Compressed Beam Alignment with Out-of-Band Assistance in Millimeter Wave Cellular Networks

Jie Zhao, Xiaomeng Wang and Xin Wang

The Department of Electrical and Computer Engineering, Stony Brook University

Contact: {jie.zhao, xiaomeng.wang, x.wang}@stonybrook.edu

Challenges and Motivation

The need of highly directional communications at millimeter-wave (mmWave) band

- ❑ A large number of candidate beamforming directions for mmWave antennas
- ❑ Basic solution: directly training all possible directions or according to a large volume of codebook
- ❑ High overhead for beam training and alignment

Assistance from low-frequency band

- ❑ Only a rough guidance
- ❑ Non-exact matching between legacy band and mmW band
- ❑ Inaccurate inference from legacy band to mmWave band
- ❑ Mis-alignment in mmWave transmissions

Compressed sensing (CS) in mmWave channel estimation in the literature

- ❑ Training a small subset of beam directions
- ❑ Failing to consider the path clustering (block) feature of mmWave channels

Objectives

To achieve better beam alignment in the mmWave band thus higher transmission rates

❑ Efficient beam alignment

- Utilizing CS to reduce training overhead
- Exploiting block-sparse properties of mmWave channels for better accuracy

❑ Flexible out-of-band assistance

- Legacy-band-assisted beam selection
- Legacy-band-assisted channel estimation

Proposed Design

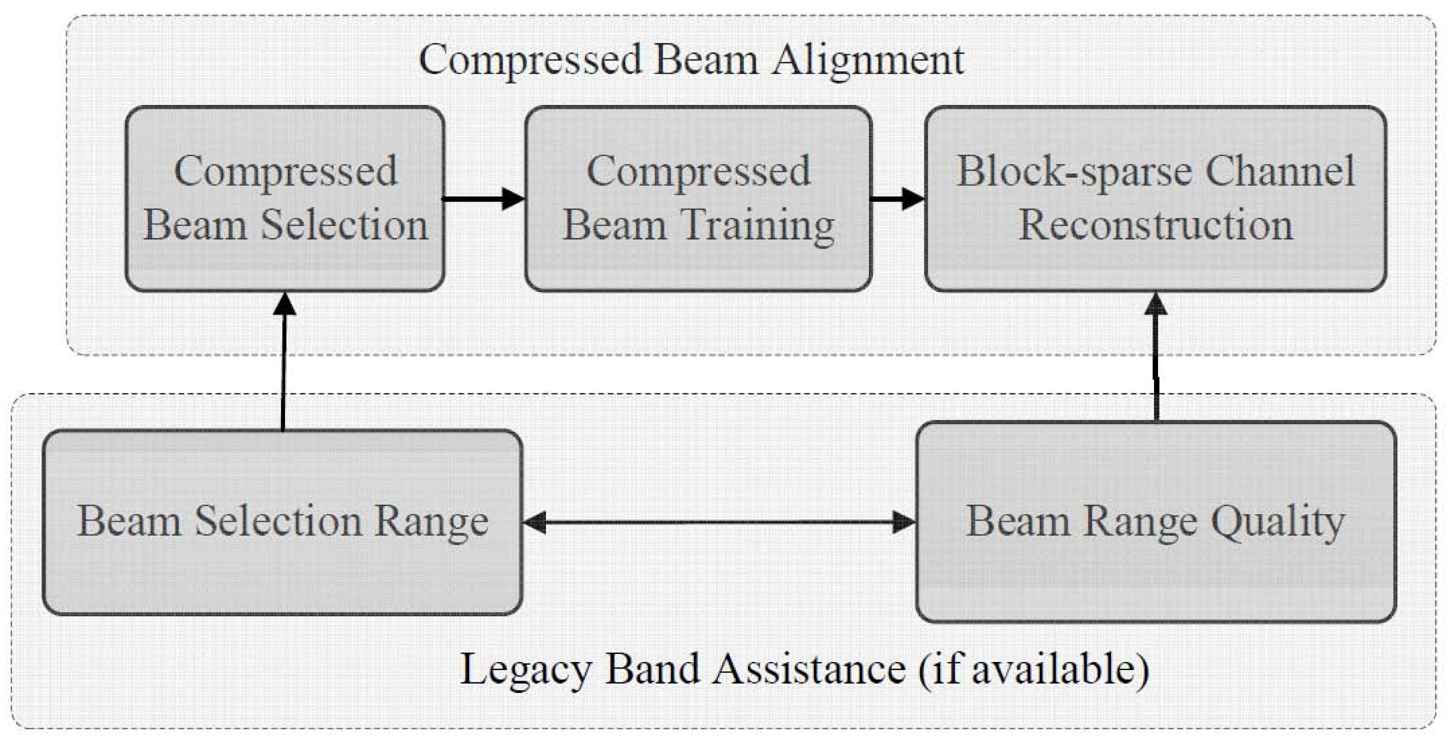


Fig. 1. Framework Overview

Integrated beam alignment design for high performance mmWave transmissions with two closely interactive components:

❑ CS-based beam alignment with block-sparse channel reconstruction

- Path clustering channel modeling

$$\mathbf{a} = [\underbrace{a_{11}, a_{12}, \ldots, a_{1L}}_{\text{cluster 1}}, \underbrace{a_{21}, a_{22}, \ldots, a_{2L}}_{\text{cluster 2}}, \ldots, \underbrace{a_{K1}, a_{K2}, \ldots, a_{KL}}_{\text{cluster } K}]^T,$$

- Block-sparse reconstruction algorithm

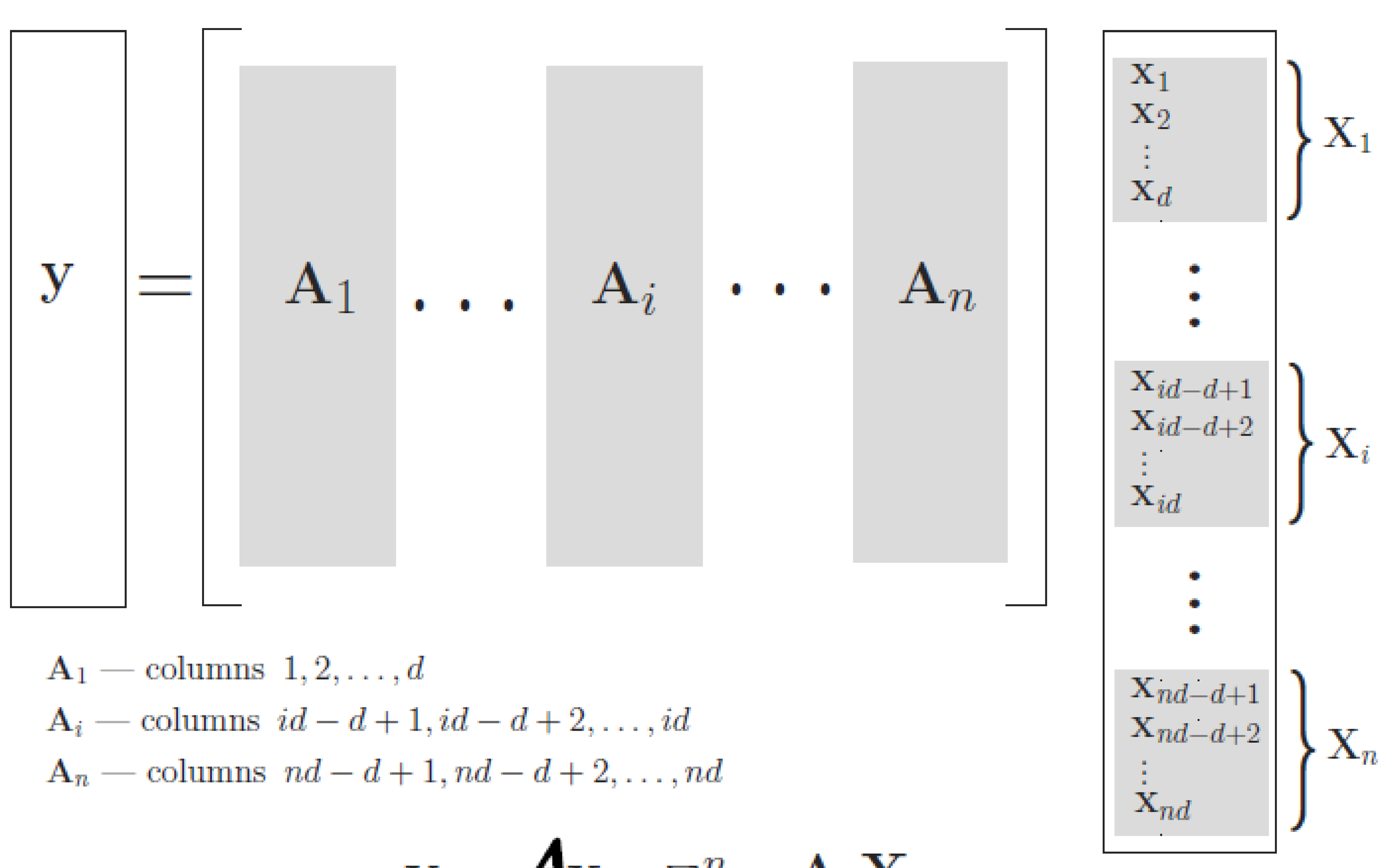


Fig. 2. Block-sparse Reconstruction

$$\mathbf{y} = \boldsymbol{A}\mathbf{x} = \sum_{i=1}^{n} \mathbf{A}_i \mathbf{X}_i$$

❑ Iterative channel reconstruction with legacy band information

- Legacy-band-assisted beam selection
  - -Restricting beam searching to a better range
- Legacy-band-assisted channel estimation

$$\min \sum_{i=1}^{n} w_i \|\mathbf{X}_i\|_2$$

  - -Block weights initialized by legacy band information
  - -Block weights updated according to the number of non-zero elements within the block
  - -Iteratively disregarding the weakest block as residual noise

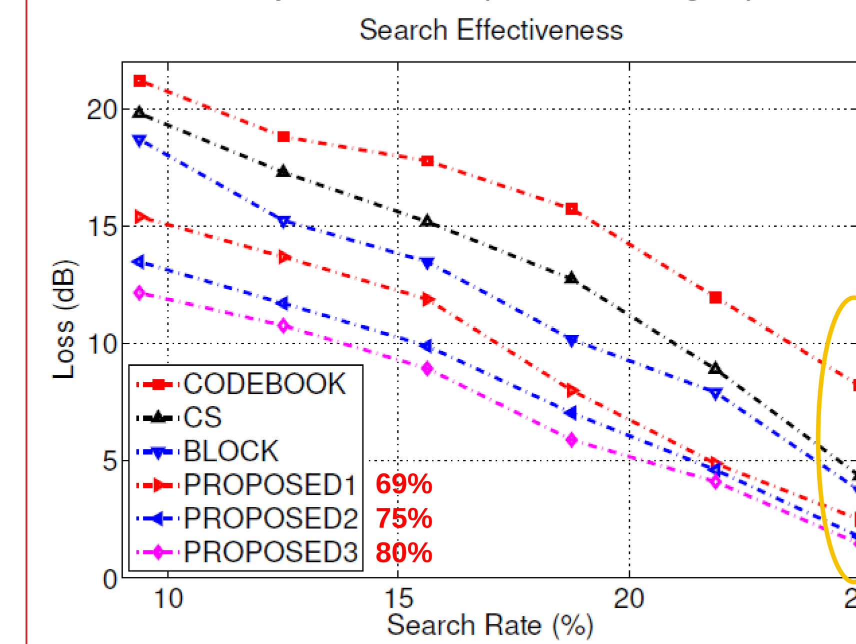
Performance Evaluations

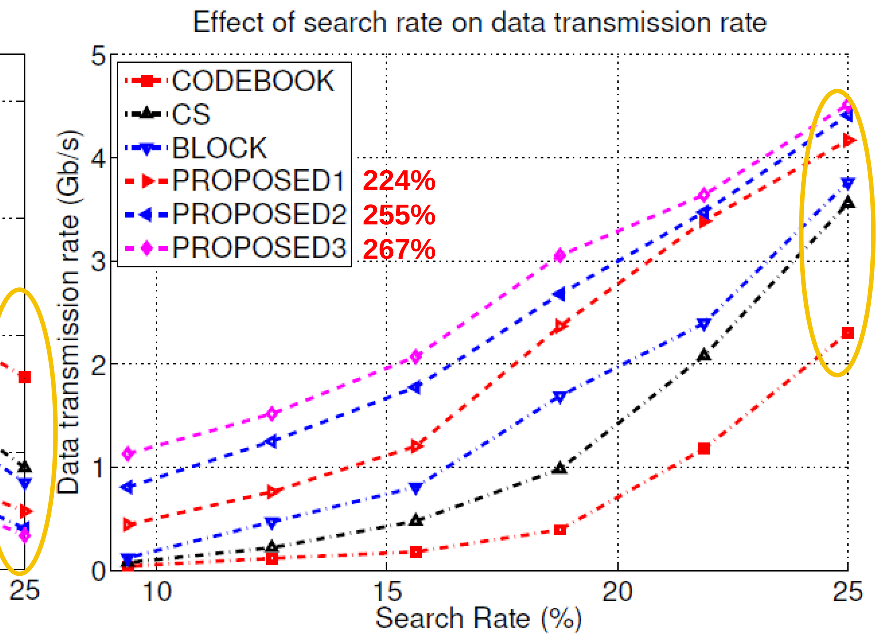
Significant improvement over baseline CODEBOOK

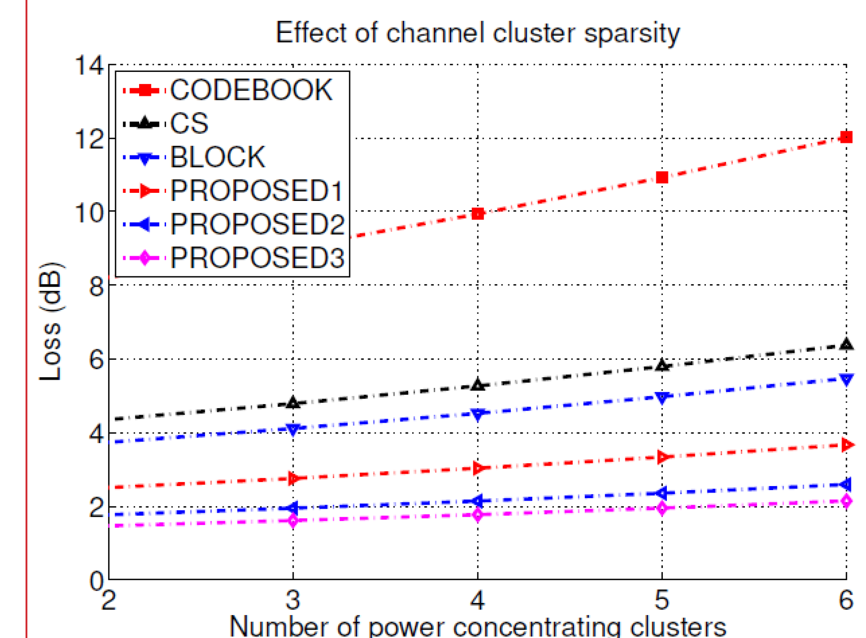
-Up to 80% SNR Loss reduction

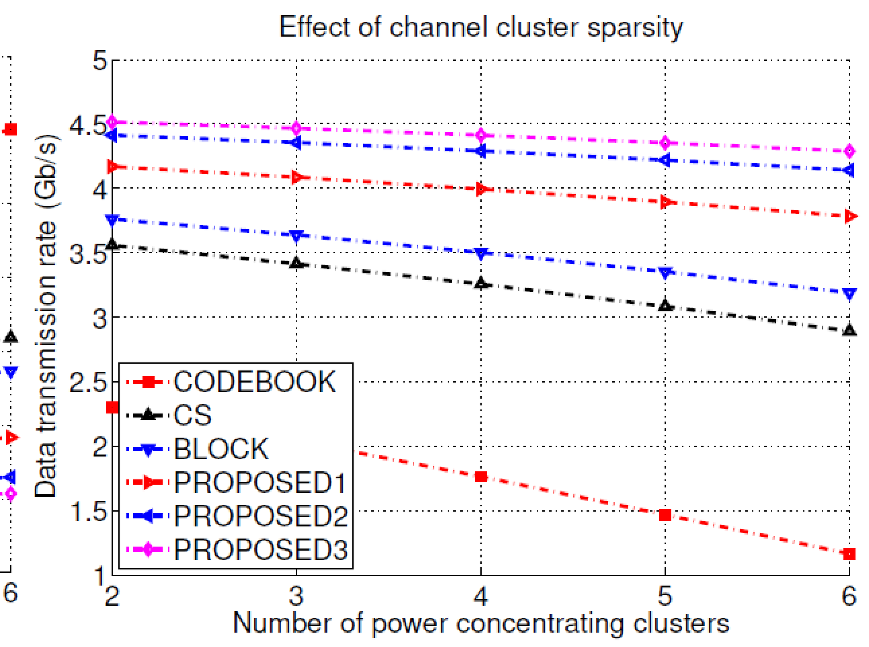
-More than 2.6x transmission rate enhancement

Loss: SNR loss compared with exhaustive search
Search rate: fraction of trained beam pairs out of all possible ones
CODEBOOK: conventional multi-level codebook-based
CS: conventional compressed sensing
Block: unweighted block-sparse construction
Proposed1: proposed weighted block-sparse reconstruction w/o low band assistance
Proposed2: proposed1 + weights initialized by legacy band assistance
Proposed3: Proposed2 + legacy-band-assisted beam selection









Conclusion

The proposed schemes significantly reduce beam training overhead and improve data transmission rates in mmWave networks with the interaction of:

❑ Compressed beam alignment with block-sparse channel estimation

- Reducing training overhead
- Considering path clustering thus block sparsity feature of mmWave channels

❑ Legacy-band-assisted beam selection and channel reconstruction

- Exploiting coarse low-frequency information flexibly
- Narrowing down to better beam search range
- Updating block weights iteratively in CS reconstruction