**Introduction & Motivation**

- 60 GHz large available Bandwidth 9 to 7 GHz
- High Data rates: IEEE 802.11ad mm-Wave provide rates up to 7 Gbps

**Directional Communication:**
- Overcome increased path loss of 20-40 dB
- Interference is no longer an issue
- How to coordinate sender and receiver in space and time

**Line of Sight Communication:**
- Receiver and transmitter directionally aligned
- Obstacles block signal

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**Background**

**802.11ad**

- The establishment of directional links or beamforming training allows each node to resolve antenna settings for both transmission and reception.
- Beamforming training in the 802.11ad standard consists of two stages:
  - **Sector Level Sweep (SLS):** an exhaustive search to select the best transmit sector is performed by both transmitter and receiver.
  - **Beam Refinement Process (BRP):** directionality gain is increased by fine-tuning antenna settings at both the transmitter and receiver.

**Angle of Arrival (AoA)**

**Multiple Omni-Directional Antennas to Infer Direction**
- Uses time of arrival or phase difference [2]
- Direction from the fraction of a frame instead of a full sweep

**Multipath Impacted AoA Detection**
- Reflection, scattering and diffraction cause “echoes”
- AoA profile shows reflections
- Strongest AoA peak from unblocked direct path [1]

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**Blind Beam Steering (BBS)**

- **BBS combines interfaces** for mm-Wave and legacy communication
- **Passively listens** to legacy 802.11ac/n transmissions
- Multi-band architecture common to 802.11ad devices for range extension [3]
- **Angle of Arrival detection on 2.4 GHz replaces exhaustive search in the mm-Wave band.**

**Direct Path Detection**

Aggregate AoA Spectra from Multiple Frames under Small Scale Mobility
- Emphasize the static direct path
- Spread fluctuating Reflection Energy
- Noise and multipath spread strongest peak

Angular spread indicates possible range of directions

**Multipath Estimation and Blockage Detection**

Reject BBS estimates with strong multipath severity
- Estimates under strong multipath are unreliable
- Blockage attenuation has lower impact on 2.4 GHz

Multipath and blockage cause high peak to average ratio

**Sector Selection**

Map direction and angular spread to mm-Wave sectors
- Efficient stand alone BRP when multiple sectors selected
- Small sector set → little overhead but chances to miss strongest sector

Scale sector set to meet gain and overhead requirements

**Mobility Management**

Continuous Direction Estimates Identify Sector Misalignment
- Initiate mm-Wave sector readjustment
- Initiate rate adaptation for link degradation without misalignment

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**References**


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**Implementation**

**Evaluation of AoA guided mm Wave steering**
- Accuracy/Reliability
- Overhead reduction

**Setup**
- 2.4 GHz AoA using WARP
- 60 GHz sector sweeps and received power measurement

**Accuracy experiments** in conference room with up to 9m distance and additional blocking experiments

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**Evaluation**

97.8% Accuracy Detecting Strongest mm-Wave Sector
- Corresponds to 4° Beam width
- Needs at least 5 antennas
- Accuracy is location dependent (multipath)

Detecting a BBS Suitable Environment
- 94% accuracy to prevent misdetection
- 95.6% certainty for detection of blocked path

0-13% Overhead Finding Optimal Sectors
- Scale sector set to include optimal sector
- Correlation between beamwidth and antenna order