Blockage-aware Deployment of 60 GHz Millimeter-wave WLANs

Zhicheng Yang[†], Parth H Pathak[‡], Jianli Pan[§], Mo Sha[*], Huanle Zhang[†], and Prasant Mohapatra[†]

[†]Dept. of Computer Science, University of California, Davis
[‡]Dept. of Computer Science, George Mason University
[§]Dept. of Maths and Computer Science, University of Missouri, St. Louis
[*]Dept. of Computer Science, SUNY Binghamton

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Introduction

60 GHz millimeter-wave networks have emerged as a potential candidate for designing the next generation of multi-gigabit WLANs. Since the 60 GHz links suffer from frequent outages due to blockages caused by human mobility, deploying 60 GHz WLANs that can provide robust coverage in presence of blockages is a challenging problem [1].

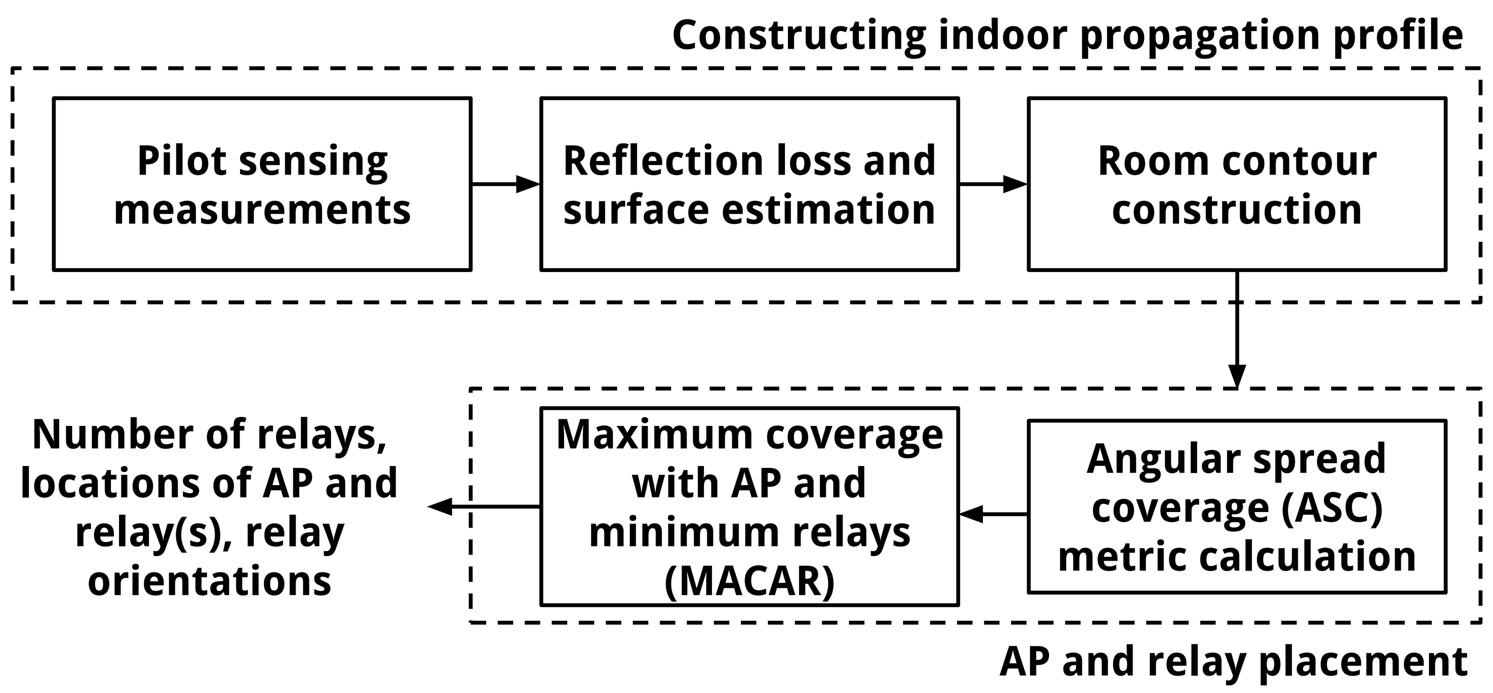

Figure 1:System overview

Sensing indoor reflection profile

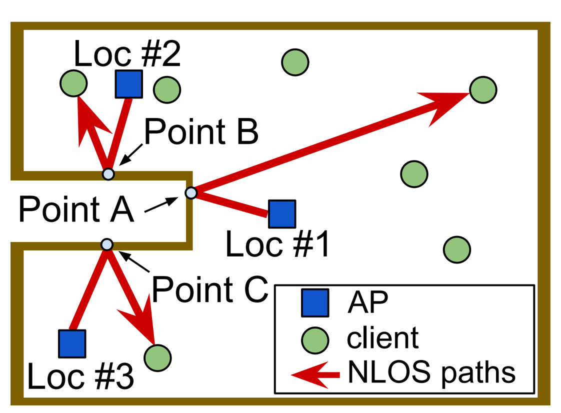

Figure 2:Profiling a concave layout using multiple AP-client location pairs

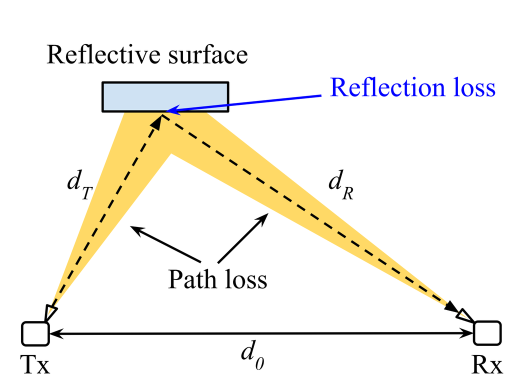

Figure 3:Profiling four reflection points using a pair of AP-client

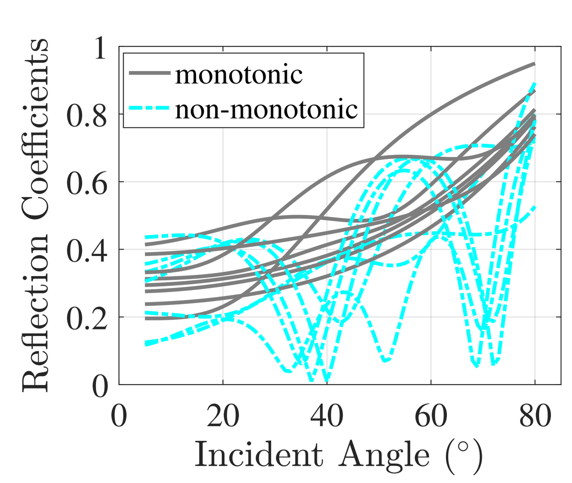

Figure 4:Reflection coefficients of various indoor materials (one line represents one material)

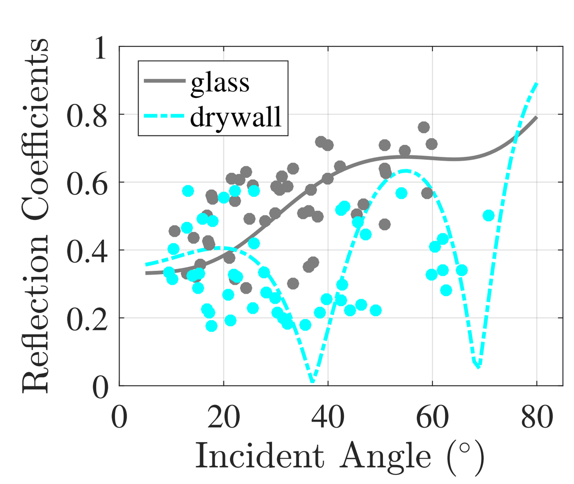

Figure 5:Using k-means clustering to categorize the reflection points in strong or moderate reflectors

We propose to use a small set of **pilot measurements** to sense and construct the indoor layout which includes the relative positions of blocking and reflective objects. Instead of identifying the exact material of the objects, we rely on classifying them into either moderate or strong reflectors based on the measurements. The error in room contour construction compared to the ground truth room layout is captured through Hu Moment Invariants (HMI) [2].

Coverage metric for spatial diversity

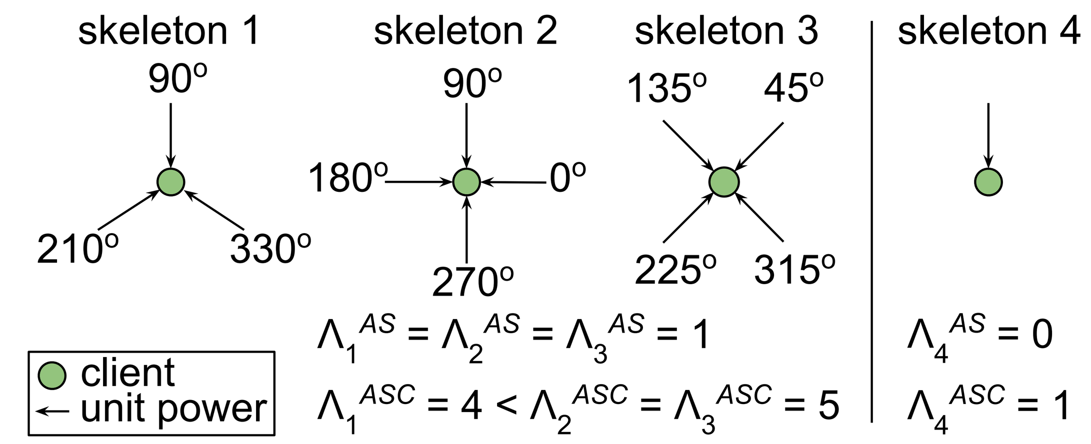

Figure 6:Angular spread (AS) [3] vs. Angular spread coverage (ASC)

We define a new coverage metric **ASC (Angular Spread Coverage)** based on the multi-path angular spread property of a millimeter-wave channel. For a given deployment of AP, ASC can quantify (1) the number of major paths available at a client location, (2) the spatial diversity of these paths and (3) the received power of the paths. Using the ASC metric, different AP deployments can be compared before choosing a suitable one.

Complexity of 60 GHz AP/relay placement

The use of relays complicates the deployment where the AP and relay placement should be jointly studied. Hence, we study the **MACAR (MAximum Coverage using Single AP And Minimum Relays)** problem which provides a joint solution for AP and relay placement in 60 GHz WLANs. We prove that the MACAR problem is **NP-hard** and provide a greedy strategy for the AP/relay placement. The strategy aims at maximizing the summation of the ASC metric for all client locations using one AP and the minimum number of relays.

Evaluations

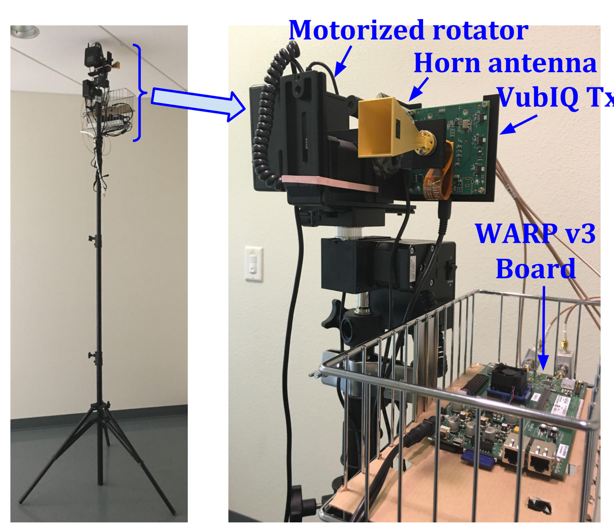

Figure 7:60 GHz transmitter setup to imitate a ceiling mounted AP

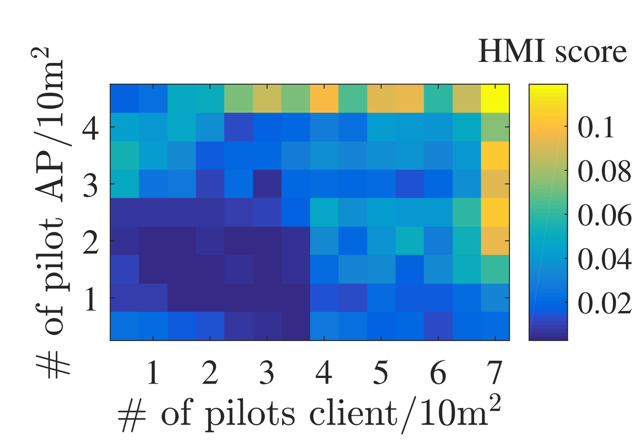

Figure 8:HMI score with different pilot AP and client densities

Average 1 AP and 1 client per $10m^2$ of indoor space is sufficient for the pilot measurements and accurate reconstruction of room profile.

References

[1] Zhicheng Yang, Parth H Pathak, Jianli Pan, Mo Sha, and Prasant Mohapatra. Sense and deploy: Blockage-aware deployment of reliable 60 ghz mmwave wlans. In *2018 IEEE 15th International Conference on Mobile Ad Hoc and Sensor Systems (MASS)*, pages 397–405. IEEE, 2018.

[2] Ming-Kuei Hu. Visual pattern recognition by moment invariants. *IRE transactions on information theory*, 8(2):179–187, 1962.

[3] Greg Durgin and TS Rappaport. Basic relationship between multipath angular spread and narrowband fading in wireless channels. *Electronics Letters*, 34(25):2431–2432, 1998.

Evaluations (cont.)

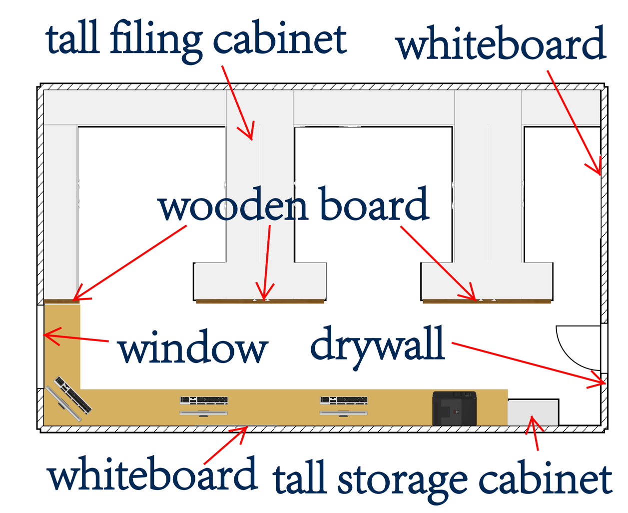

Figure 9:Layout of an office room (10.3m × 6.2m)

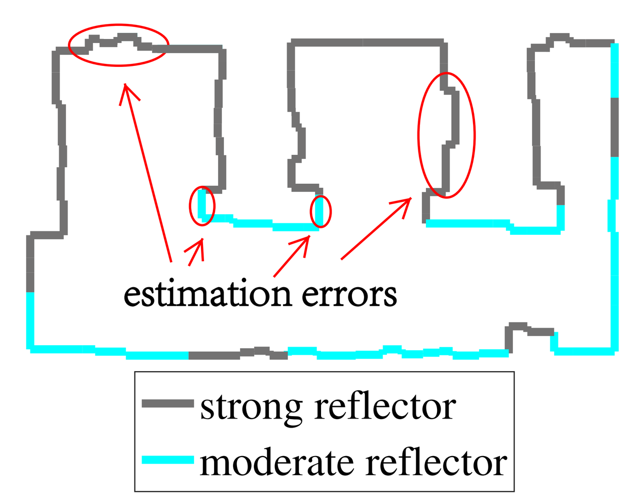

Figure 10:Constructed contour of the office room

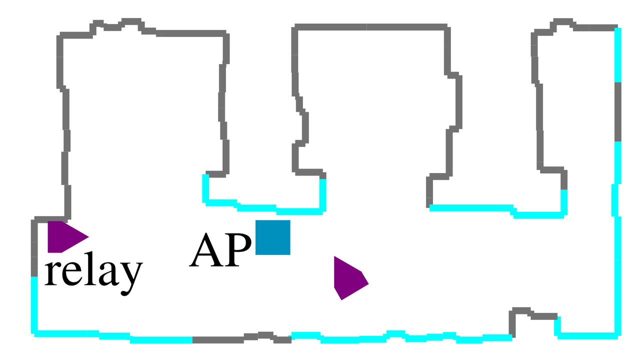

Figure 11:AP and relay placement under BC

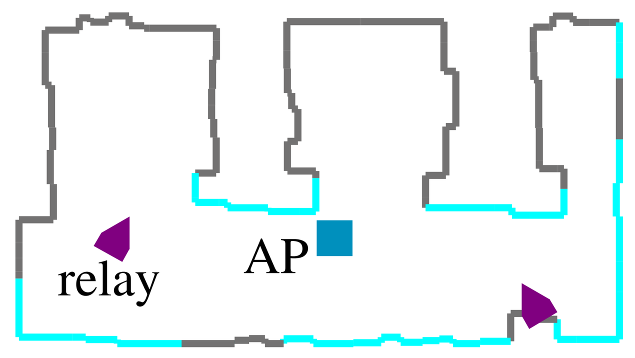

Figure 12:AP and relay placement under ASC

Traditionally, a coverage metric refers to a binary value representing whether a client location is covered by the AP or not. We refer to this metric as "Binary Coverage" (BC). Two relays are used on an average. MACAR can cover 88% of all possible client locations with at least two spatially diverse paths.

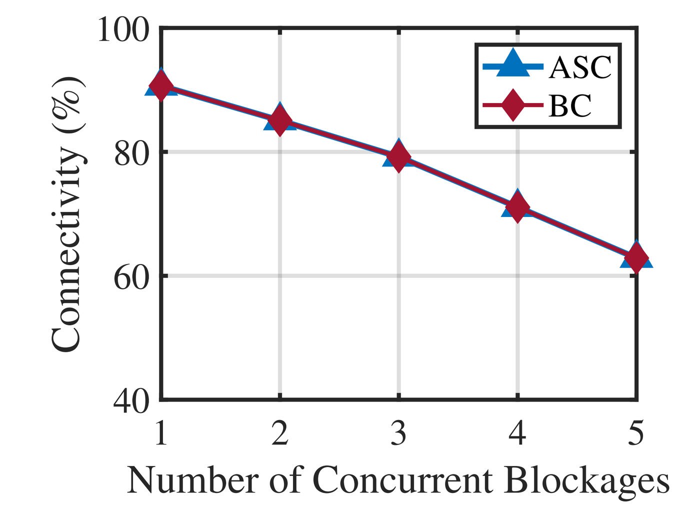

Figure 13:Conference room

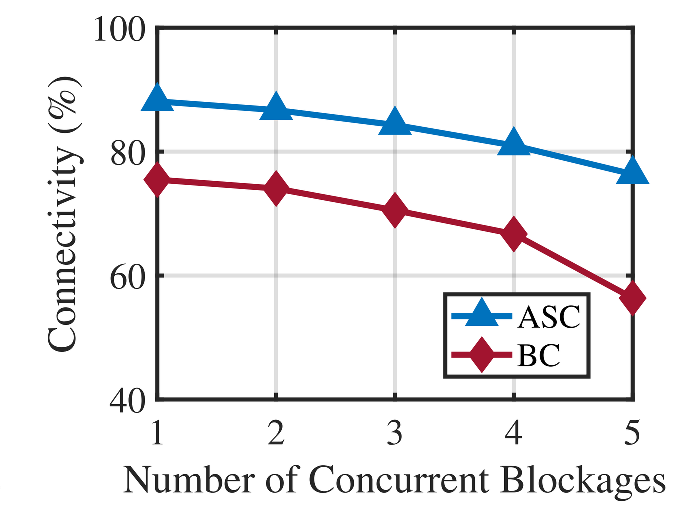

Figure 14:Office room

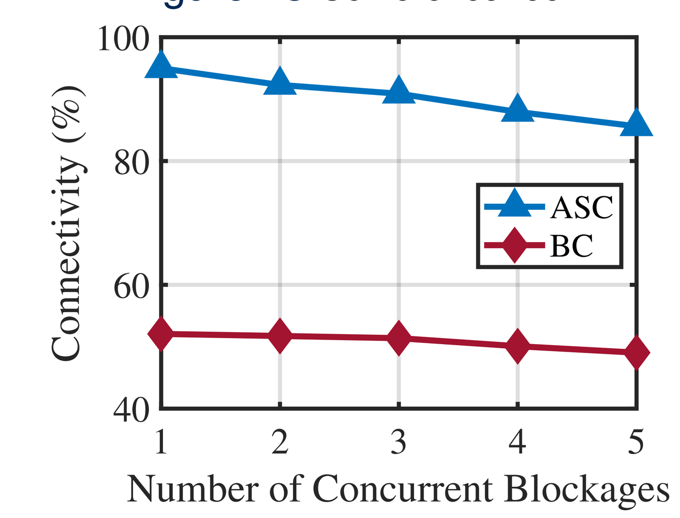

Figure 15:Lab room

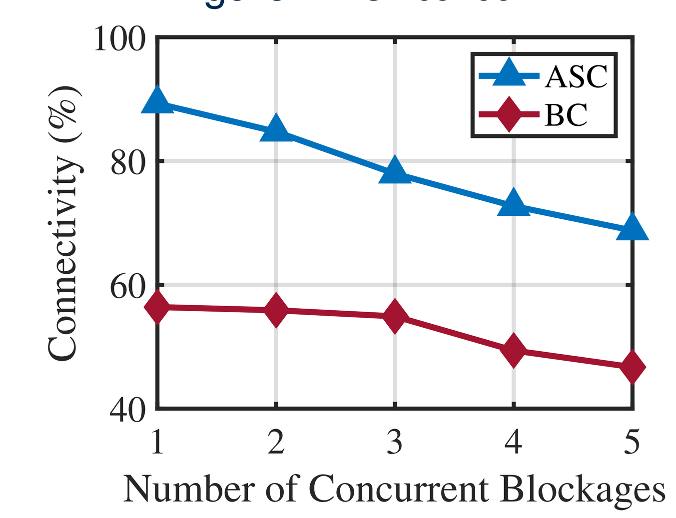

Figure 16:Home master bedroom

We find that MACAR deployment can guarantee average connectivity of 91.7%, 83.9%, and 74.1% of clients in the presence of 1, 3 and 5 concurrent (human) blockages, respectively. Compared to a deployment that is agnostic of spatial diversity (captured through the ASC metric), MACAR deployment results in on an average 25%, 21.6% and 22.6% more connected clients for 1, 3 and 5 concurrent human blockages, respectively.