Exact and Fuzzy Sensor-Task Assignment

H. Rowaihy, M. Johnson, D. Pizzocaro, A. Bar-Noy, L. Kaplan, A. Preece and T. La Porta

ABSTRACT Sensor networks introduce new resource allocation problems in which sensors need to be assigned to the tasks they best help. A task requires one or more sensors, possibly of different types. In addition, there may be more than a single combination of sensor types that will satisfy a task. We refer to a combination of sensors as a *sensor bundle*. Likewise, the number of sensors required to satisfy a task may vary depending on their deployment. Given this multiplicity of task types and needs, our goal is to assign specific sensors to the tasks in order to maximize the utility of the sensor network. In this work, we focus on two particular applications: event detection and target localization. We develop distributed algorithms to assign sensing resources of different types to multiple simultaneous tasks that have different information needs. We show that our schemes perform well using both *exact* location information or *fuzzy* location information, which may be desirable to *save on computational overhead* and/or for *privacy reasons*.

Contributions

1. We provide a formal definition of the abstract problem of assigning bundles of sensor instances to tasks, as well as specific problem definitions for event detection and localization tasks. We show that both of these problems are NP-hard.
2. We propose two distributed algorithms, for the event detection task, and for the localization task when exact sensor locations are disclosed. Through simulation we show that they achieve close to optimal performance.
3. We extend the schemes to cases in which only fuzzy locations of sensors are used. This entails defining the notion of fuzzy location with respect to detection and localization. We show through simulation that, as the granularity of fuzzy location is refined, performance improves to a point after which the gain is insignificant.

Event Detection

Goal: assign *N* sensors that combined can detect an event with the highest probability taking into account overall network utility.

- Each sensor has a detection probability (e_{ij}) based on its type and distance from the event. We need to maximize the cumulative detection probability of all tasks:

$$\sum_j p_j \left(1 - \prod_{S_i \to T_j} (1 - e_{ij})\right)$$

Algorithm Run in rounds to allow sensors to be assigned to their best match. When a task arrives to the network, the task leader announces the presence of the task and its profit to nearby sensors. All tasks that compete for the same sensing resources participate in the process.

```
initialize each task cumulative detection probability u_j ← 0
initialize number of assigned sensors to T_j, n_j ← 0
Protocol for Task Leader (T_j):
  announce presence of T_j to each neighboring sensor S_i
  for round = 0 to R do
    if n_j ≤ N then
      among responding sensors G, choose i ← arg max_i {e_ij : S_i ∈ G}
      update u_j ← u_j + e_ij
      send accept messages and announce new u_j
    else done
Protocol for Sensor (S_i):
  wait for task requests
  among requesting tasks Q, choose j ← arg max_j {e_ij p_j : T_j ∈ Q}
  send offer to T_j including exact location
  if accepted then
    S_i is assigned to T_j
    done
  else
    listen to current u_j values for requesting tasks
    update detection probability based on new u_j's
    e_ij ← 1 − (1 − u_j)(1 − e_ij) − u_j
  repeat
```

Target Localization

Goal: assign *two* sensors that combined can localize a target with the lowest uncertainty taking into account overall network utility.

- The uncertainty (*U*) of two sensors *i and j* to a task is a function of their distances and separating angle:

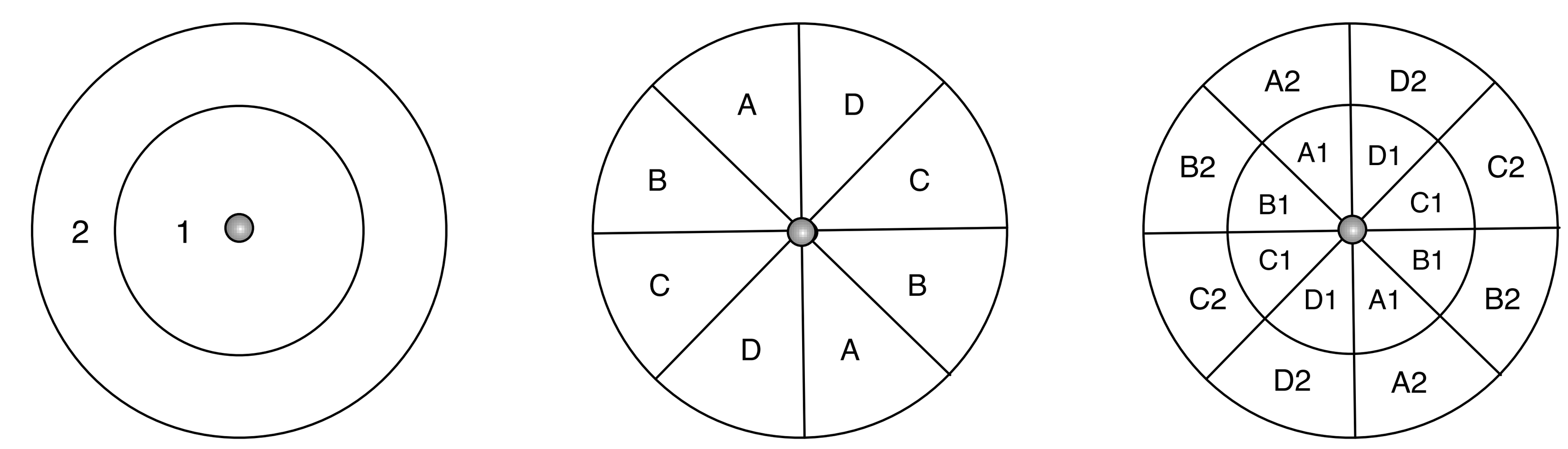
$$U = \sigma \frac{\sqrt{d_1^2 + d_2^2}}{|\sin(\theta_1 - \theta_2)|}$$

Algorithm Leader announces the arrival of a task. Then, all nearby nodes (within the sensing range) reply with their location. Leader evaluates the uncertainty of all pairs and selects the best one.

Fuzzy Location

Fuzzy location clusters nearby nodes into classes based on their locations which leads to two benefits:

1. *Lower computational cost:* it requires consideration of fewer assignment choices.
2. *Privacy:* sensors do not disclosed their exact location.



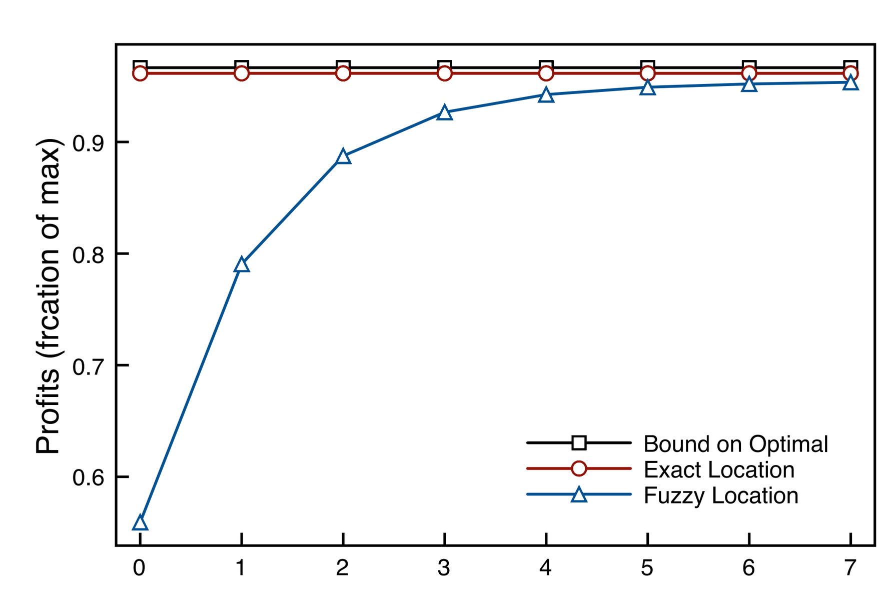
Fuzzy Distance | Fuzzy Angle | Fuzzy Distance and Angle

Event Detection (Fuzzy Distance): The detection probability depends on distance. So, fuzzy location is determined based on different distance granularities. Divide the circle (with radius equal to sensing range) surrounding a mission to *rings* of equal sizes. Sensors in the same ring are equivalent. Sensors report back to leader their *ring* instead of exact location. Leader chooses the sensors that are within closest rings.

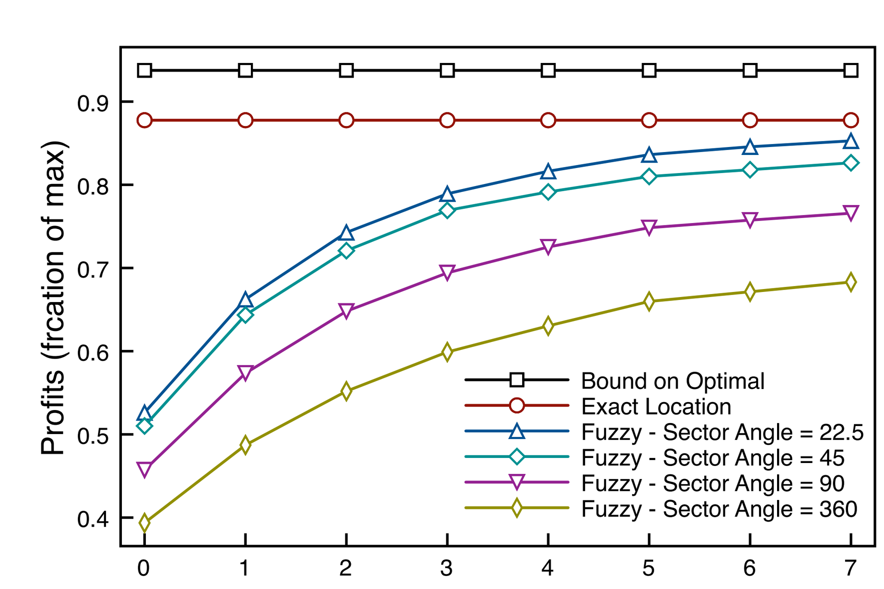
Target Localization (Fuzzy Angle): The localization quality depends not only on distance but also on the angle. So, fuzzy location is determined based on distance and a *fuzzy angle* which divides the circle into *sectors* based on an angle granularity (AG). Sensors in the same sector are equivalent. Sensors report back to leader their *sector* instead of exact location. Leader chooses the best pair based on the lowest uncertainty.

Simulation Results

- Trade-off between solution quality and efficiency/privacy

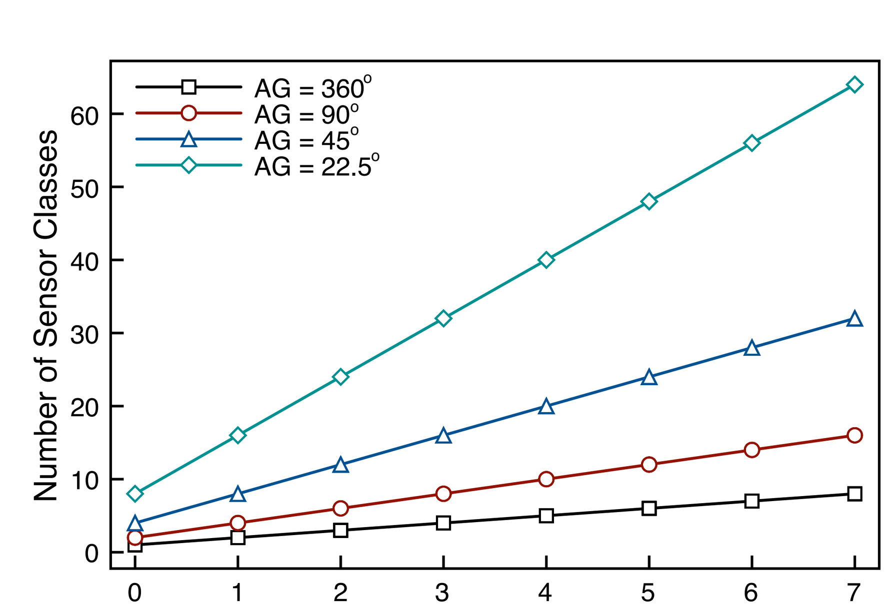


Event Detection

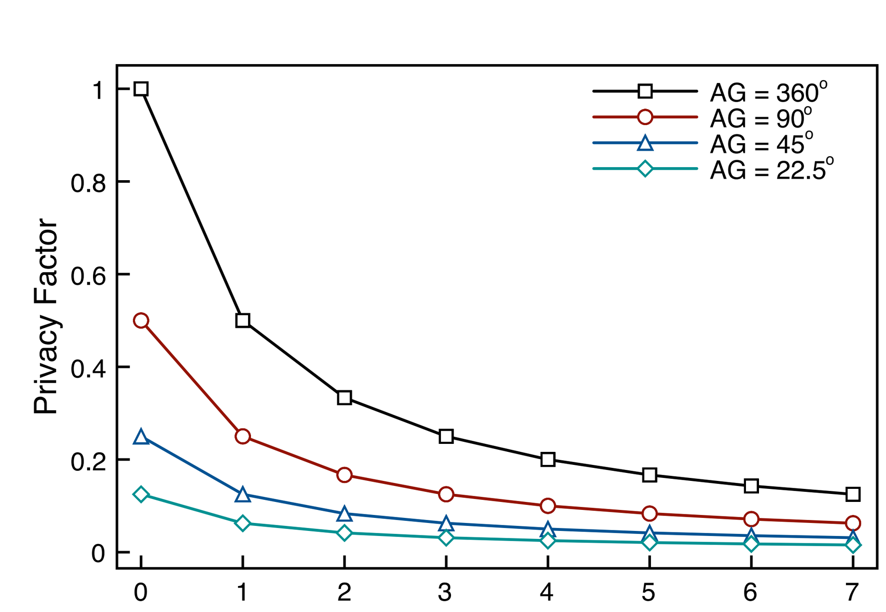


Target Localization

- Finer granularity leads to better solution **BUT** more sensors to consider (higher computational cost) and less privacy.



Computational Overhead



Privacy

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