# Infrastructure-assisted Link Reliability in 60 GHz WLANs

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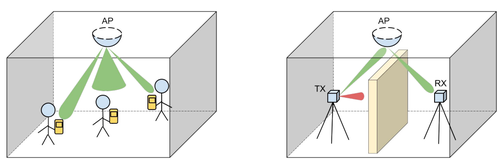
## Problem: Unreliable links in 60 GHz WLANs

- Frequent outages
  - Blockage: obstruction between the communicating endpoints, human body a common type of blockage
  - Mobility: one or both endpoints are mobile, results in beam misalignment
- Proposed solutions
  - Beam switching: switch to an alternate path, exploit reflections
  - Beamwidth adaptation: dilate beamwidth to cover moving endpoints
- Challenges and limitations
  - Beam switching and adaptation have limited effectiveness in point-to-point cases
  - Most obstructions happen in horizontal plane due to human mobility
  - Both approaches are mostly reactive in nature - fix after link is broken, penalties at upper layer

## Approach: Infrastructure-assisted link reliability

- 3D beamforming with ceiling mounted AP
  - AP has better reach/knowledge of device locations
  - Exploit this information for WLAN/P2P link reliability



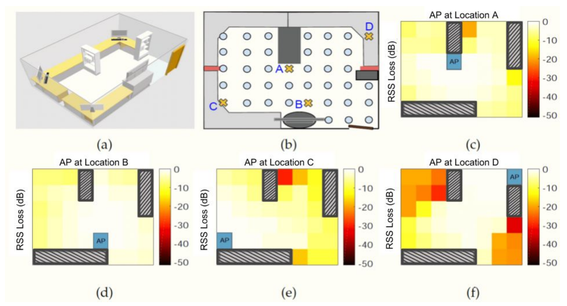

- Light-weight centralized control
  - AP keeps track of device mobility, location
  - Devices use this information for reliable beamforming
- Blockage and device mobility
  - Beam switching and beamwidth dilation can be guided by the AP - reduced overhead on devices
  - Links from AP to devices less likely to be blocked because mobility primarily restricted to the horizontal plane

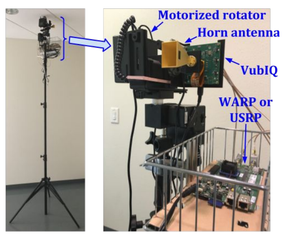
## Link Discovery and Outage Recovery

- Proactive control and management
  - AP uses a probing protocol to receive updated information about device locations, associated beams and mobility
  - 802.11ad compliance - beacon interval and association training
- Faster link discovery
  - Current Sector Level Sweep (SLS) and Beam Refinement induce latencies in orders of seconds - worse in case of mobility
  - With AP-assisted discovery, two endpoints can restrict their search in directions towards each other, directions known through AP
- Outage recovery
  - In case of mobility or blockage related outage, the endpoints can consult the AP to rediscover each other with minimal overhead
  - AP can also conclude that no direct or reflected path can be available between two endpoints
  - AP can act as a relay if P2P is not feasible at desired QoS

## AP Placement and Coverage

- Intelligent placement of AP on the ceiling
  - Maximize beam switching and beamwidth dilation opportunities
  - Increase Line-Of-Sight (LOS) and reflection coverage

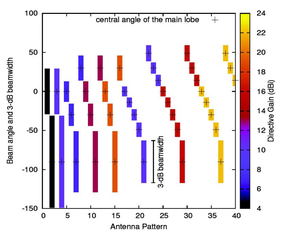


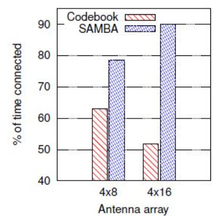



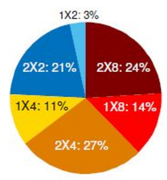

- Channel sparsity and spatial diversity
  - Find fewer available paths that are spatially diverse and robust to blockage

## Antenna Configuration and Codebook Design

- Multi-level codebook design
  - Antenna subset selection - selectively switch ON and OFF antenna elements - generate wider beams in same directions
  - Objective: diverse set of beamwidths in many different directions
  - AP can use multi-level codebook to adaptively change beamwidths when client is mobile



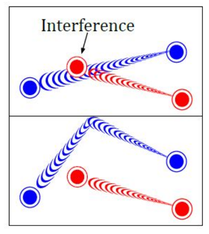




- Beamwidth adaptation
  - Increase beamwidth if client is mobile, decrease otherwise for better SNR and data rate
  - Multi-level codebook can be used by the AP for 2D sectored or 3D beamforming
  - Adopted in recent schemes MOCA (MobiHoc ‘16), SAMBA (MASS ‘15)

## Interference Mitigation and Scheduling

- Infrastructure assisted approach
  - AP can learn about the interference between links
  - Use the interference information for path diversification




- Interference-aware path diversification
  - AP manages the directions of paths taken by links
  - Centrally schedules links on paths that don’t interference - can be combined with beamwidth adaptation as reflected paths known to change their interference footprint
- WLAN, P2P and relay
  - 802.11ad employs hybrid MAC - time-divided and contention based
  - AP can use the dedicated service periods for relaying data if a direct P2P link cannot be established
  - Channel allocation: use non-interfering channels for links where interference-based conflicts cannot be avoided
  - Joint path, beamwidth and channel scheduling