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Coordinated Per-Antenna Power Minimization for Multicell Massive MIMO Systems with Low-Resolution Data Converters

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I MOTIVATION

Massive MIMO Communications

- Many antennas & RF chains to offset propagation loss
- Need techniques to manage resulting data explosion

Low-Resolution Data Converters

- Each BS antenna has RF chain with two high-res converters.
- To reduce power consumption, use low-res ADCs and DACs.

Per-Antenna Power Constraint

- Limit antenna powers for energy efficiency
- Place less burden on electronics

Problem

- Inter-cell and inter-user interference
- Non-trivial quantization error
- OFDM modulation

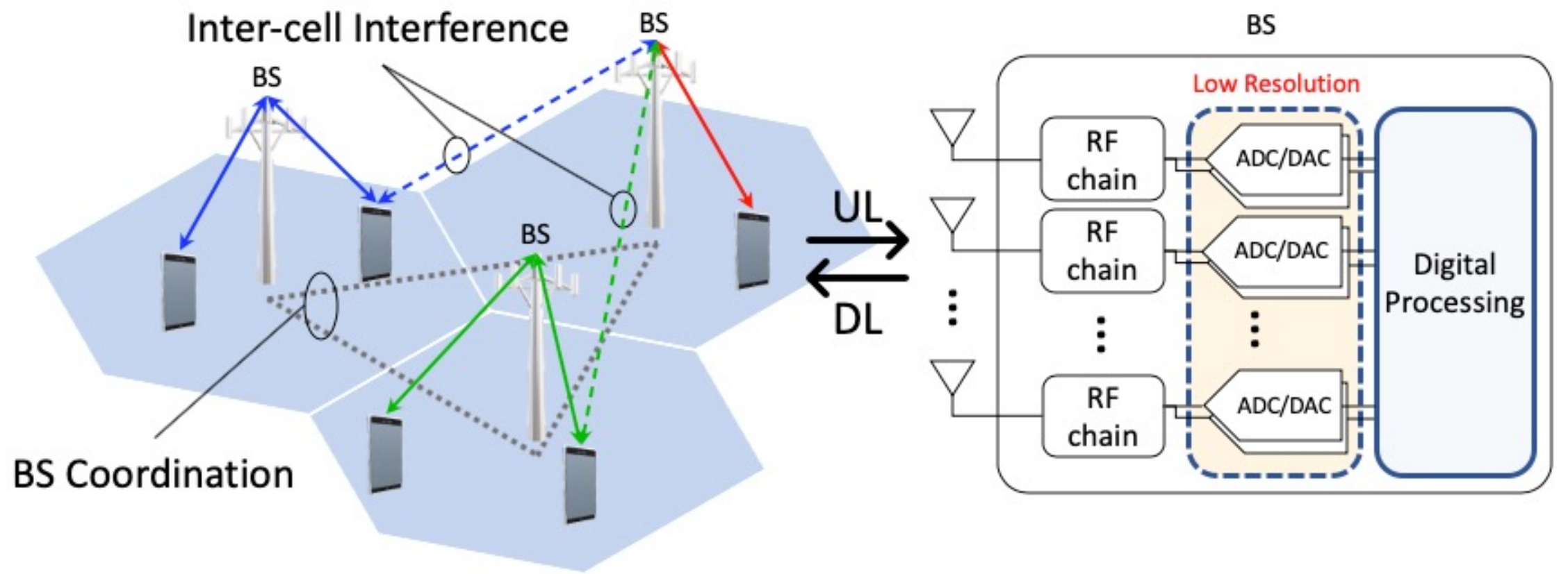
Goal

Optimal downlink beamforming (primal)
via optimal uplink solution (dual)

II MODELS & ASSUMPTIONS

Multicell & Multiuser MIMO OFDM

- Multi-cell environment (N_c cells)
- Each BS has N_b antennas w/ low-res converters
- Each BS serves N_u users w/ single antenna
- OFDM with K subcarriers
- TDD assumption



☐ Quantized downlink received signal

$$y_{i,u}(k) = \boxed{\alpha}\, \mathbf{g}^H_{i,i,u}(k)\boxed{\mathbf{w}_{i,u}(k)}\, s_{i,u}(k) + \boxed{\alpha \sum_{(j,v)\neq(i,u)}^{N_c,N_u} \mathbf{g}^H_{j,i,u}(k)\mathbf{w}_{j,v}(k) s_{j,v}(k)} + \boxed{\tilde{q}_{i,u}(k)} + \tilde{n}_{i,u}(k)$$

Quantization gain ≪ 1

inter-cell interference
+ inter-user interference

Quantization error

Need to be designed: beamforming $\mathbf{w}_{i,u}(k)$

III Coordinated Beamforming for Per-Antenna Power Minimization

Maximum Transmit Power Minimization (Primal, Downlink)

$$\underset{\mathbf{w}_{i,u}(k),\ p_0}{\text{minimize}}\ \boxed{p_0}$$

Upper bound to be minimized

$$\text{subject to}\ \ \Gamma_{i,u}(k) \geq \gamma_{i,u,k} \quad \forall i,u,k$$

$$\left[\mathbb{E}[\mathbf{x}_{\mathrm{q},i}(k)\mathbf{x}^H_{\mathrm{q},i}(k)]\right]_{m,m} \leq \boxed{p_0} \quad \forall i,k,m$$

$$\Gamma_{i,u}(k) = \frac{\alpha^2|\mathbf{g}^H_{i,i,u}(k)\mathbf{w}_{i,u}(k)|^2}{\mathrm{I}_{i,u}(k) + \mathrm{Q}_{i,u}(k) + \sigma^2}$$

: function of OFDM modulation, interference, and quantization.

Maximum Transmit Power Minimization (Dual, Uplink)

$$\max_{\mathbf{D}_i}\ \min_{\lambda_{i,u}(k)} \sum_{i,u,k}^{N_c,N_u,K} \lambda_{i,u}(k)\sigma^2$$

$$\text{subject to}\ \ \max_{\mathbf{f}_{i,u}(k)} \hat{\Gamma}_{i,u}(k) \geq \gamma_{i,u,k},$$

Inner minimization

$$\mathbf{D}_i \succeq 0,\ \ \mathbf{D}_i \in \mathbb{R}^{N_b \times N_b} : \text{diagonal},$$

$$\mathrm{tr}(\mathbf{D}_i) \leq N_b \quad \forall i,u,k$$

Outer maximization

Theorem 1: Duality + **Corollary 1: Strong Duality**

Corollary 2: Optimal Uplink Solution

Optimal transmit power of uplink subproblem for fixed $\mathbf{D}_i$ is given as

$$\lambda_{i,u}(k) = \frac{1}{\alpha\left(1+\frac{1}{\gamma_{i,u,k}}\right)\mathbf{g}^H_{i,i,u}(k)\mathbf{K}^{-1}_{i,k}(\underline{\boldsymbol{\Lambda}})\mathbf{g}_{i,i,u}(k)}$$

Derivative of Lagrangian of downlink problem becomes zero

Corollary 3: Optimal Downlink Solution

Optimal downlink beamformer is linear scaled instance of uplink MMSE equalizer

$$\mathbf{w}_{i,u}(k) = \sqrt{\tau_{i,u}(k)}\,\mathbf{f}_{i,u}(k)$$

where $\tau_{i,u}(k)$'s satisfy downlink SQINR constraints

Corollary 4: Subgradient

$\mathrm{diag}\left(\sum_{u,k}\mathbf{w}_{i,u}(k)\mathbf{w}^H_{i,u}(k)\right)$ is a subgradient of uplink subproblem in updating $\mathbf{D}_i$

Step 1) Initialize $\lambda^{(0)}_{i,u}(k), \forall i,u,k$

Step 2) Iteratively update transmit power $\lambda^{(n+1)}_{i,u}$ until converges using

$$\lambda^{(n+1)}_{i,u}(k) = \frac{1}{\alpha\left(1+\frac{1}{\gamma_{i,u,k}}\right)\mathbf{g}^H_{i,i,u}(k)\left[\mathbf{K}^{(n)}_{i,k}(\underline{\boldsymbol{\Lambda}}^{(n)})\right]^{-1}\mathbf{g}_{i,i,u}(k)}, \quad \forall i,u,k$$

Step 3) Find uplink MMSE equalizer $\mathbf{f}_{i,u}(k)$ using converged $\lambda^{(n+1)}_{i,u}(k)$

Step 4) Compute downlink beamformer $\mathbf{w}_{i,u}(k)$ based on Corollary 3

Step 5) Repeat the following operations until no update is possible

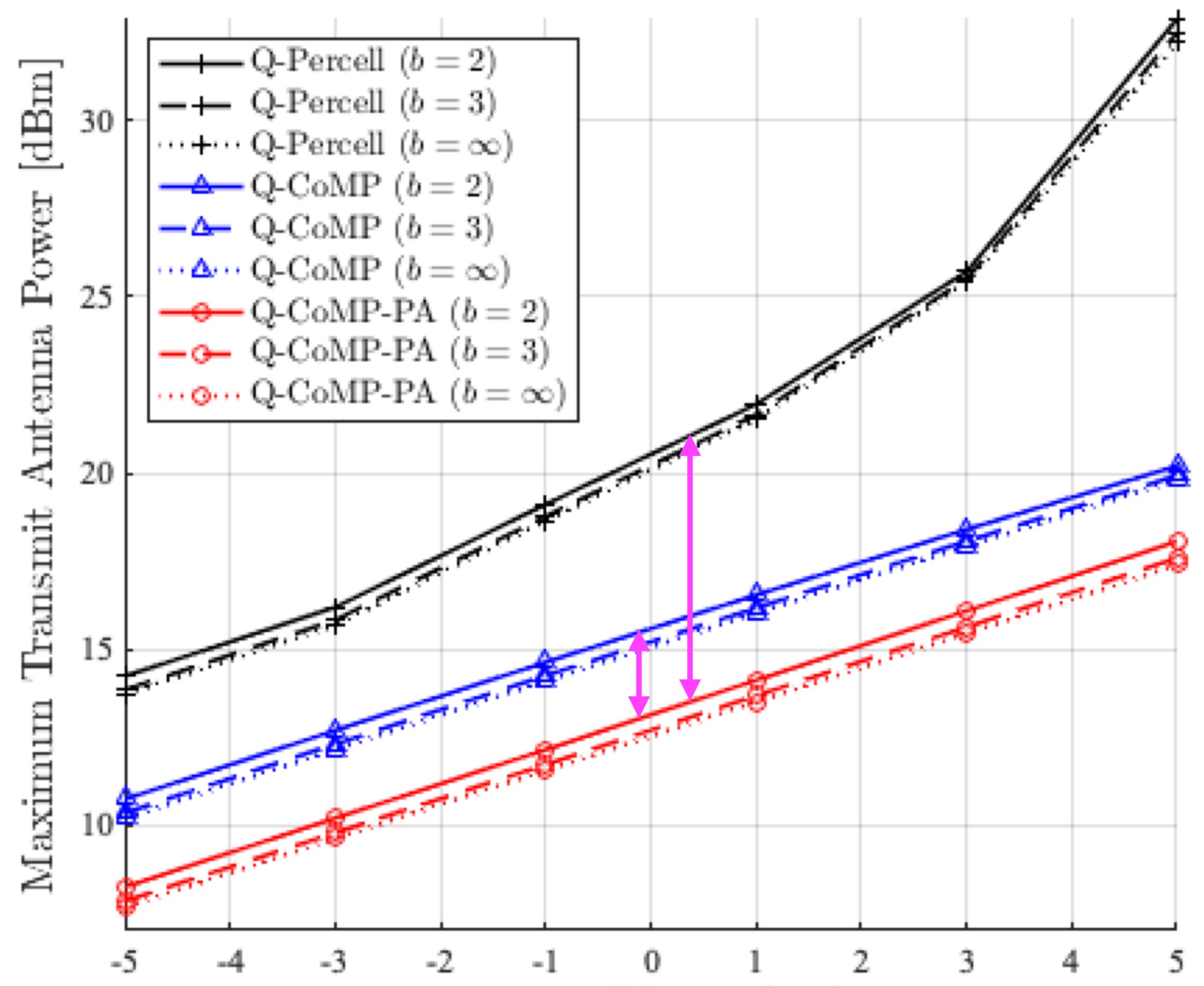
$$\mathbf{D}^{(n+1)}_i \leftarrow \mathbf{D}^{(n)}_i + \eta\ \mathrm{diag}\left(\textstyle\sum_{u,k}\mathbf{w}_{i,u}(k)\mathbf{w}^H_{i,u}(k)\right)$$ subgradient ascent

$$\mathbf{D}^{(n+1)}_i \leftarrow \frac{\max\left(0, \mathrm{tr}\left(\mathbf{D}^{(n+1)}_i\right) - N_b\right)}{\|\mathbf{1}_{N_b}\|^2}\mathbf{1}_{N_b}$$ projection

Step 6) Go to Step 2

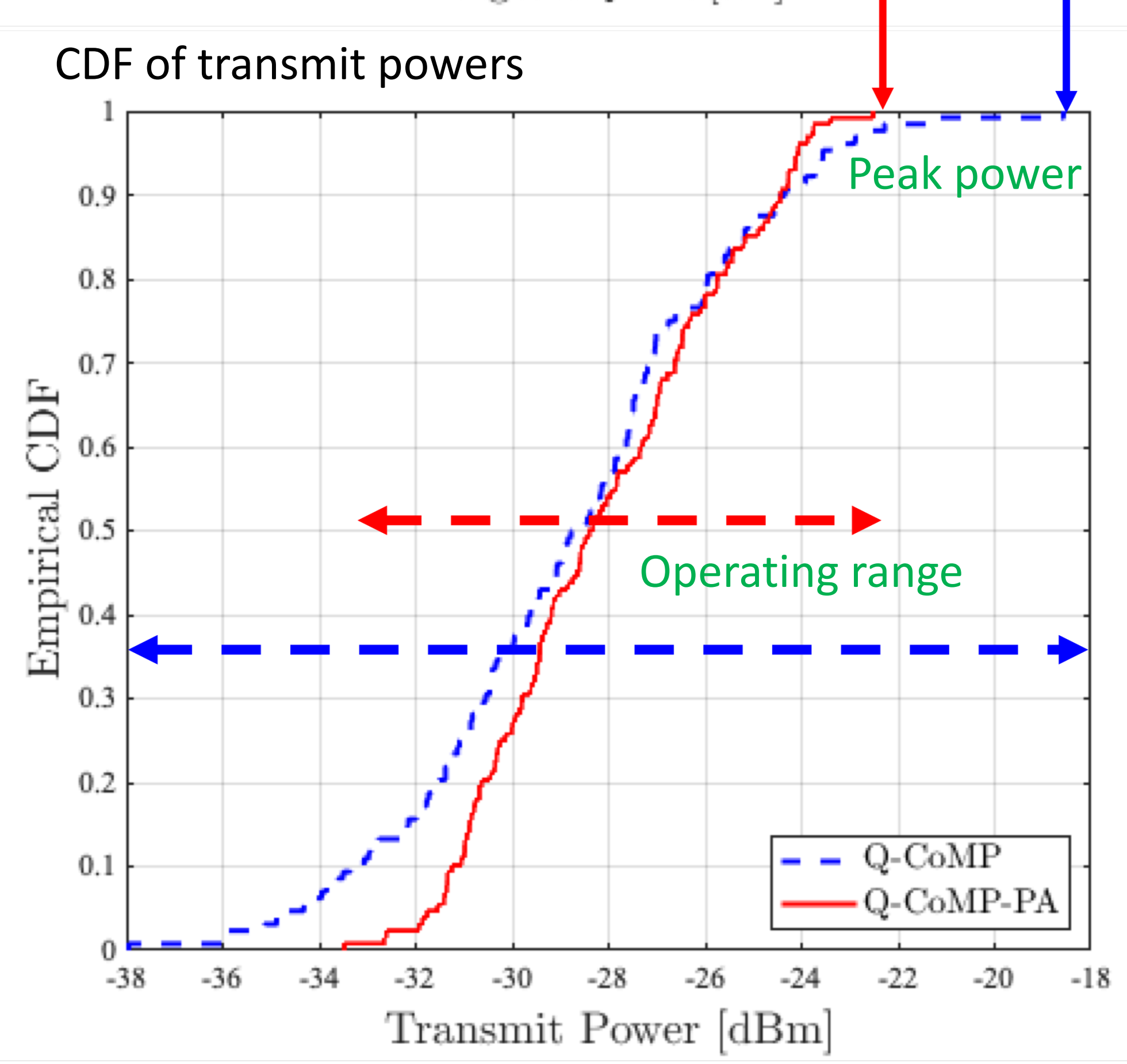
IV VALIDATION

Max power vs. target SQINR



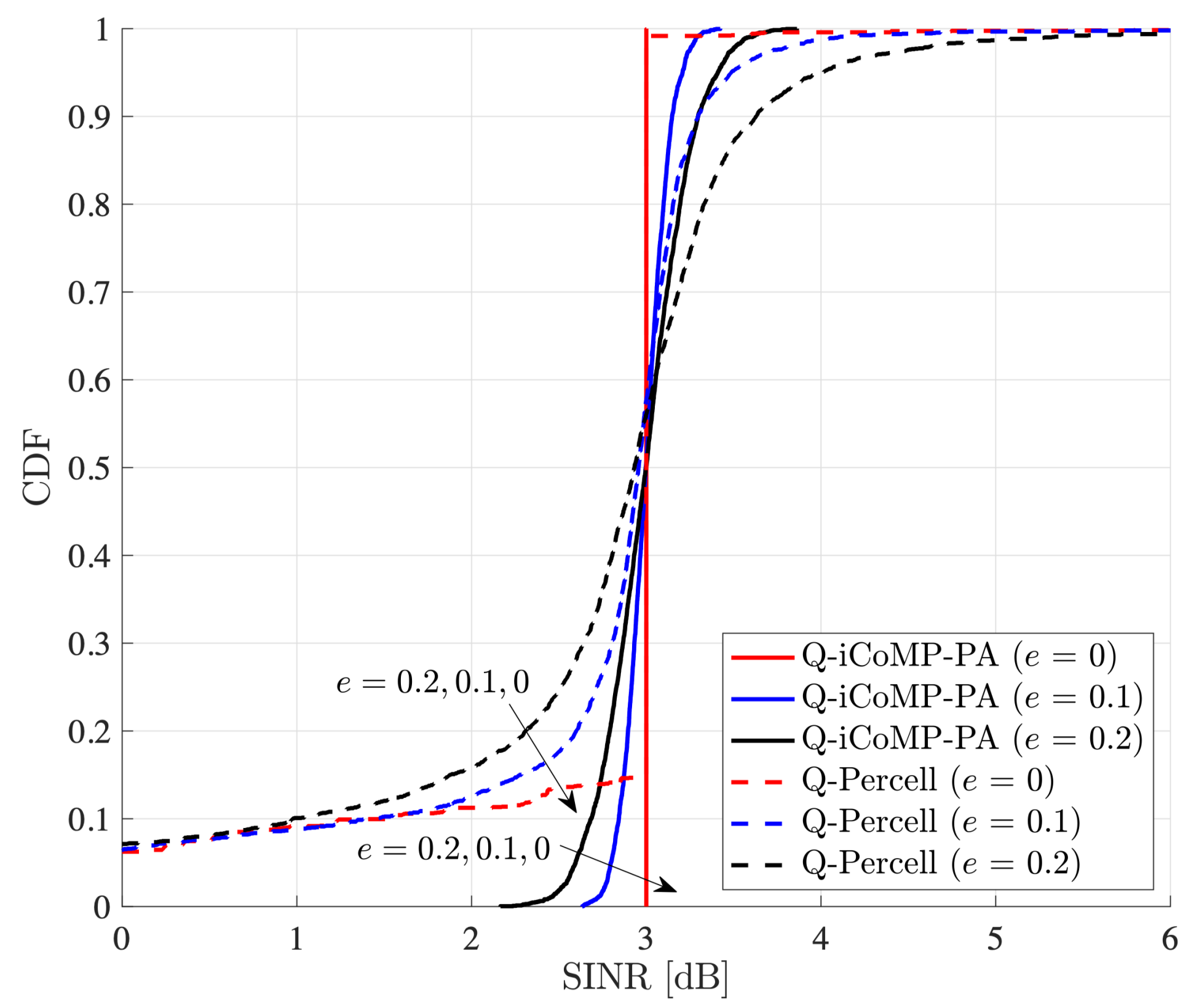
N_b	16
N_c	4
N_u	2
K	32

CDF of transmit powers



N_b	32
N_c	4
N_u	2
K	64
γ	-1 dB

Imperfect CSI



N_b	32
N_c	4
N_u	2
K	32
γ	3 dB

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6G@UT Student Showcase
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