Towards Efficient Medium Access for Millimeter-wave Networks

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Challenges and Motivation

The need of highly directional communications at mmWave frequencies introduces high overhead for beam training and alignment.

- Urgent need of efficient beam training & alignment
- Difficulties in directional medium access control (MAC).
- Necessity to concurrently schedule radio resources for beam training and data transmission.

Objectives

Achieve high performance mmWave transmissions
- Efficient beam training and alignment with lower training overhead and higher beam gain
- Joint beam training and transmission scheduling to efficiently allocate resources among users while coping with environment dynamics
  - channel condition, user population, location, traffic

Proposed Design

Integrated MAC design for high performance mmWave network transmissions with 3 closely interactive components:

- Accurate & light-weight beam training
  - multi-user, multi-level, bi-directional coarse training
  - block-sparse channel modeling
    \[ a = [a_{11}, a_{22}, \ldots, a_{K1}, a_{K2}, \ldots, a_{KL}]^T, \]
  - fine beam adaptive training with multi-resolution channel estimation
    \[ \text{dim}(H_{QO}) < \text{dim}(H_{RS}) < \text{dim}(H_{BS}) \]
  - Joint beam training and data transmission scheduling
    - self-adaptive virtual resource scheduling
      \[ x = \arg \max_x a(x)W(x)r(x)/\tau(x), \]  
      - a: priority parameter, W: queuing delay, r: transmission rate, \( \tau \): average rate obtained
    - Trade-off among beam training, data transmission and beam tracking for an overall high network performance
      \[ T_{sf} = T_{BT} + T_{DTT}, \quad T_{DTT} = T_{fan} + T_{sp} + T_{dp} \]

- Effective beam tracking for more stable beam alignment
  - beam-width adaptation
  - mobility estimation
    \[ \theta_{dev} = T_{lat} \sum_{i=1}^{N_e} |\theta_{dev,i}| / \sum_{i=1}^{N_e} \tau_{lat,i} \]

Conclusion

The proposed schemes significantly reduce training overhead and improve throughput with the interaction of:

- a low-cost multi-user beam training scheme
  - multi-level coarse training
  - multi-resolution adaptive sparse channel estimation for fine beam alignment
- concurrent allocation of radio resources for beam training and data transmission
  - virtual scheduling based on user application types and demands
- flexible beam tracking scheme
  - beam-width adaptation
  - mobility estimation