Enhanced Normalized Conjugate Beamforming for Cell-Free Massive MIMO

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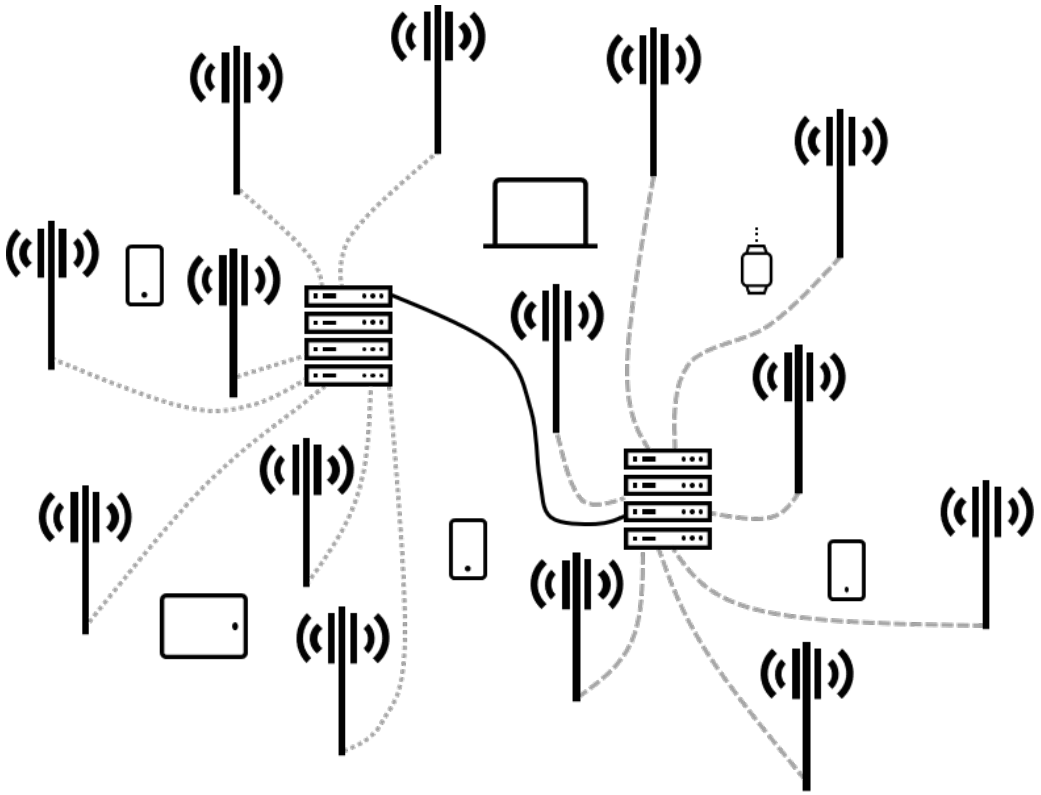
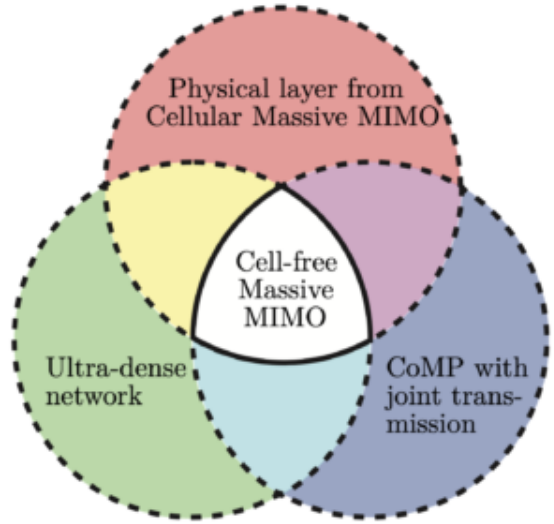
Cell-Free Massive MIMO focuses on the user

"*Network MIMO* with the analytical framework of massive MIMO"

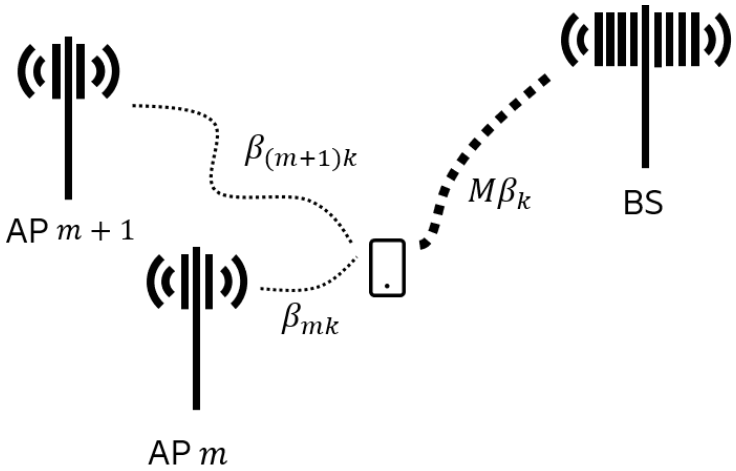




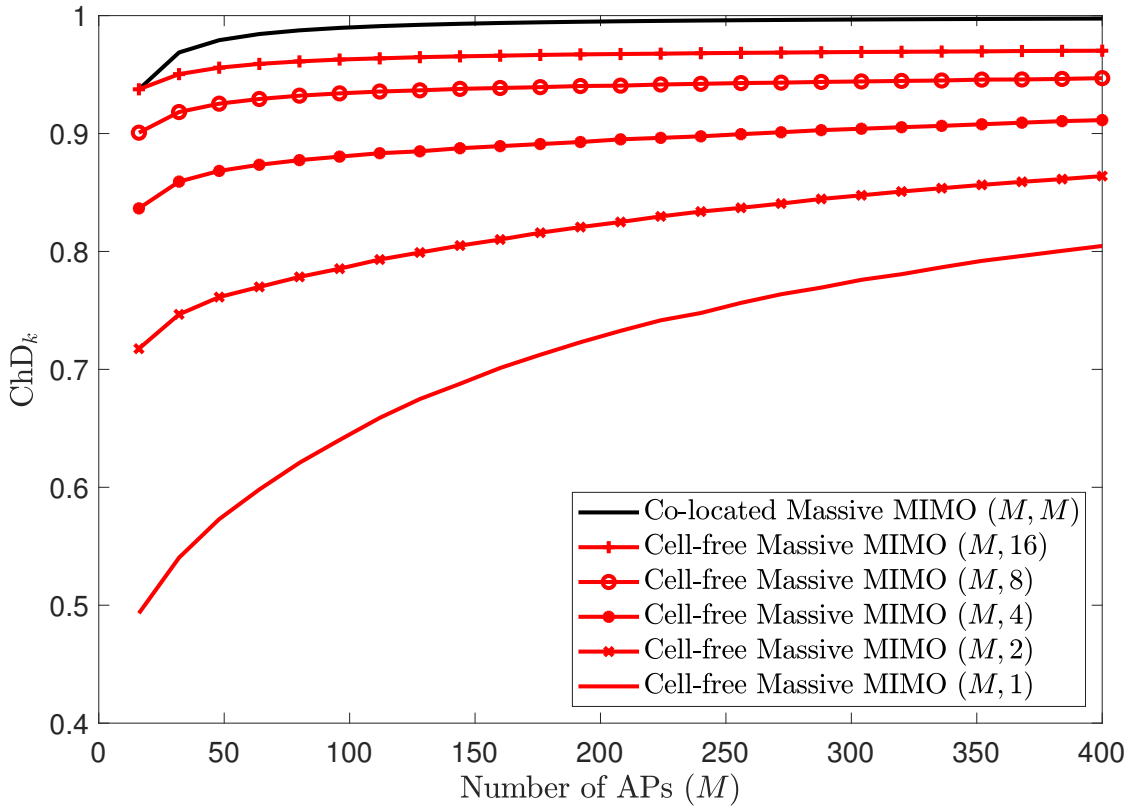
Picture from "http://ma-mimo.ellintech.se"

- distributed dense deployment $\Longrightarrow$ ubiquitous connectivity
- joint coherent operation $\Longrightarrow$ macro-diversity, interference mitigation
- user-centric network $\Longrightarrow$ more uniform user experience

Channel hardening is less pronounced in cell-free



Distributed APs contribute differently to the effective channel gain which thereby presents large fluctuations



ChD_k is a normalized measure of the channel hardening degree at user k (conjugate beamforming and perfect CSI is assumed above)

Boosting channel hardening "artificially"

- Conj. beamforming (CB) poorly contributes to harden the effective DL channel
- Designing a CB-based scheme that reduces the fluctuations and equalizes the effective DL channel
- Data signal transmitted by AP m with N antennas

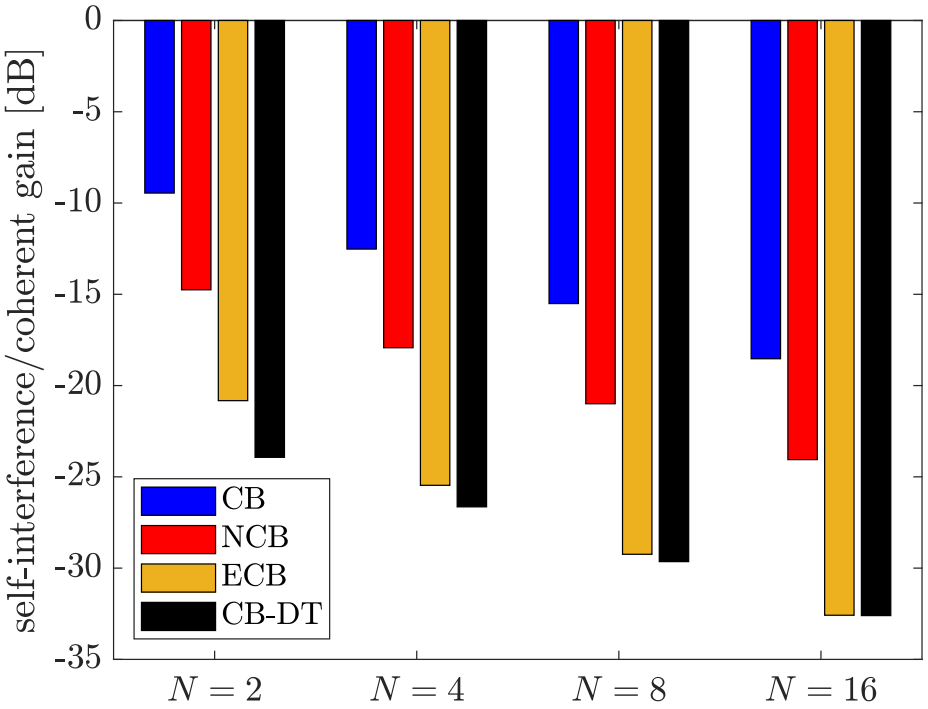
$$\boldsymbol{x}_m = \sqrt{\rho_{\mathrm{d}}} \sum_{k=1}^{K} \sqrt{\eta_{mk}} \boldsymbol{w}_{mk} q_k$$

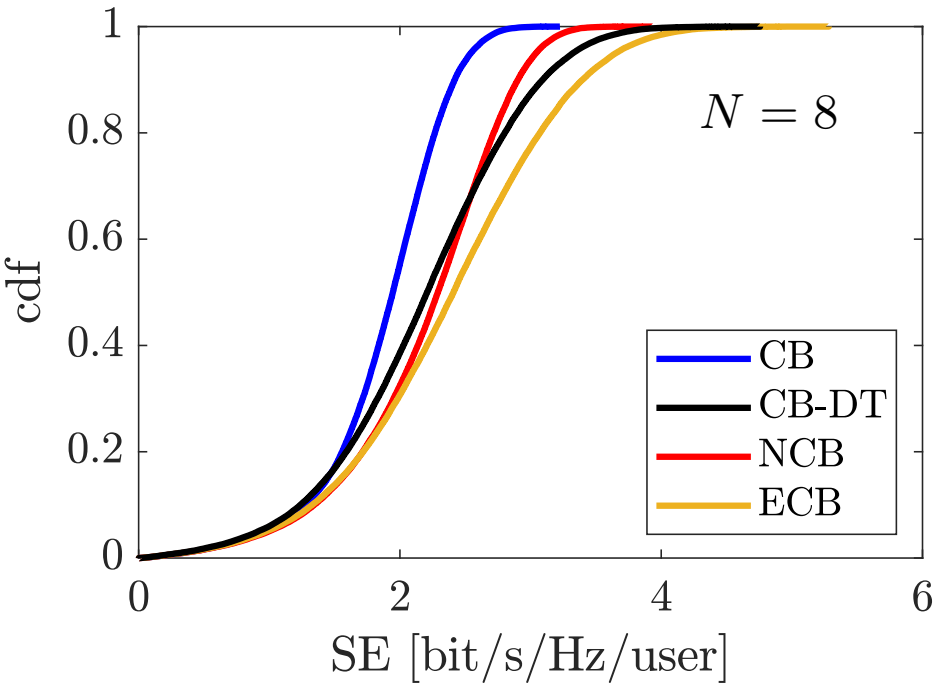
CB	Normalized CB	**Enhanced Normalized CB**
$\boldsymbol{w}_{mk}^{\mathsf{CB}} = \hat{\boldsymbol{g}}_{mk}^{*}$	$\boldsymbol{w}_{mk}^{\mathsf{NCB}} = \dfrac{\hat{\boldsymbol{g}}_{mk}^{*}}{\|\hat{\boldsymbol{g}}_{mk}\|}$	$\boldsymbol{w}_{mk}^{\mathsf{ECB}} = \dfrac{\hat{\boldsymbol{g}}_{mk}^{*}}{\|\hat{\boldsymbol{g}}_{mk}\|^2}$

Effective DL channel: $a_{kk} = \sum_{m=1}^{M} \sqrt{\eta_{mk}} \boldsymbol{g}_{mk}^{\mathsf{T}} \boldsymbol{w}_{mk} \approx \sum_{m=1}^{M} \sqrt{\eta_{mk}} \hat{\boldsymbol{g}}_{mk}^{\mathsf{T}} \boldsymbol{w}_{mk}$

If $\boldsymbol{w}_{mk} = \boldsymbol{w}_{mk}^{\mathsf{ECB}}$, then $a_{kk} \approx \sum_{m=1}^{M} \sqrt{\eta_{mk}}$ ideally deterministic

ECB reduces users' uncertainty of the channel





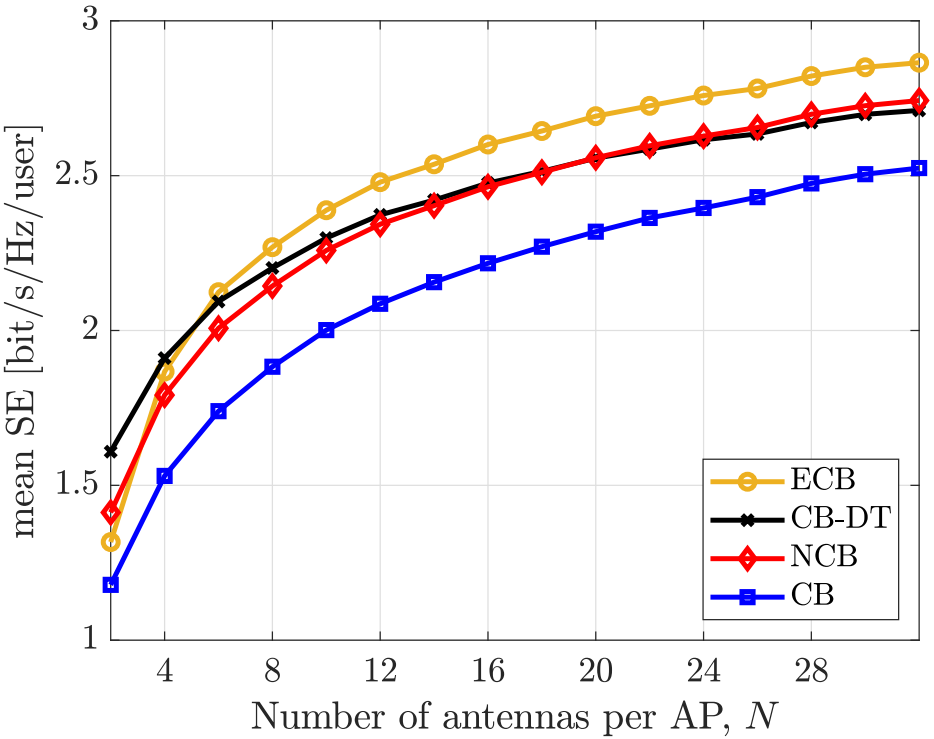
$M = 200, K = 40, \tau_{\mathrm{u,p}} = 20$. N antennas per AP.

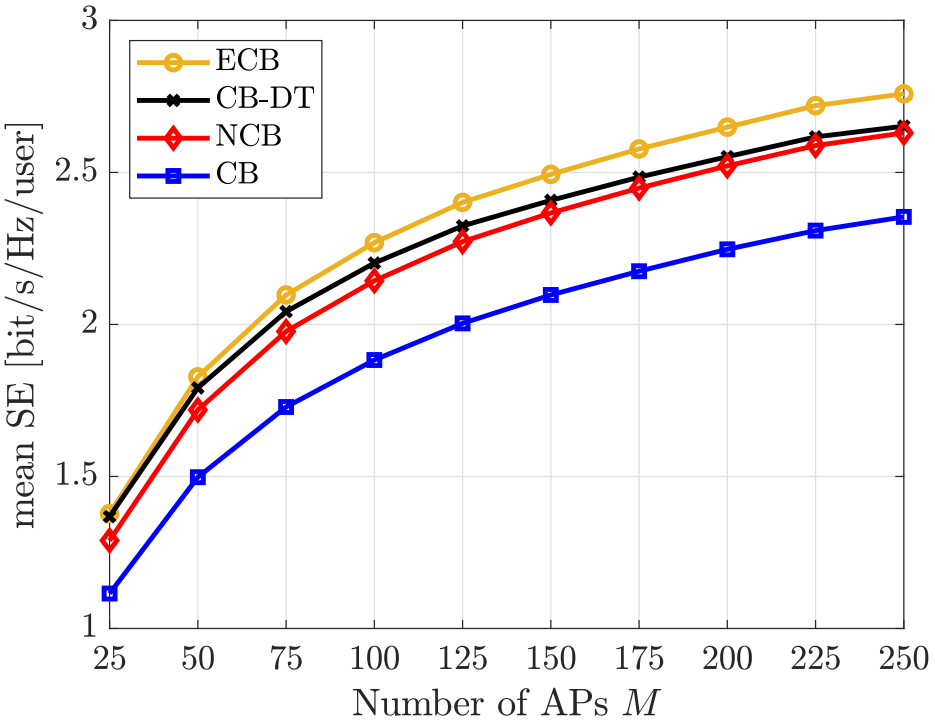
CB-DT: CB with downlink training, $\tau_{\mathrm{d,p}} = 20$.

Self-interference

- CB/NCB/ECB: variance of the effective DL channel gain
- CB-DT: variance of the DL channel estimation error

Is estimating the DL channel really needed?





CB-DT is preferable over CB regardless of N, M

ECB might make downlink channel estimation useless for $N \geq 4$

Cell-free massive MIMO: a key enabler of beyond-5G

The best of two worlds:

1. **macro-diversity** from distributing many APs,
2. all the benefits inherited from massive MIMO,

Uniformly great service as the users are "equally treated"

ECB greatly **boosts the channel hardening** enabling the users to reliably decode data relying only on statistical CSI.

As the provided effective **channel is nearly deterministic**, acquiring CSI at the users does not yield a significant gain.

Thanks for your attention

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