Fast Localization of Multiple Users in Mm-Wave Cells

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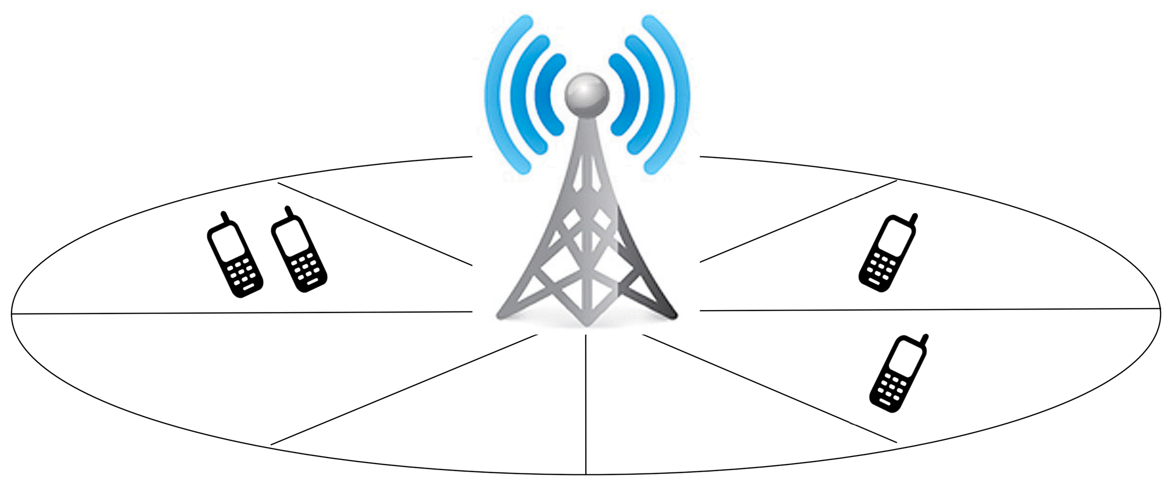
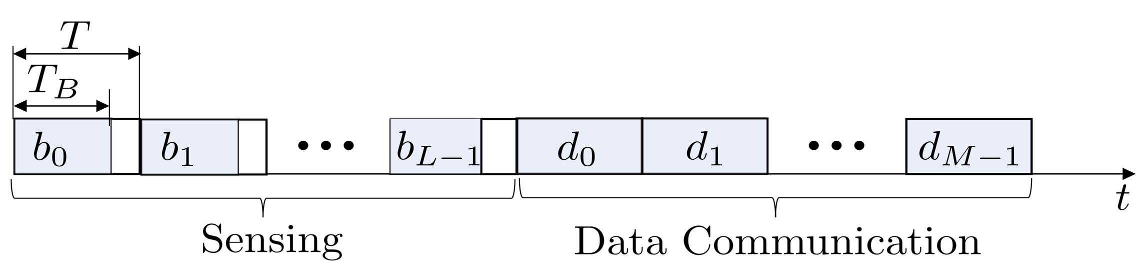
A Mm-Wave Cell



Each communication session consists of a fixed no. of epochs, and is devided into two phases:

- Sensing (via beam alignment)
- Data Communication



Goal

Design an optimal sensing strategy that minimizes the duration of sensing phase so as to:

- Maximize the communication throughput
- Minimize the amount of energy consumed for sensing

Approaches

- Sensing each user separetely: Poor performance
- Sensing all users simultaneously: Optimal performance
- ID-based: Susceptible to interference
- ID-oblivious: Insensitive to interference

A Related Problem

- A collection N of n coins, each coin $i \in N$ of an unknown weight $w_i \in \{0, 1, \ldots, k\}$
- The total weight of N, i.e., $w(N)$, is k

Problem: Find the weight of all coins in N by weighing subsets of N in a spring scale with minimum average no. of weighings over all configurations.

Special Cases: { Quantitative Group Testing / Integral Compressed Sensing

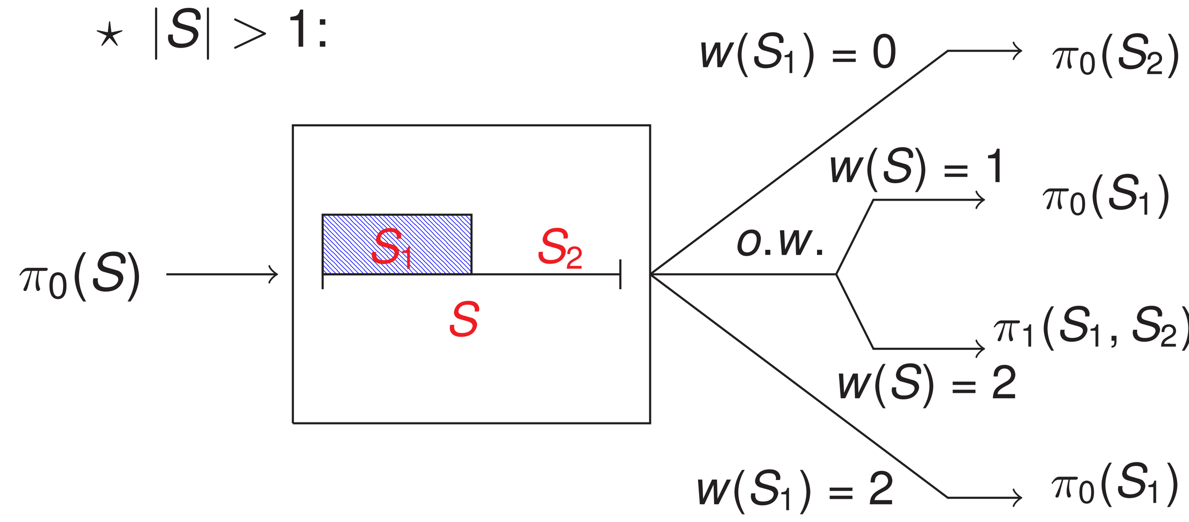
Proposed Strategy for $k = 2$

- Initialize the weight of all coins ($\hat{w}_i = 0,\ i \in N$)
- Update $\{\hat{w}_i\}$ recursively according to the procedures π_0, π_1, and π_2
- Terminate once $\sum_{i\in N} \hat{w}_i = 2$, and return $\{\hat{w}_i\}$

Procedure π_0: (Input: A set S and its weight $w(S)$)

⋆ $S = \{i\}$: procedure $\pi_0(S)$ updates $\hat{w}_i$ by $w(S)$

⋆ $|S| > 1$:

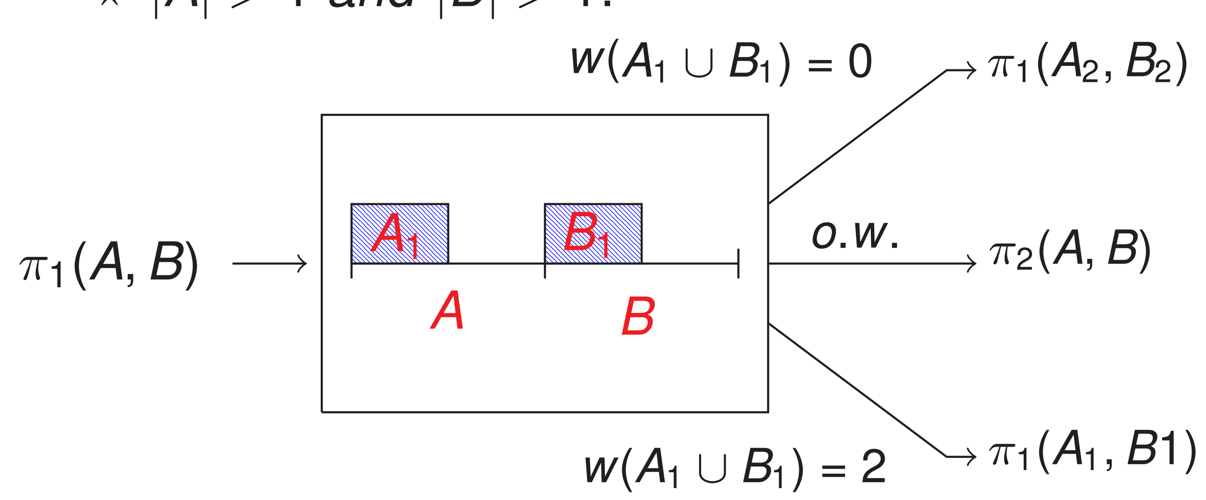


Procedure π_1: (Input: Two disjoint sets A and B such that $w(A) = w(B) = 1$)

⋆ $A = \{i\}$, $B = \{j\}$: procedure $\pi_1(A, B)$ updates $\hat{w}_i$ and $\hat{w}_j$ by 1.

⋆ $|A| = 1$, $|B| > 1$, or $|A| > 1$, $|B| = 1$, procedure $\pi_1(A, B)$ continues with $\pi_0(A)$ and $\pi_0(B)$.

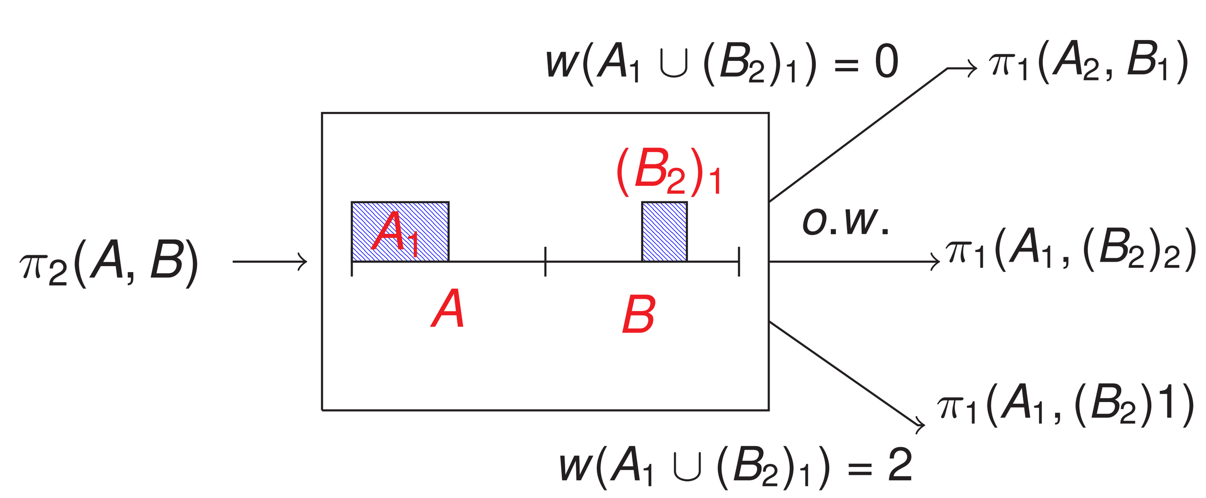
⋆ $|A| > 1$ *and* $|B| > 1$:



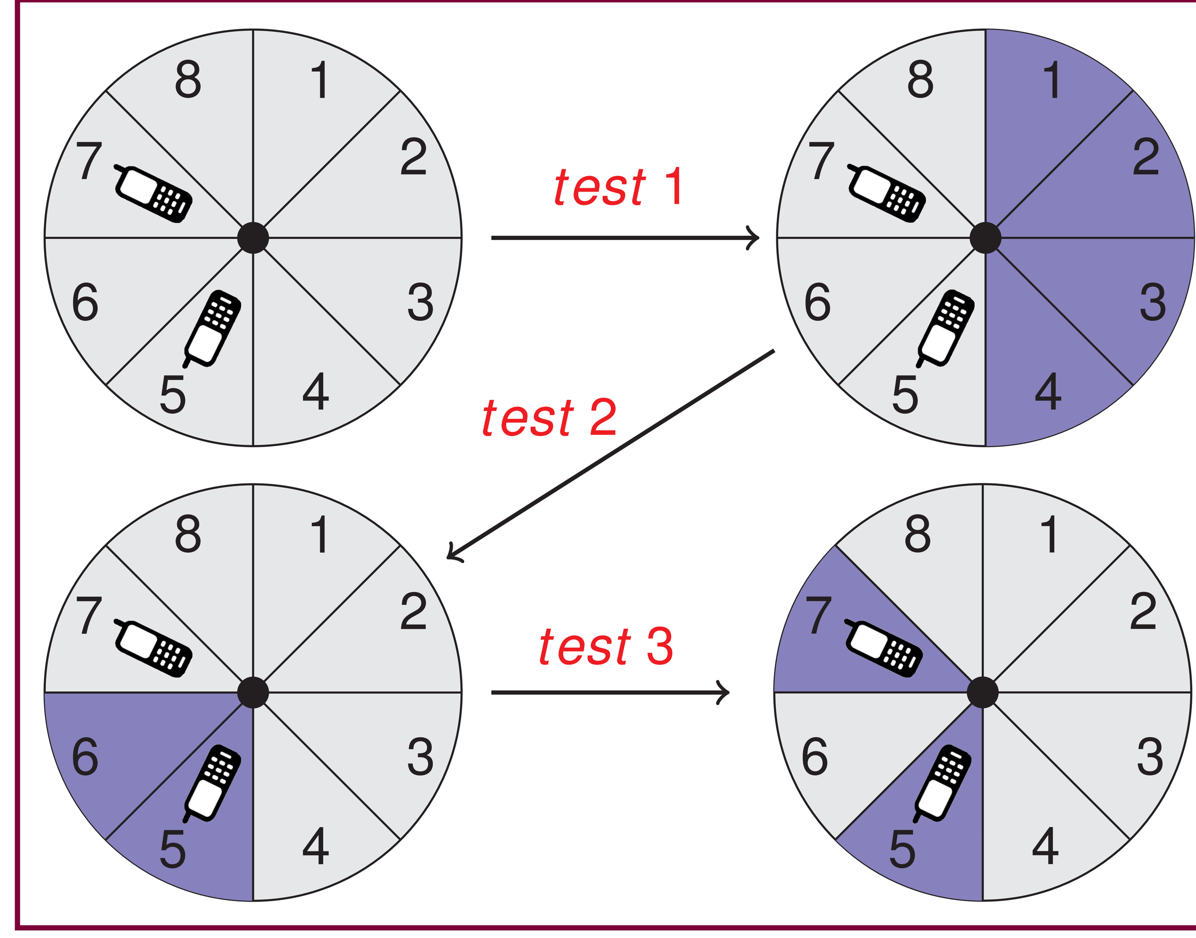
Procedure π_2: (Input: Two disjoint sets A and B such that $w(A) = w(B) = 1$ and $w(A_1 \cup B_1) = 1$)

⋆ $A = \{i_1, i_2\}$, $B = \{j_1, j_2\}$: procedure $\pi_2(A, B)$ weighs $A_1 = \{i_1\}$, and updates $\hat{w}_{i_1}$ and $\hat{w}_{j_2}$ (or $\hat{w}_{i_2}$ and $\hat{w}_{j_1}$) by $w(A_1)$ (or $1 - w(A_1)$).

⋆ $\max(|A|, |B|) > 2$ *and* $|A| \leq |B|$:



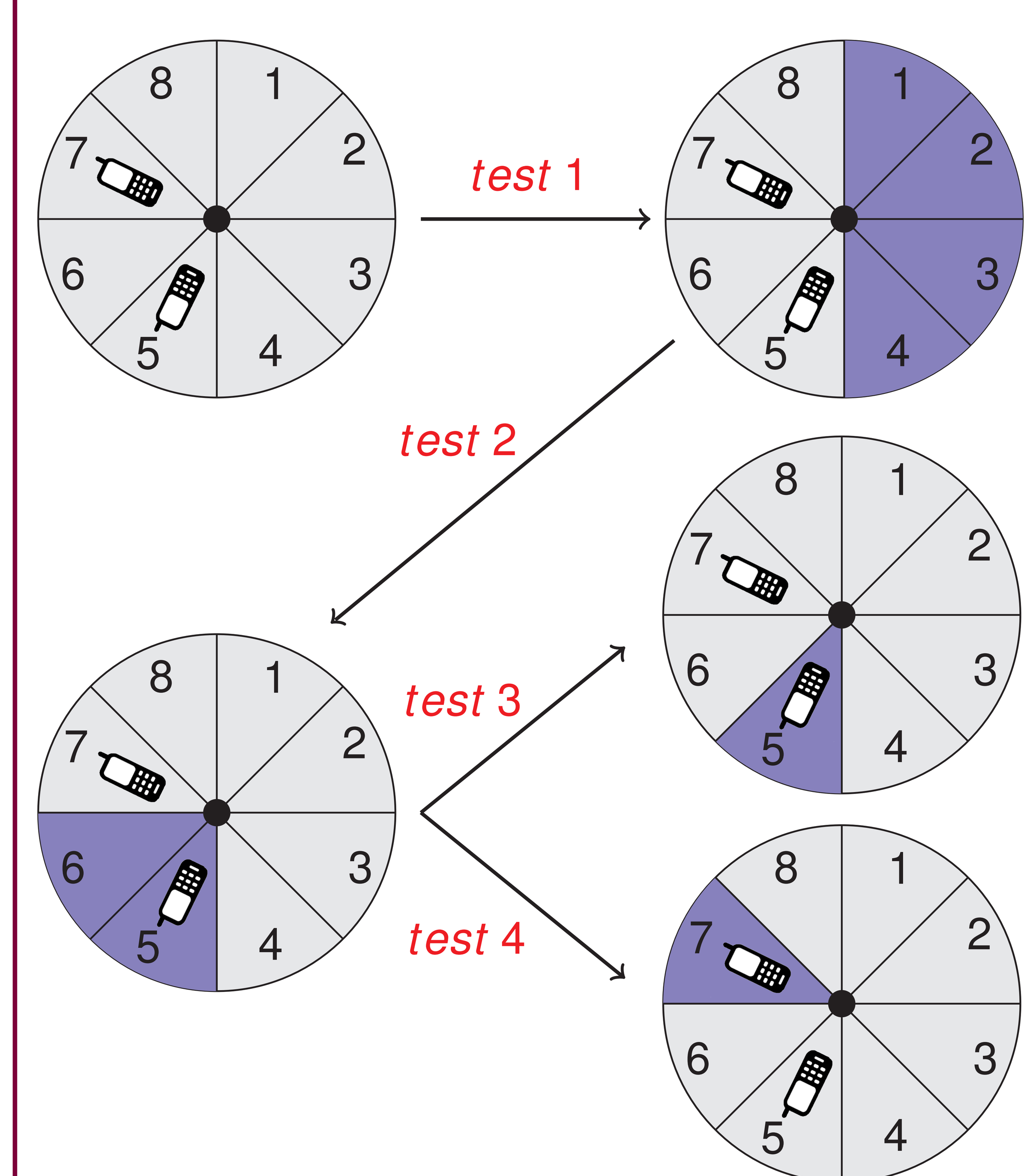
Example (Proposed Strategy)



An Optimal Nested Strategy

- In a nested strategy, after weighing a subset S of coins, if the weight of some coin(s) in S remains undetermined, the next weighing must be performed on a proper subset of S
- Nested strategies are being used in most of today's applications, due to their simplicity and efficiency

Example (Optimal Nested Strategy)

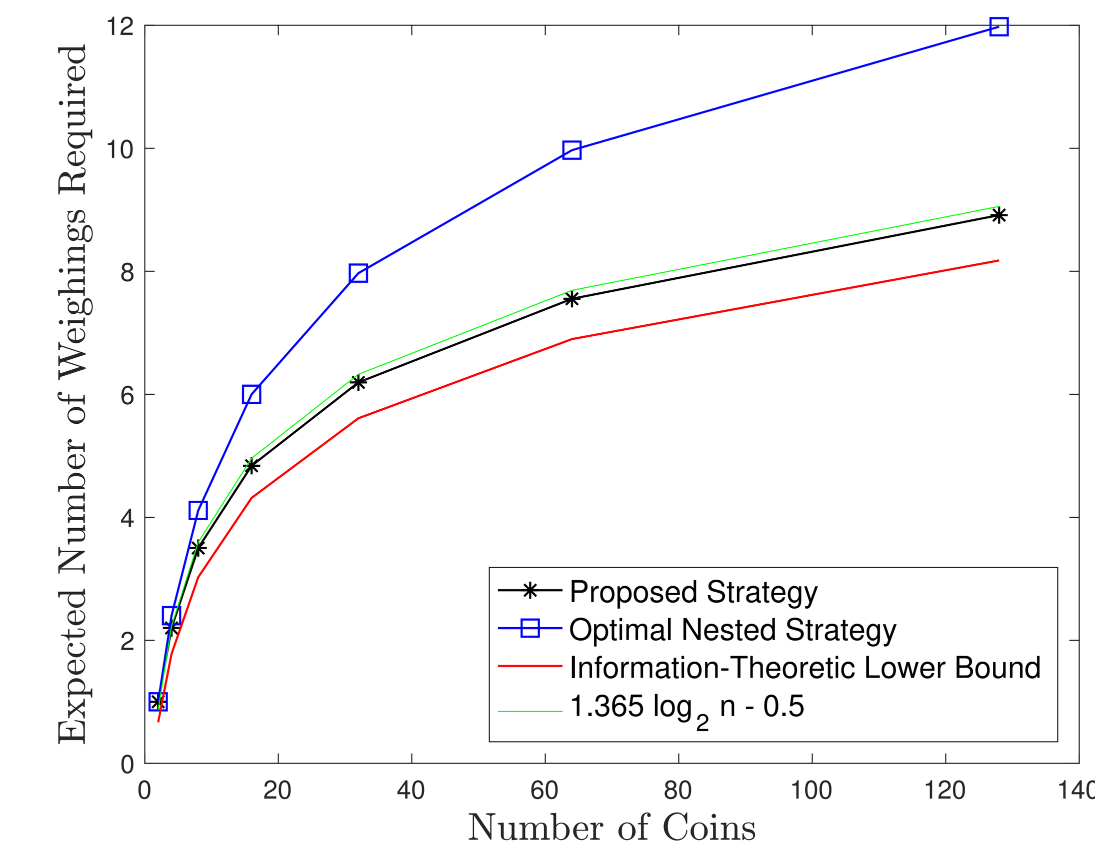


Information-Theoretic Lower Bound

The average no. of weighings (over all configurations) required by any strategy is lower bounded by

$$\frac{2}{n+1}\log_2 n + \frac{n-1}{n+1}\log_3 \binom{n}{2}$$

Results



- The proposed strategy, when compared to the optimal nested strategy, requires 31.75% less no. of weighings on average.
- The proposed strategy, when compared to the lower bound, requires at most 8.16% extra no. of weighings on average.

Future Work

- Extension of the proposed strategy to the cases with arbitrary number of users
- New strategies for the scenarios in which the number/geometry of the beams that can be activated simultaneously is constrained

References

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[2] H. Muddassar and N. Michelusi, "Throughput Optimal Beam Alignment in Millimeter Wave Networks," *Information Theory and Applications Workshop 2017.*

[3] C. Wang, Q. Zhao, C.N Chuah "Optimal Nested Test Plan for Combinatorial Quantitative Group Testing," *IEEE Transactions on Signal Processing*, 2017.

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