Massive MIMO Power Reduction

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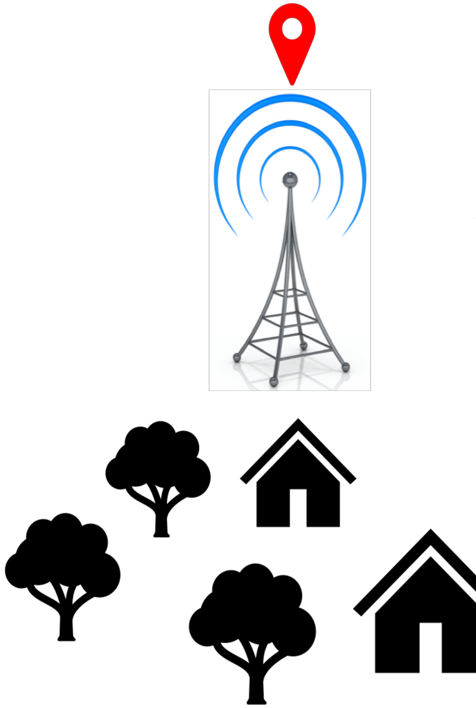
Overview

Receiver Design

1. Resolution-Adaptive ADC
2. Two-stage analog combining
3. Antenna selection
4. Learning-based one-bit detection

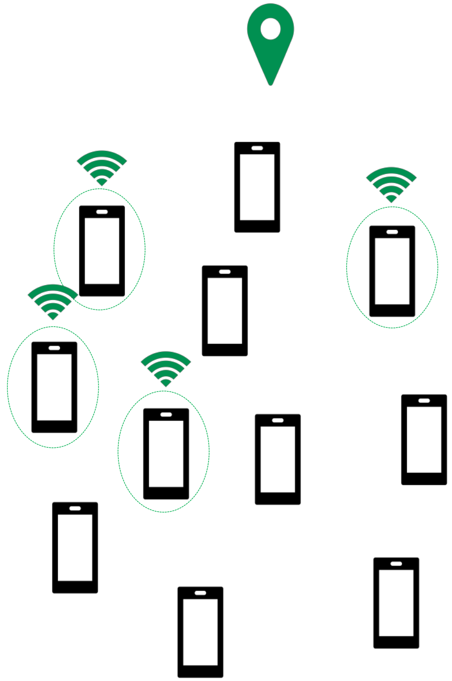


Channel Estimation

1. MmWave One-bit ADC
2. Deterministic beamforming design

User Scheduling

1. New user scheduling criteria
2. Partial CSI-based scheduling



Selected Topics

Summary and Future work

*GAMP: generalized approximate message passing

Channel Estimation

❑ Summary

- Compressive-sensing (CS)-based millimeter wave channel estimation in hybrid beamforming systems

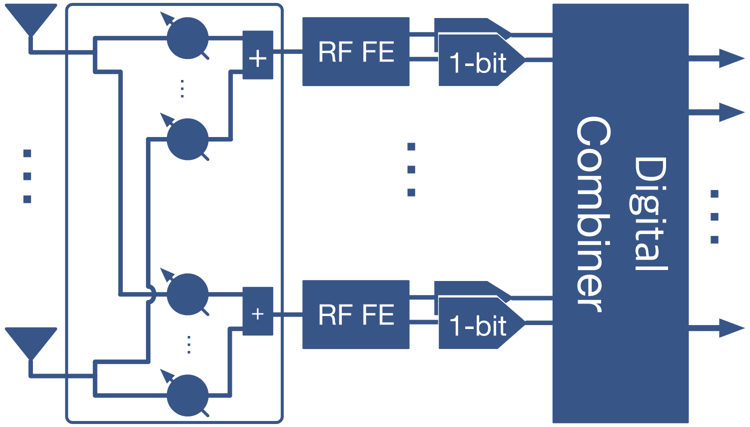
1. Hybrid Beamforming with One-bit ADCs

System

- PS Hybrid Architecture w/ 1-bit ADC
- Frequency-Flat Channels
- Beamformer w/ Random Configuration
- Downlink

Key Technique

- Modified one-bit GAMP*



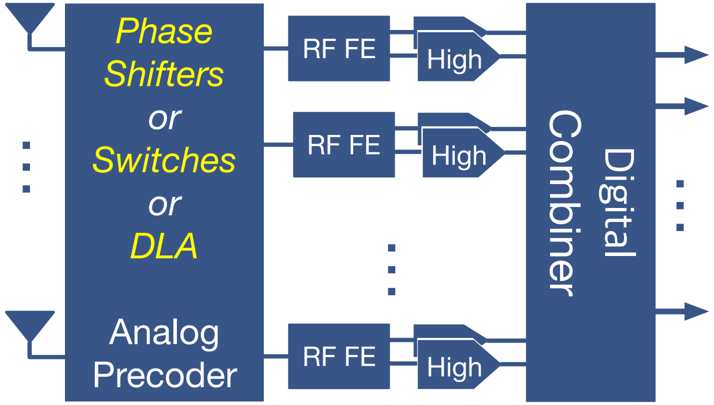
2. Universal and Deterministic Beamformer Design

System

- PS/SW/Lens Hybrid Architecture
- Frequency-Flat Channels
- Beamformer w/ Deterministic Configuration
- Downlink

Key Technique

- Deterministic optimal beamformer design



Channel Estimation

❑ Future work

: development of universal channel estimation technique

Deterministic hybrid beamformer design for channel estimation

Goal

: Design beamformer codebooks and pilots that minimize the mutual coherence of sensing matrix

Mutual Coherence

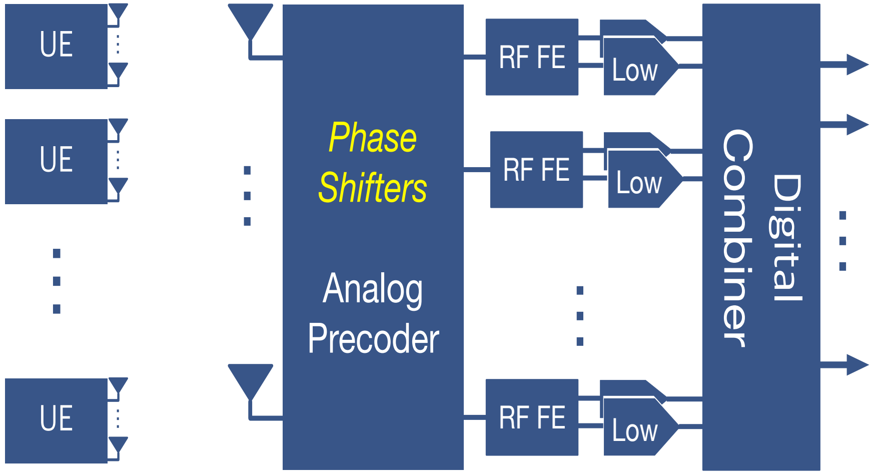
$$\mu(\mathbf{A}) = \max_{i \neq j} \frac{|\mathbf{a}_i^{\mathsf{H}} \mathbf{a}_j|}{\|\mathbf{a}_i\|_2 \, \|\mathbf{a}_j\|_2} = \max_{i \neq j} \frac{|(\mathbf{A}^{\mathsf{H}} \mathbf{A})_{ij}|}{\|\mathbf{a}_i\|_2 \, \|\mathbf{a}_j\|_2}$$

minimize

$$\mathcal{F}_{RF}, \mathcal{F}_{BB}, \mathcal{W}_{RF}, \mathcal{W}_{BB}, \mathcal{X}$$

Possible targets for extension:

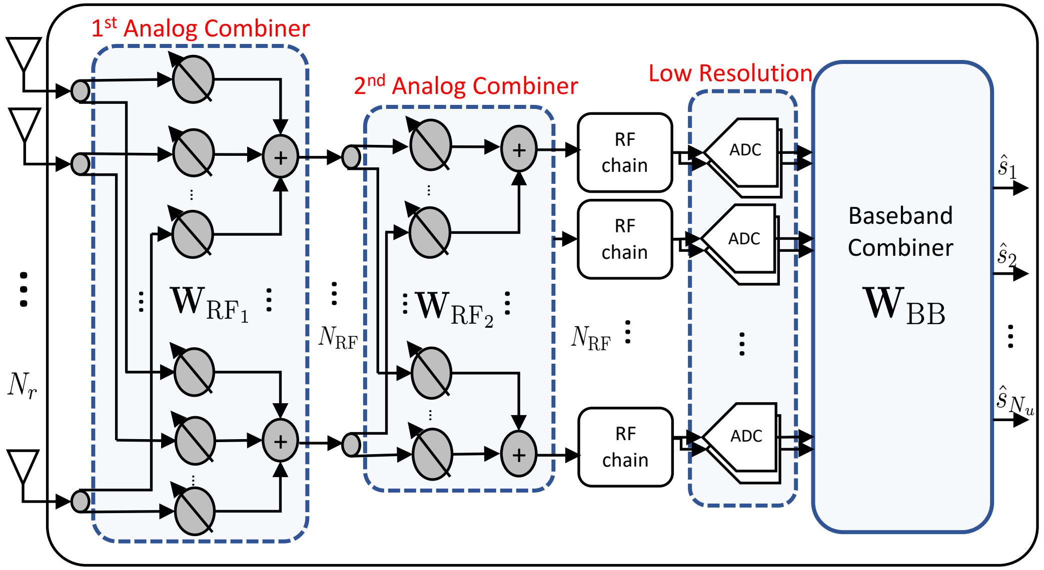
- Frequency-selective channels
  - ➢ OFDM
- Low-resolution ADCs
  - ➢ AQNM
- Arbitrary antenna array
  - ➢ Unstructured matrix into account
- Uplink
  - ➢ Multi-user into account



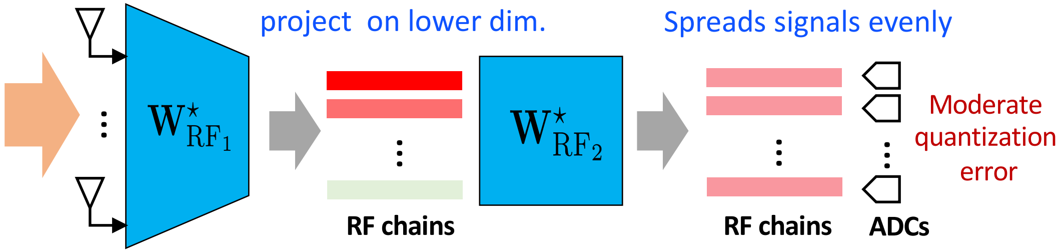
Receiver: Two-Stage Analog Combining

❑ Summary

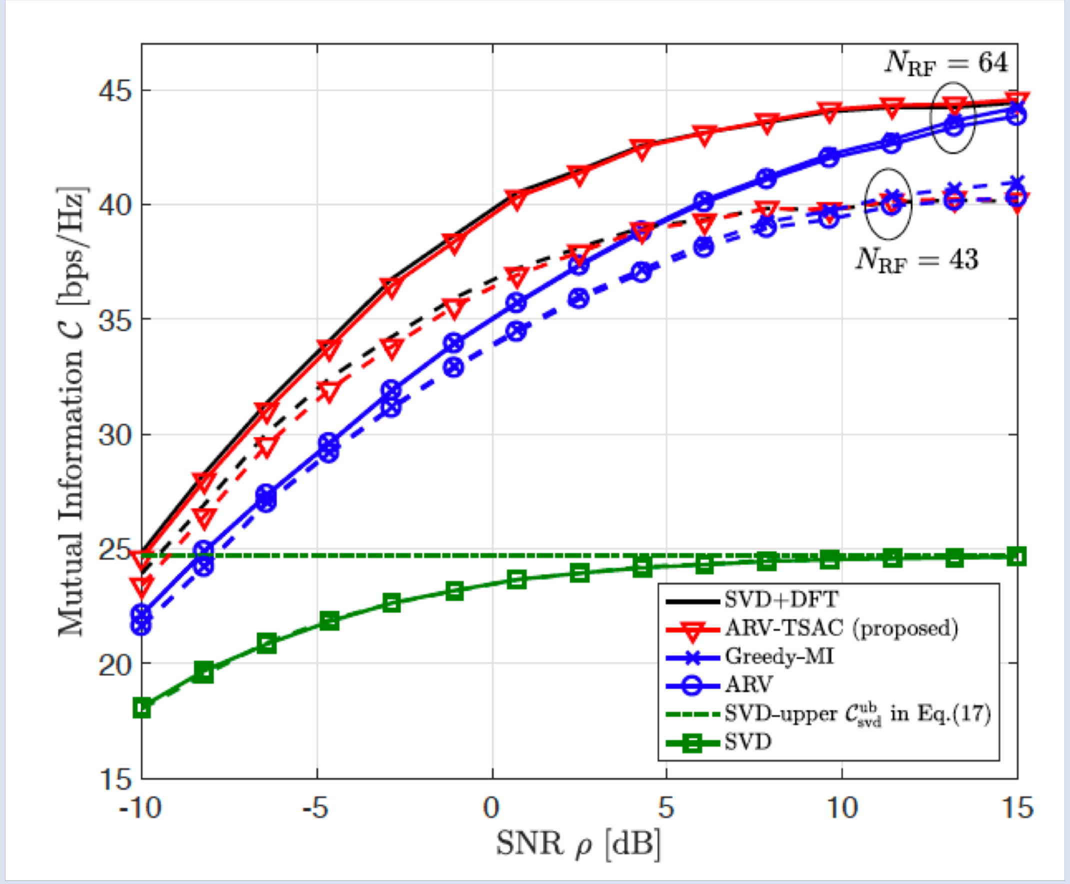
Two-Stage Analog Combining



Two-stage solution



Two-stage analog combining vs. One-stage analog combining



(N_r = 128 , N_{ue} = 8, b = 2, channel paths = 3)

Receiver: Two-Stage Analog Combining

❑ Future work

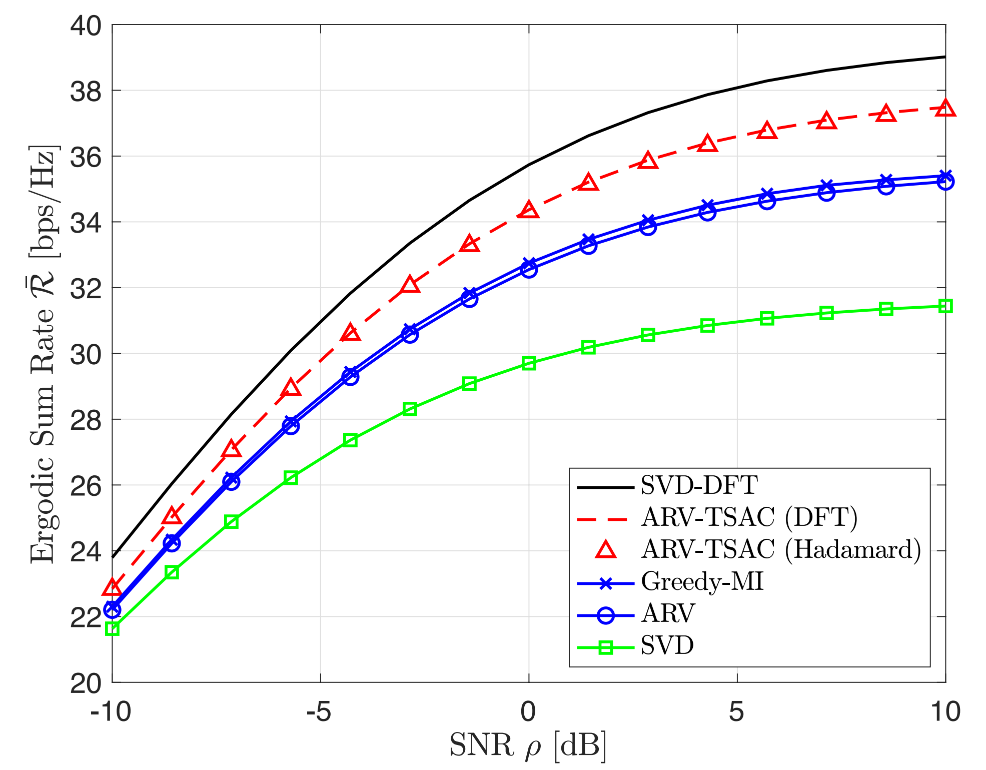
- Implementation complexity reduction
  - First analog combiner $\mathbf{W}_{\mathrm{RF1}}$
    : use subarray structure to reduce # of phase shifters

    ex.
    1. Disjoint subarray – simplest
    2. Joint subarray – few overlaps among subarrays
    3. Dynamic subarray – adaptive subarray structure

  - Second analog combiner $\mathbf{W}_{\mathrm{RF2}}$
    : use simpler unitary matrix with constant amplitude

    ex.
    Hadamard matrix
    - only composed of 1s and -1s
    - requires $(N_{\mathrm{RF}}^2 - N_{\mathrm{RF}})/2$ phase shifters with -180 phase

Performance with Hadamard Matrix

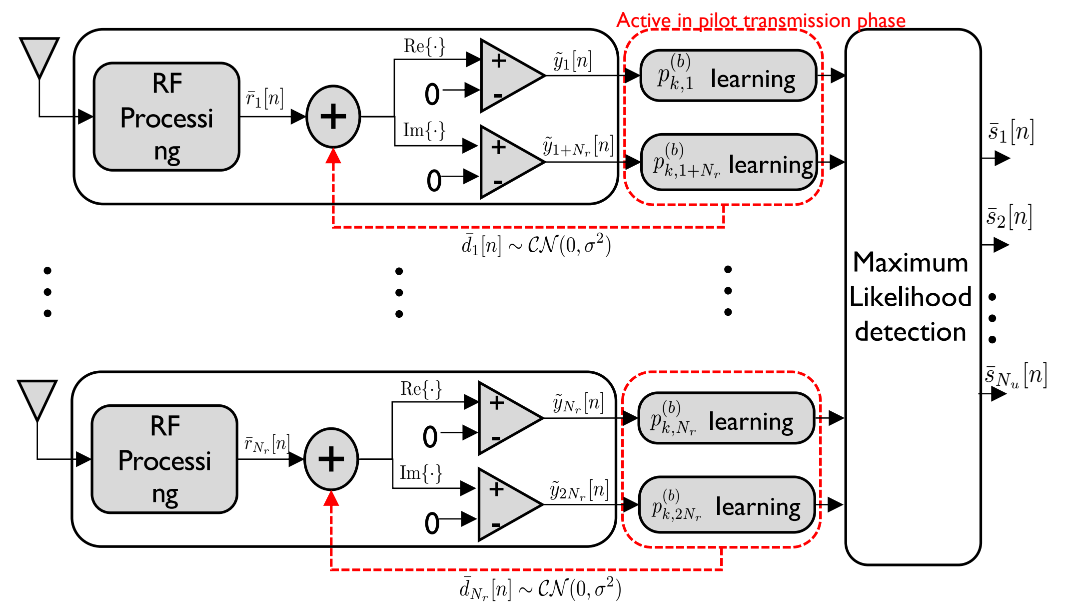


(N_r = 128 , N_{RF} = 32, N_{ue} = 8, b = 3, channel paths = 3)

Receiver: 1-Bit Detection without Channel State Information

❑ Summary

Robust Learning-based 1-Bit Detection



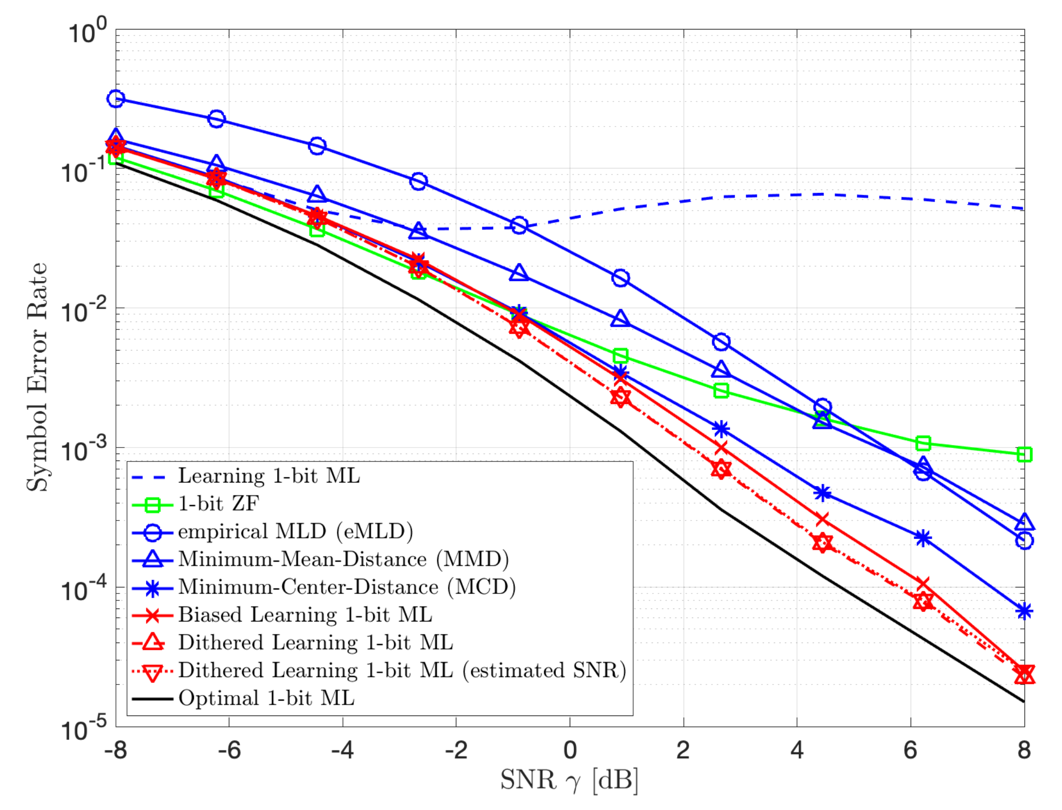
Dithering-and-learning

- Maximum likelihood detection
  - Add dithering to robustly learn likelihood probability

$$k^\star = \operatorname*{argmax}_{k\in\mathcal{K}} \prod_{i=1}^{2N_r} p_{k,i}^{(b)} = \begin{cases} p_{k,i}^{(1)} = \frac{1}{N_{tr}}\sum_{t=1}^{N_{tr}} \mathbf{1}(y_i[(k-1)N_{tr}+t]=1) \\ p_{k,i}^{(-1)} = 1 - p_{k,i}^{1} \end{cases}$$

Proposed Method vs. other 1-Bit Detectors

Training length: N_{tr} = 50



(32 BS antennas, 4 users, 4-QAM, 1-bit ADCs, Rayleigh fading)

Receiver: 1-Bit Detection without Channel State Information

☐ Future work

- 1-bit detection with coded MIMO system
  - Computation of soft metric (e.g., log likelihood ratio)
    : uses subset of likelihood probability

LLR computation

$$L^{u}_{mn-(p-1)}(\mathbf{y}[n]) = \log \frac{\prod_{k\in\mathcal{A}^{u}_{(p,0)}} \prod_{i=1}^{2Nr}\left\{\hat{p}^{(1)}_{k,i}\mathbf{1}(y_i[n]=1)+\hat{p}^{(-1)}_{k,i}\mathbf{1}(y_i[n]=-1)\right\}}{\prod_{k\in\mathcal{A}^{u}_{(p,1)}} \prod_{i=1}^{2Nr}\left\{\hat{p}^{(1)}_{k,i}\mathbf{1}(y_i[n]=1)+\hat{p}^{(-1)}_{k,i}\mathbf{1}(y_i[n]=-1)\right\}}$$

Subset of Collected symbols

$$\mathcal{A}^{u}_{(p,j)} = \bigcup_{\mathbf{b}\in\{0,1\}^m,\, b^u_p=j} \{k: \mathcal{S}^u = f(\mathbf{b})\}$$

where

$u \in \{1,\dots,N_u\}$

$f: M-\text{QAM modulation}$

$m = \log_2 M$

$p \in \{1,\dots,m\}$

Subset filtering by SIC

- Successive Interference Cancellation
  - Detection of next bit
  - Computation over refined subset
    : reduces size of subset
    : removes detection ambiguity (improves accuracy)

Refined subset

$$\mathcal{A}^{u}_{(p,j|\underline{\hat{\mathbf{b}}}^{n}_{p})} = \bigcup_{\substack{\mathbf{b}\in\{0,1\}^m,\, b^n_p=j \\ \underline{\mathbf{b}}^{n}_{p}=\underline{\hat{\mathbf{b}}}^{n}_{p}}} \{k: \mathcal{S}^u = f(\mathbf{b})\}$$

where

$$\underline{\mathbf{b}}^{n}_{p} = [b^1_1, \dots, b^1_p, b^2_1, \dots, b^u_{p-1}]$$

User Scheduling in Coarse Quantization System

❑ Summary

- **Goal**

  : To mitigate quantization error by effectively scheduling users

- **Key idea**

  : Derive new scheduling criteria that reduce quantization error

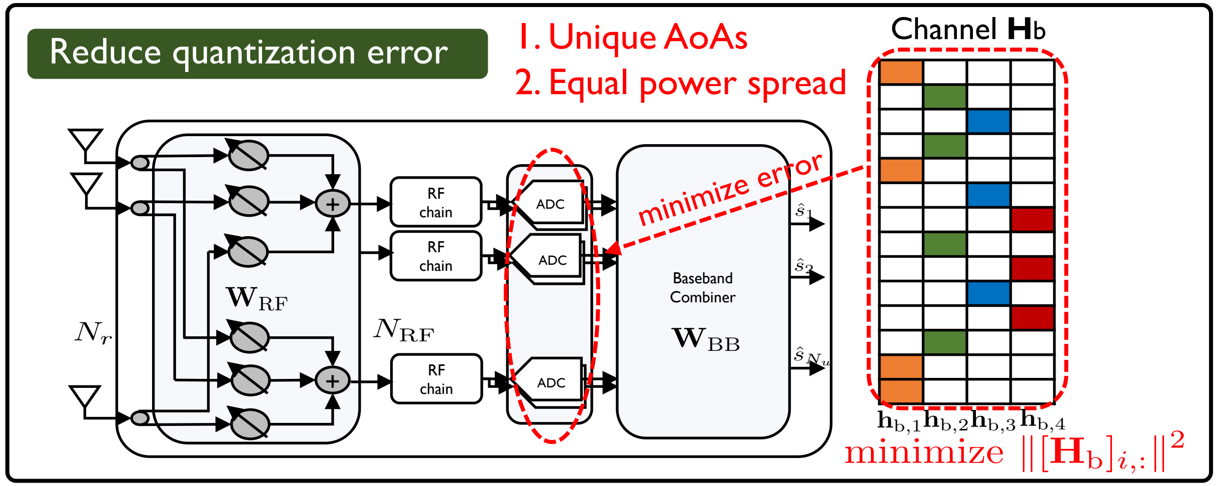
- **Optimization**

  : Maximum sum rate user scheduling

New criteria

*Angle of arrivals

1. Unique *AoAs for channel paths of each scheduled user
2. Equal power spread across complex path gains



Reduce quantization error

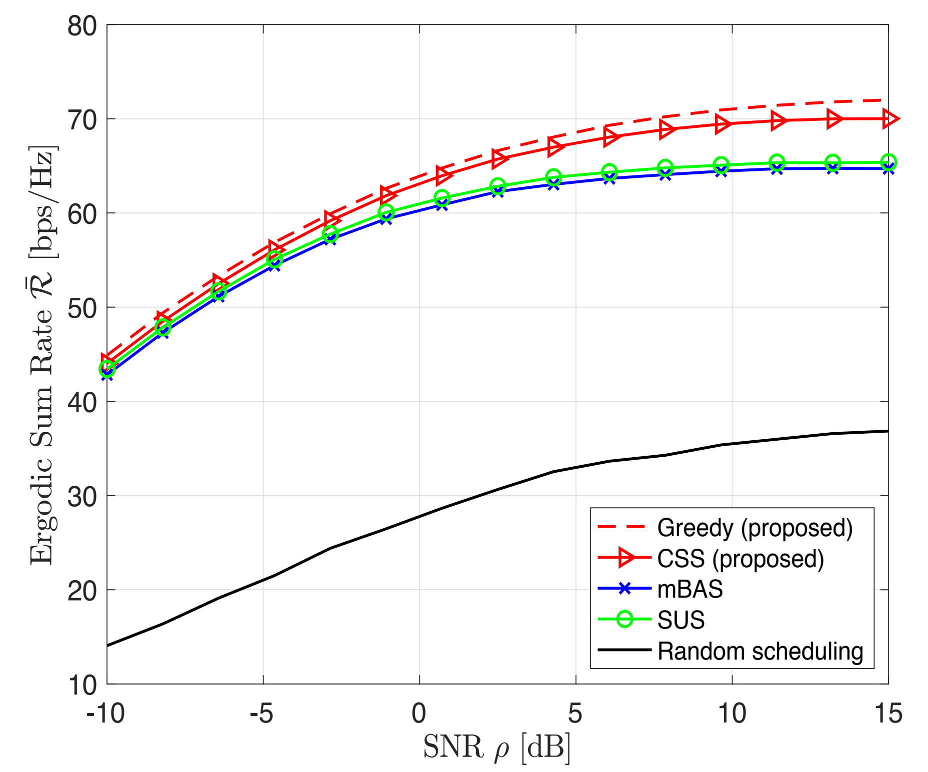
1. Unique AoAs
2. Equal power spread

Channel $\mathbf{H}_\mathrm{b}$

minimize error

$\mathrm{minimize}\ \|[\mathbf{H}_\mathrm{b}]_{i,:}\|^2$

Proposed Scheduler vs. Other Schedulers



(N_r = 128, N_RF = 40, N_ue = 12 out of 200, b = 3, channel paths = 3)

User Scheduling in Coarse Quantization System

❑ Updated Results: scheduling with partial CSI

- Alternative to instantaneous full CSI

  : Exploit Angles of arrival (AoA) - long-term characteristics

- Chordal distance-based user scheduling

Channel Vector

$$\mathbf{h}_k = \sqrt{\frac{N_r}{L_k}} \sum_{\ell=1}^{L} g_{k,\ell}\mathbf{a}(\phi_{k,\ell})$$

$$\mathbf{A}_k = \left[\mathbf{a}(\phi_{k,1}),\ldots,\mathbf{a}(\phi_{k,|\mathcal{V}_k|})\right]$$

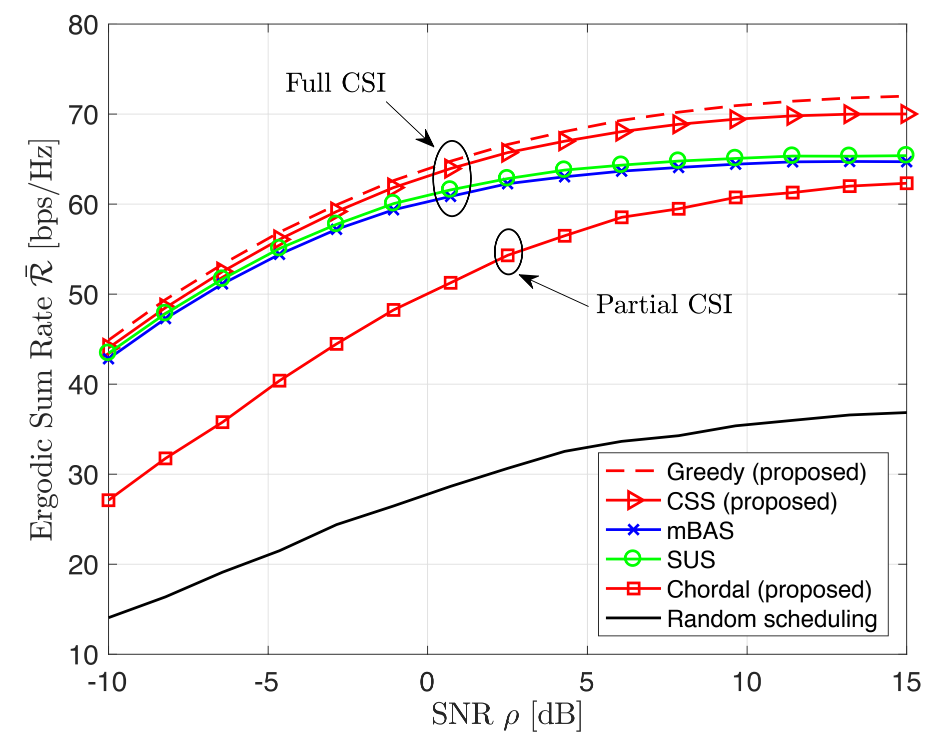
measure separation between channel subspaces

Chordal Distance

$$d_{\mathrm{cd}}\left(k,k'\right) = \sqrt{L_{min} - \mathrm{tr}\left(\mathbf{Q}_k^H\mathbf{Q}_{k'}\mathbf{Q}_{k'}^H\mathbf{Q}_k\right)}$$

$$\mathbf{Q}_k = \text{column basis of } \mathbf{A}_k$$

Proposed Scheduler vs. Other Schedulers



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User Scheduling in Coarse Quantization System

☐ Future work

- Fairness among scheduled user

1. Round-Robin manner
   : schedule users repeatedly by using proposed method

2. Proportional fairness
   : schedules users by using weighted objective function

   - Weighted objective function

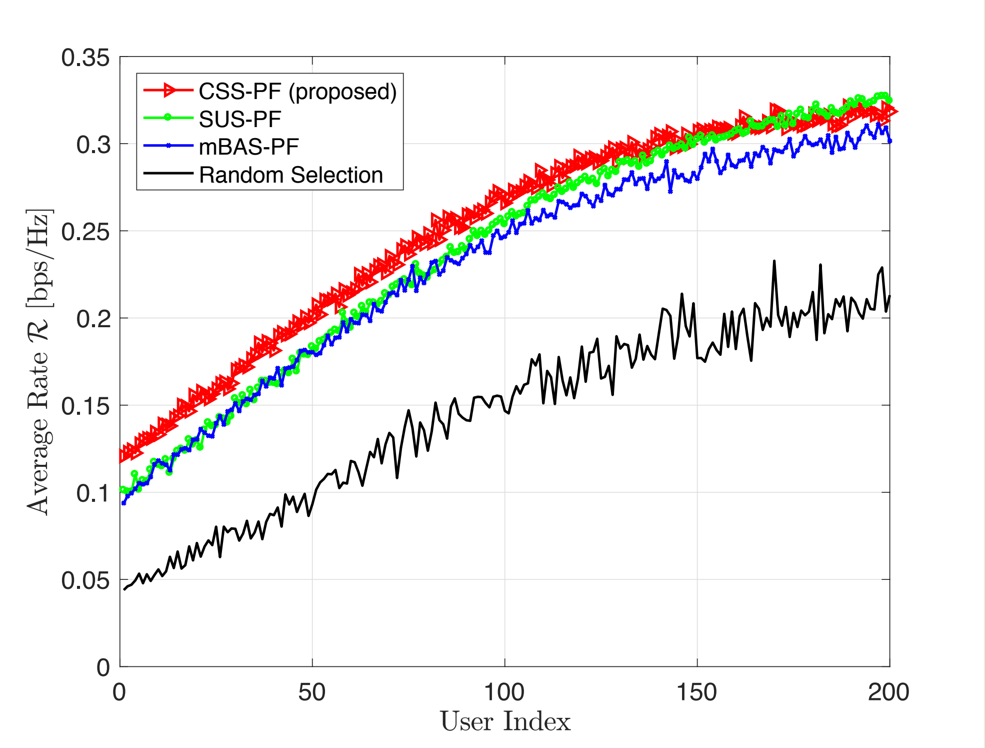
$$\mathcal{S}_t(i) = \arg\max_{k \in \mathcal{K}_i} \frac{\log_2(1 + \mathrm{SINR}_k(\mathbf{H}_\mathrm{b}(t)(\mathcal{S}_t \cup \{k\})))}{\mu_k(t)}.$$

   - Weight update (previously supported rate)
     : first-order autoregressive (AR) filter

$$\mu_k(t+1) = (1-\delta)\mu_k(t) + \delta R_k(t)\mathbf{1}_{\{k \in \mathcal{S}_t\}}$$

Preliminary – Proportional Fairness

SNR = 6 dB



(N_r = 128, N_RF = 40, N_ue = 12 out of 200, b = 3, channel paths = 3)

Related Publications

[1] Junmo Sung and Brian L. Evans, "Deterministic Hybrid Beamformer Design to Improve Compressed Sensing Narrowband mmWave Channel Estimation Algorithm Performance," *IEEE Trans. Wireless Comm*. (under revision)

[2] Junmo Sung, Jinseok Choi, and Brian L. Evans, “Narrowband Channel Estimation for Hybrid Beamforming Millimeter Wave Communication Systems with One-bit Quantization,” *IEEE ICASSP* 2018

[3] Jinseok Choi, Gilwon Lee, and Brian L. Evans, “Two-Stage Analog Combining in Hybrid Beamforming Systems with Low-Resolution ADCs”, *IEEE Trans. Commun.* (under revision)

[4] Jinseok Choi, Gilwon Lee, and Brian L. Evans, “A Hybrid Combining Receiver with Two-Stage Analog Combiner and Low-Resolution ADCs”, *IEEE ICC* 2019, (under revision)

[5] Jinseok Choi, Yunseong Cho, Brian L. Evans, and Alan Gatherer, “Robust Learning-Based ML Detection for Massive MIMO Systems with One-Bit Quantized Signals”, *IEEE ICC* 2019, (submitted)

[6] Jinseok Choi and Brian L. Evans, “Analysis of Ergodic Rate for Transmit Antenna Selection in Low-Resolution ADC Systems”, *IEEE Trans. Veh. Techonol.*

[7] Jinseok Choi, Brian L. Evans, and Alan Gatherer “Antenna Selection for Large-Scale MIMO Systems with Low-Resolution ADCs”, *IEEE ICASSP* 2018

[8] Jinseok Choi, Brian L. Evans, and Alan Gatherer, “Resolution-Adaptive Hybrid MIMO Architecture for Millimeter Wave Communications”, *IEEE Trans. Signal Process.*

[9] Jinseok Choi, Junmo Sung, Brian L. Evans, and Alan Gatherer, “ADC Bit Optimization for Spectrum- and Energy-Efficient Millimeter Wave Communications”, *IEEE GLOBCOM* 2017

[10] Jinseok Choi, Gilwon Lee, and Brian L Evans, “User Scheduling for Millimeter Wave Hybrid Beamforming Systems with Low-Resolution ADCs”, *IEEE Trans. Wireless Commun.* (under revision)

[11] Jinseok Choi and Brian L. Evans, “User Scheduling for Millimeter Wave MIMO Communications with Low-Resolution ADCs”, *IEEE ICC* 2018

[12] Yunseong Cho, Seonho Kim, and Songnam Hong, “Successive Cancellation Soft-Output Detector for Uplink MIMO system with One-bit ADCs”, IEEE ICC 2018, Kansas city, MO, USA.

[13] Songnam Hong, Seonho Kim, and Namyoon Lee, “A Weighted Minimum Distance Decoding for Uplink Multiuser MIMO Systems With Low-Resoultion ADCs”, IEEE Transactions on Communications, 2018.