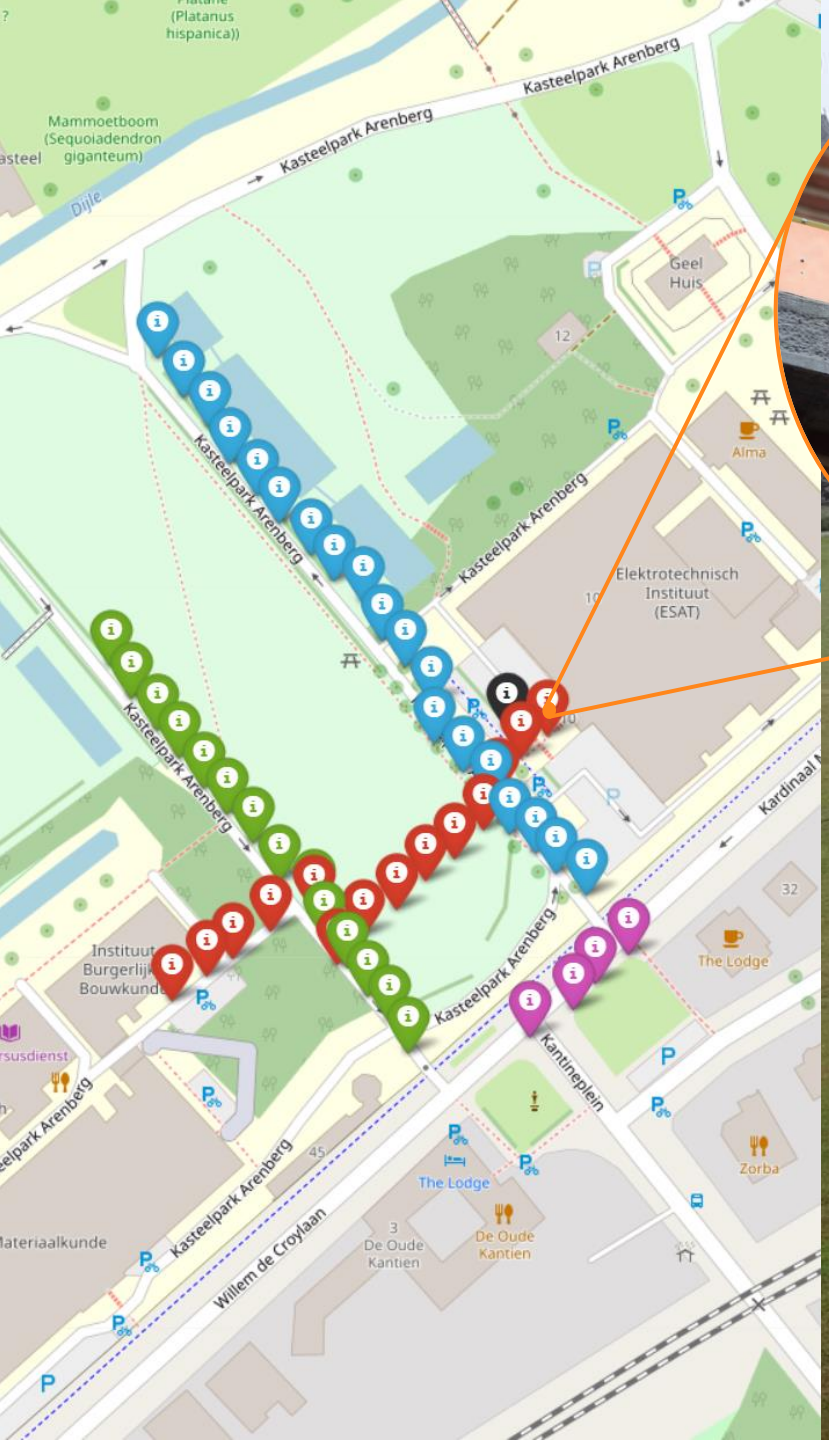
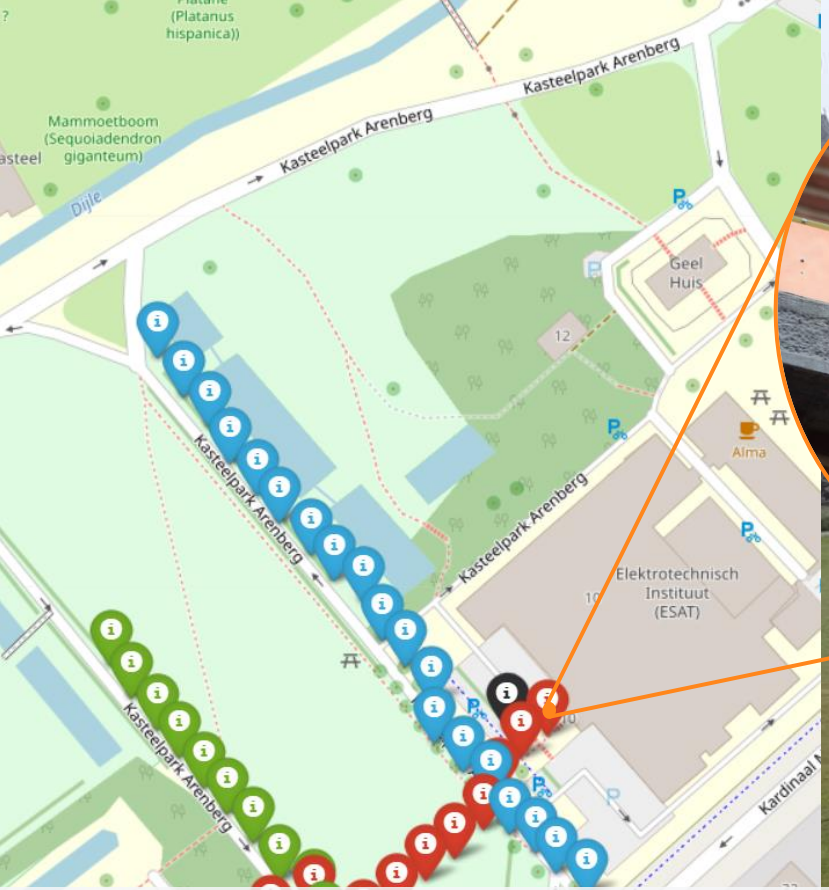
DRAMCO
DRAMCO
DRAMCO
EFD


LEGO


Kasteelpark Arenberg
Mammoetboom
(Sequoiadendron
giganteum)
Dijle
Geel
Huis
Alma
Elektrotechnisch
Instituut
(ESAT)
Kardinaal
Instituut
Burgerlijke
Bouwkunde
The Lodge
Zorba
Kantineplein
Willem de Croylaan
De Oude
Kantien
Materiaalkunde



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DRAMCO Massive MIMO

Sub-GHz

Measurement points

- [ ] All

Frequencies

- [ ] 868 MHz
- [ ] 2.61 GHz

Language

- [ ] MATLAB
- [ ] Python

Download

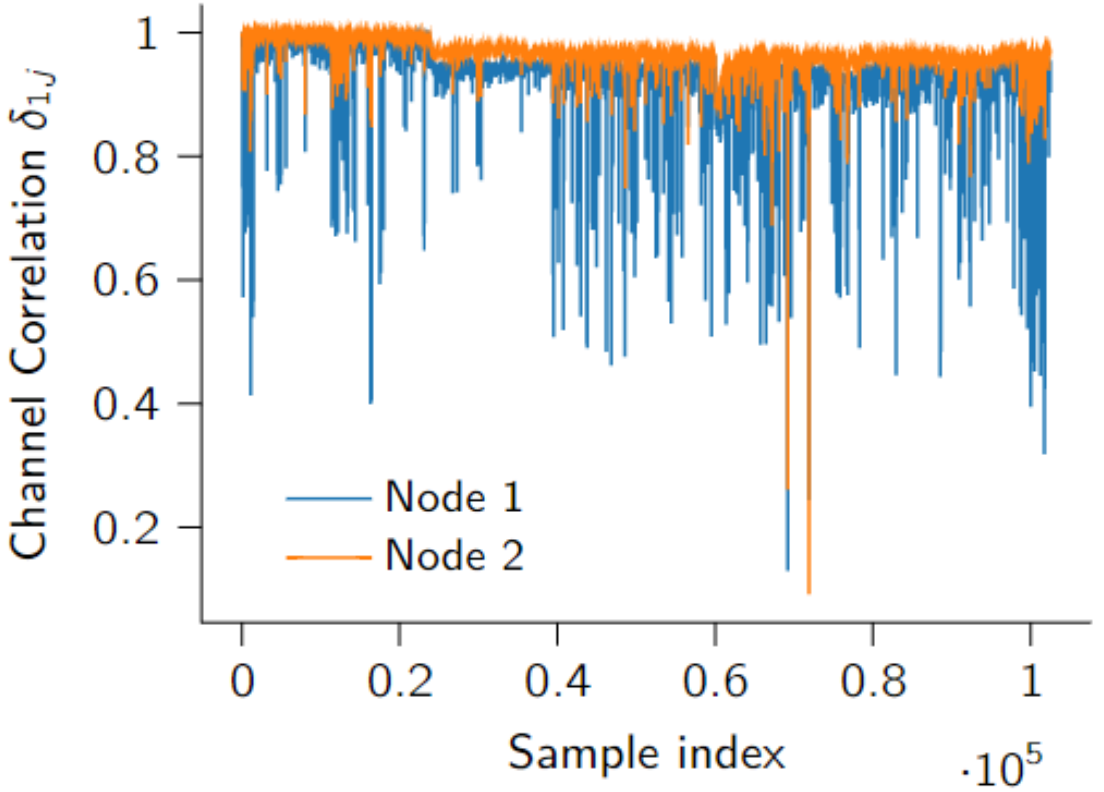
https://dramco.be/massive-mimo/measurement-selector/


Voor
een meer
duurzame
wereld.
Ontdek jezelf.
Begin bij de wereld.

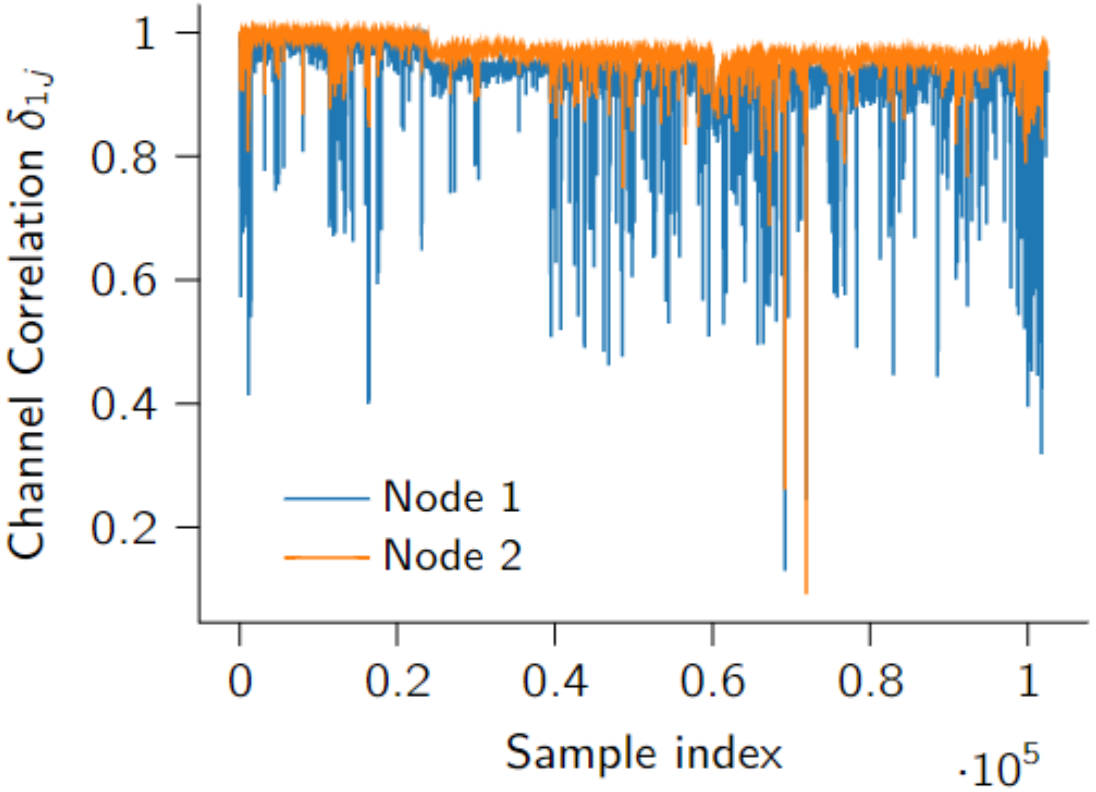
9h-17h
>100k snapshots

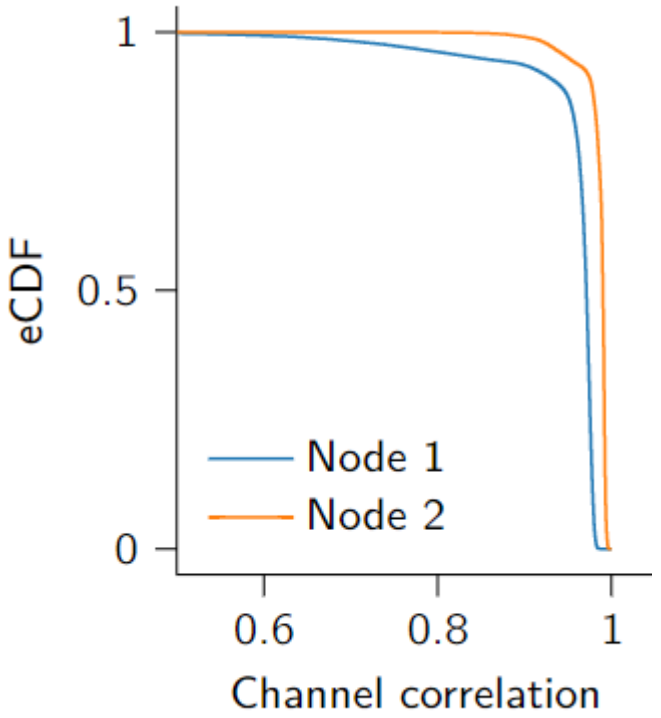
Channel Dynamics

$$\delta_{i,j}(n,f) = \frac{\left|\bar{\boldsymbol{h}}_i(n,f)^H \cdot \bar{\boldsymbol{h}}_j(n,f)\right|}{\left\|\bar{\boldsymbol{h}}_i(n,f)\right\| \left\|\bar{\boldsymbol{h}}_j(n,f)\right\|}$$

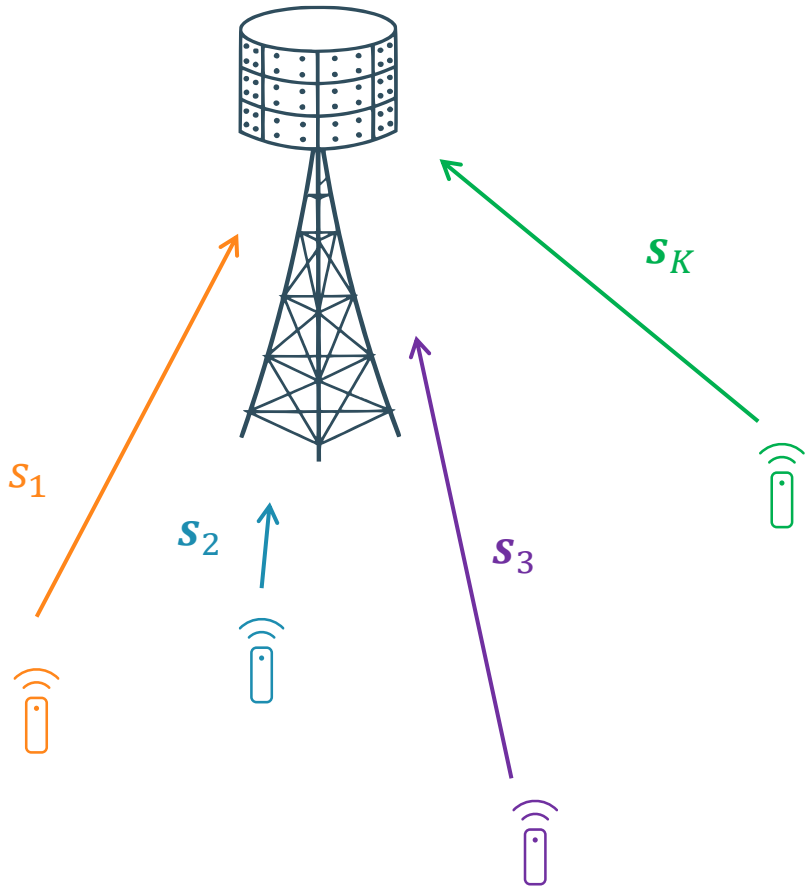


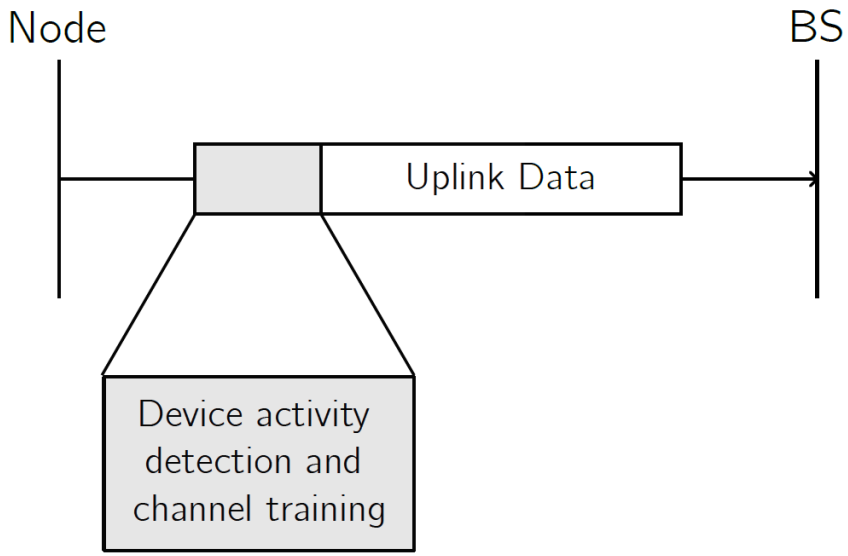
Channel Dynamics





System Model

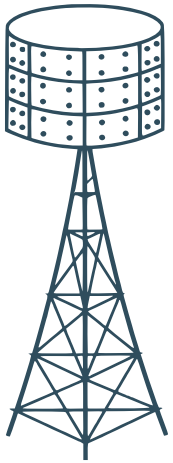




$s_k \sim \mathcal{CN}(0, 1)$

Pilot sequence

System Model



Transmit power

Activity {0,1}

$$\gamma_k = \sqrt{\rho_k}\, a_k$$

Channel knowledge/mismatch

Unknown complex scalar

$$y_{m,n,t} = \sum_{k=0}^{K-1} (g_{m,n,k} + \epsilon_{m,n,k}\lambda_{n,k}) e^{\jmath\phi_{n,k}} s_{k,t}\gamma_k + w_{m,n,t}$$

AWGN noise

e.g., CFO

$s_k \sim \mathcal{CN}(0,1)$

Pilot sequence

Received signal

at time t at antenna m at Access Point n

Known CSI

$\sim \mathcal{CN}(0,1)$

Log-likelihood of the received signal

$$\log p(\mathbf{y}|\boldsymbol{\gamma}) = -M \ln\left(|\mathbf{C}|\right) - MT \ln(\pi) - \sum_{m=0}^{M-1} \boldsymbol{\Theta}_m^H \mathbf{C}^{-1} \boldsymbol{\Theta}_m$$

$$\mathbf{C} = \sum_{k=0}^{K-1} \lambda_k^2 |\gamma_k|^2 \mathbf{s}_k \mathbf{s}_k^H + \sigma^2 \mathbf{I}_T$$

$$\boldsymbol{\Theta}_m = \mathbf{y}_m - \sum_{k=0}^{K-1} g_{k,m} \mathbf{s}_k \gamma_k$$

Iterative Algortihm

Require: $\sigma^2, \lambda_k, \mathbf{y}_m, g_{k,m}, \hat{\gamma}_{\text{init}}\ \forall k, m$

$k' \leftarrow 0$

$\hat{\boldsymbol{\gamma}} \leftarrow \hat{\boldsymbol{\gamma}}_{\text{init}}$

$\mathbf{C}^{-1} \leftarrow \left(\sum_{k=0}^{K-1} \lambda_k^2 |\hat{\gamma}_k|^2 \mathbf{s}_k \mathbf{s}_k^H + \sigma^2 \mathbf{I}_T\right)^{-1}$

while Not converged **do**

Compute $\mathbf{y}_{k',m}$, $\mathbf{C}_{-k'}^{-1}$, α, β and δ (13)

$\hat{r}_{k'} \leftarrow \arg\max \tilde{f}(r_{k'})$ (16) or (17)

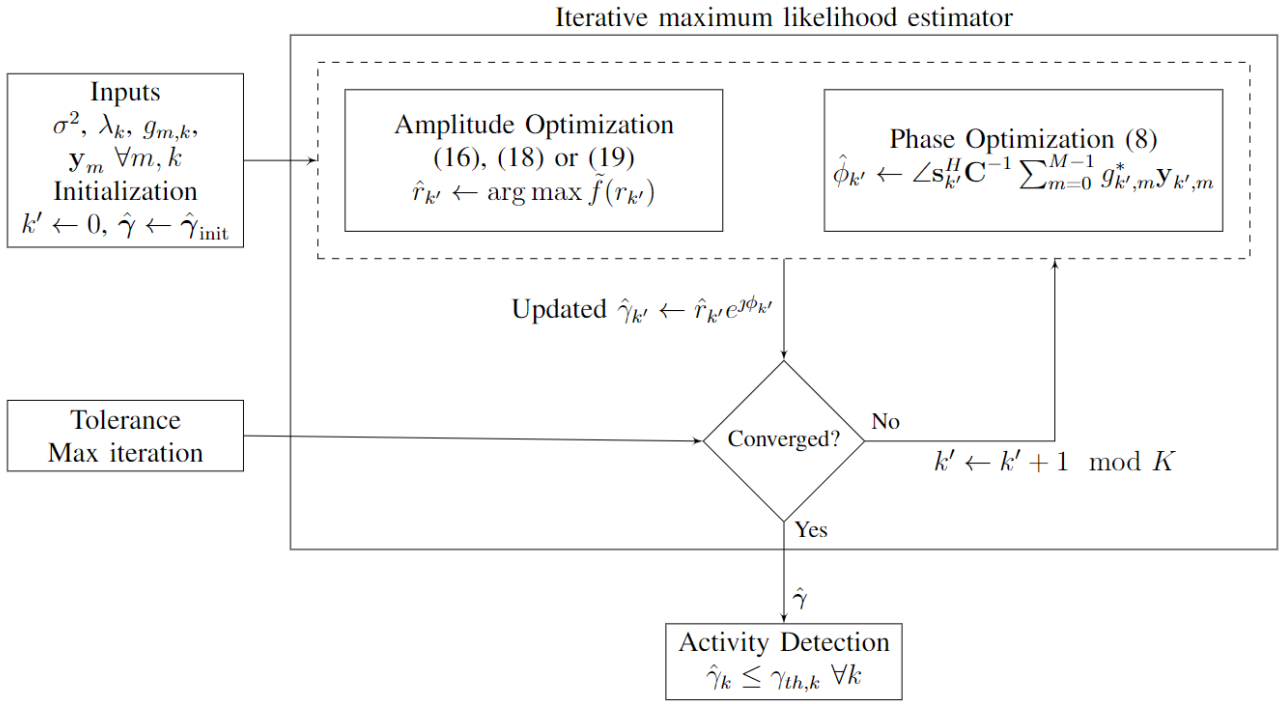
$\hat{\phi}_{k'} \leftarrow \angle \mathbf{s}_{k'}^H \mathbf{C}^{-1} \sum_{m=0}^{M-1} g_{k',m}^* \mathbf{y}_{k',m}$

$\hat{\gamma}_{k'} \leftarrow \hat{r}_{k'} e^{\jmath \hat{\phi}_{k'}}$

$\mathbf{C}^{-1} \leftarrow \mathbf{C}_{-k'}^{-1} - \frac{\mathbf{C}_{-k'}^{-1} \mathbf{s}_{k'} \mathbf{s}_{k'}^H \mathbf{C}_{-k'}^{-1} r_{k'}^2 \lambda_{k'}^2}{1 + \mathbf{s}_{k'}^H \mathbf{C}_{-k'}^{-1} \mathbf{s}_{k'} r_{k'}^2 \lambda_{k'}^2}$

$k' \leftarrow k' + 1 \mod K$

end while



https://github.com/wavecore-research/grant-free-random-access-partial-csi

Performance characterization & Simulation Parameters

Missed detection

Set of active devices

$$\hat{\mathcal{K}}_a = \{k | \hat{a}_k = 1, \forall \in [1, K]\}$$

$$P_{md} = 1 - \mathbb{E}\left\{ \frac{|\mathcal{K}_a \cap \hat{\mathcal{K}}_a|}{|\mathcal{K}_a|} \right\}$$

False alarm

$$P_{fa} = \mathbb{E}\left\{ \frac{|\hat{\mathcal{K}}_a \setminus \mathcal{K}_a|}{K - |\mathcal{K}_a|} \right\}$$

Set of devices

Parameter	Symbol	Default value
Number of devices	K	500
Number of total BS antennas	M	64
Signal-to-noise ratio	SNR	20 dB
Device activity probability	ϵ_a	0.1
Pilot sequence	s_k	$\sim \mathcal{CN}(0, 1)$
Pilot length	τ_p	10 symbols
Phase offset	ϕ_k	$\sim \mathcal{U}_{[0,2\pi]}$
Number of simulations	N_{sim}	>10 000
Number of algorithm iterations	N_{iter}	$K \cdot 4$
Initialization vector	$\hat{\boldsymbol{\gamma}}_{\text{init}}$	$\hat{\boldsymbol{\gamma}}_{\text{init}}^{\text{LMMSE}}$ (19)
Unknown part of the CSI	λ	0.3

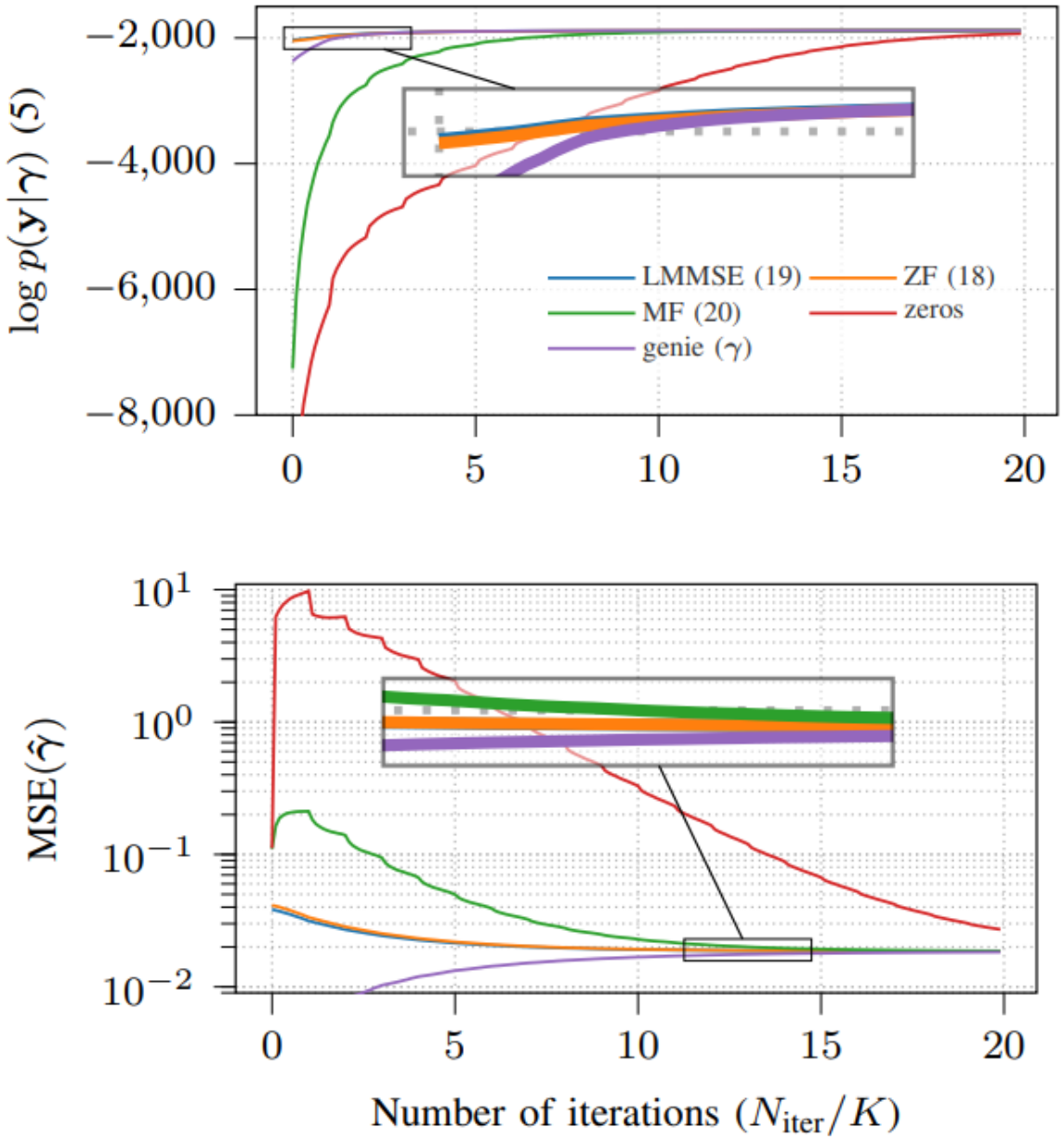
Impact on initial input vector

$$\left(\mathbf{s}_0 \dots \mathbf{s}_{K-1}\right) \operatorname{diag}\left(g_{0,m} \dots g_{K-1,m}\right)$$

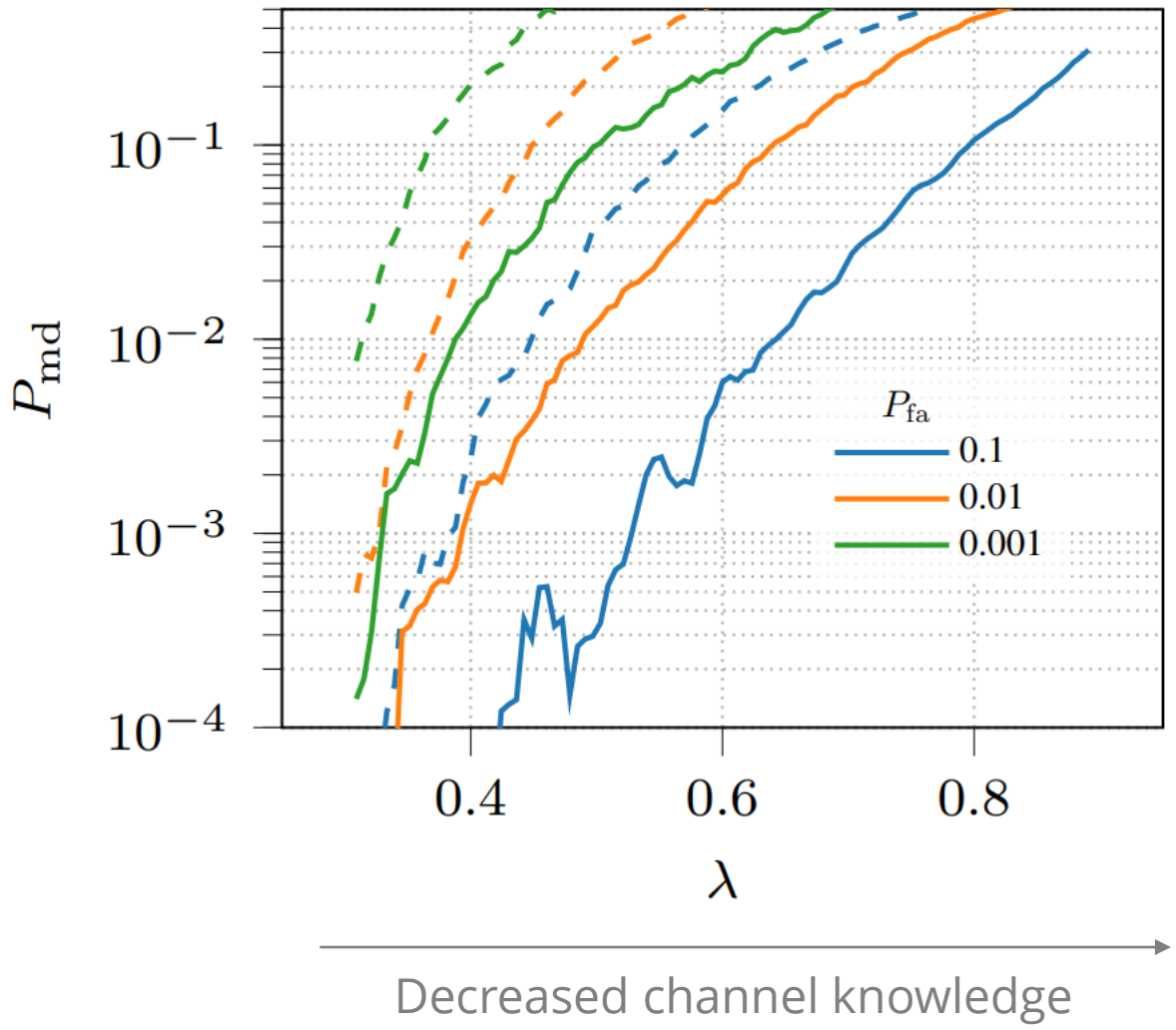
$$\hat{\boldsymbol{\gamma}}_{\text{init}}^{\text{ZF}} = \left(\boldsymbol{\Gamma}^H \boldsymbol{\Gamma}\right)^{-1} \boldsymbol{\Gamma}^H \mathbf{y}$$

$$\hat{\boldsymbol{\gamma}}_{\text{init}}^{\text{MF}} = \left(\operatorname{diag}(\boldsymbol{\Gamma}^H \boldsymbol{\Gamma}) + \sigma^2 \mathbf{D}^{-1}\right)^{-1} \boldsymbol{\Gamma}^H \mathbf{y}$$

$$\hat{\boldsymbol{\gamma}}_{\text{init}}^{\text{LMMSE}} = \left(\boldsymbol{\Gamma}^H \boldsymbol{\Gamma} + \sigma^2 \mathbf{D}^{-1}\right)^{-1} \boldsymbol{\Gamma}^H \mathbf{y}$$



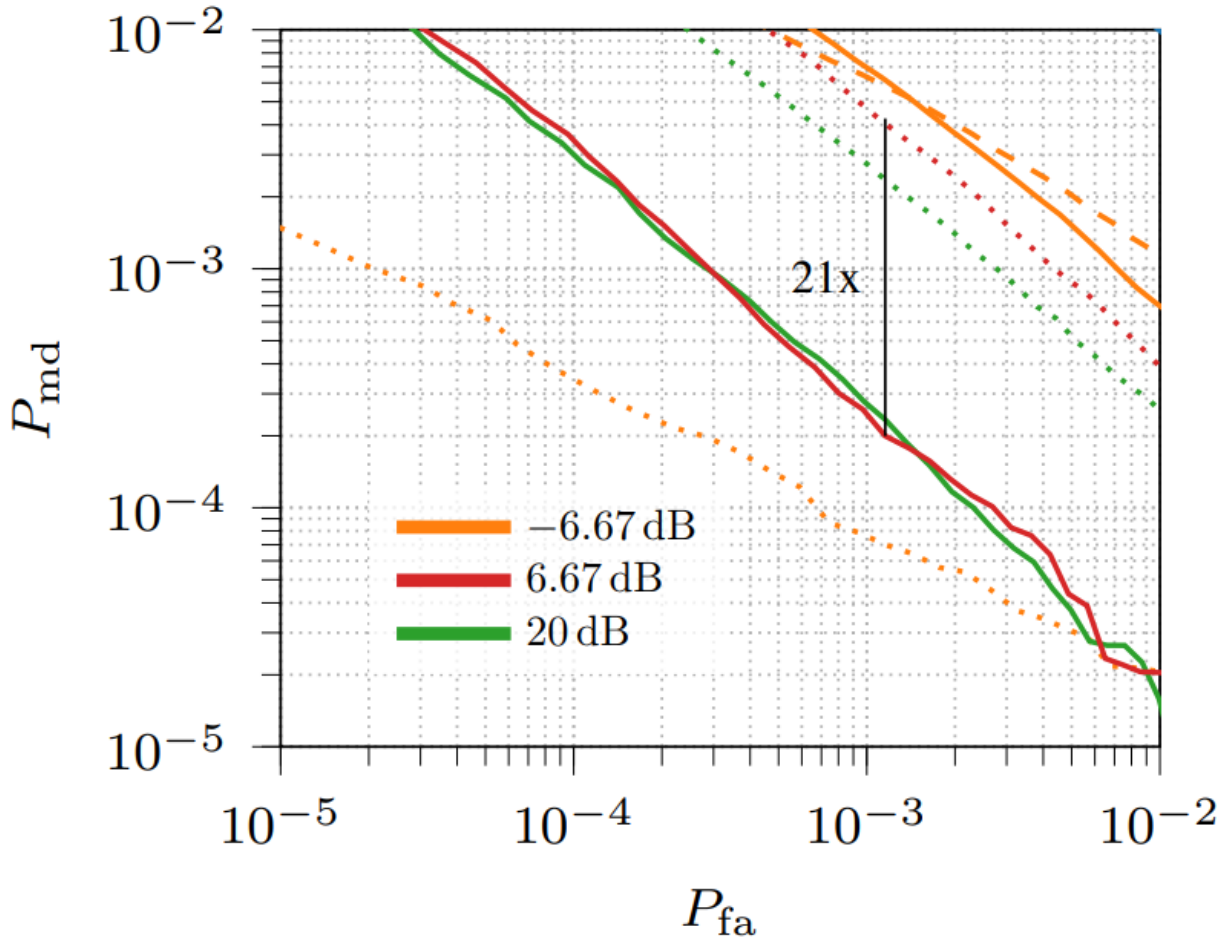
Impact of CSI quality



Our algorithm

LMMSE

Impact of SNR



Our algorithm ($\lambda = 0.3$)

LMMSE ($\lambda = 0.3$)

LMMSE (full CSI)

Conclusions & Future Work

- Ensure **antennas** are **mounted** firmly
- **Iterative** algorithm to **detect** IoT devices' **activity** in **static**, i.e., less time-variant conditions.

- **Extend** this algorithm to the **cell-free** case,
  where the λ (partial CSI) and phase offset become access point/base station independent.
- Compare algorithm to other works

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