# Minimizing the Uncertainty of Zone Localization

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## I. Problem Definition

Consider a spatial domain subdivided into rooms (or cells or zones). In Many scenarios require determining in which rooms people are located, while the exact location is not necessary.

A common technology used in such problems is the WiFi wireless networking. Individuals who carry mobile devices with wireless network adapters can communicate with WiFi access points, which can use the signal strengths to estimate the distance from the users. The access points can also identify the individuals by their ID. Unfortunately, the strength of the signals is noisy. We model the noise as a simple fraction of the strength. Therefore, if the strength is $s$, indicating that the user is estimated at a distance of $d$ meters, we assume that the real distance ranges between $(1-\alpha)d$ to $(1+\alpha)d$. This defines a ring of the possible locations with the corresponding radii.

Let $x$ be a mobile user, $s$ be the location of a WiFi access point, and $\alpha$ be the noise parameter. Let $R(s, x, \alpha)$ be the ring of $x$ with respect to $s$. If $R(s, x, \alpha) \in C$ for some room $C$, we say that $x$ is guaranteed to be in room $C$. When $R(s, x, \alpha)$ intersects more than one room, it induces uncertainty regarding the room that $x$ is in with respect to $s$. Note that this scheme divides the spatial domain into two areas with respect to a specific access point: one area contains the locations where we are certain in which room a user is— that it where the corresponding ring lies inside one room. The second area is the complement of the first, namely, the areas where the corresponding rings intersect more than one room, thus the localization is uncertain.

When more than one access points are used, we deal with two models. In the first, which we term *the independent model*, we consider the information from each access point independently as described above. Thus, to determine where an individual is, we examine the induced rings of all access points to find at least one ring which lies inside one room. In this model, once the access points are fixed, and assuming that they are identical, we can split the spatial domain into two regions. The first, denoted as the *certainty* region, contains all the points for which there is at least one access point that contains the corresponding ring completely. The second region, denoted as the *uncertainty* region is the complement of the first. Note that if we are allowed to determine the location of the access points, we can define the following optimization problem: given a spatial domain $S$ divided into rooms, a noise parameter $\alpha$ and $k$, place $k$ access points inside $S$ to maximize the area of the certainty region (or minimize the area of the uncertainty region).

In the second model, which we term *the cooperative model*, we use triangulation to decrease the uncertainty area. The idea is to combine the information of the different access points. As each reports a ring where a mobile user can be, the intersection of all rings substantially shrinks the possible locations. Using the same definitions we used with the first model, we get that the uncertainty region in the second model is usually (possibly much) smaller than the region obtained with the first model. The definition of the problem follows accordingly.

## II. Simple Examples

In very basic settings, the domain consists of one square room and the area outside the room, which is the complement of the room with respect to the domain. Our goal is to determine whether the mobile user is inside the room or not. Figures 1 (a) and (b) show the result of placing access points in the middle and in the corner of the room, respectively[1]. Consider Figure 1 (a). We drew two orange rings. Consider the inner one that lies inside the square (denote it by $r_1$). Since $r_1$ touches the boundary of the room, it is the biggest one that guarantees a positive answer. Clearly, any smaller ring also provides certain answers. The vicinity of the points whose ring is $r_1$ is the blue circle inside the inner ring (denote it by $c_1$). It follows that any point on or inside $c_1$ has a certain positive answer. Next consider the outer ring ($r_2$). For similar reasons, any point outside the blue circle inside $r_2$ has a certain negative answer. Thus, the uncertainty region is the ring defined by the two blue circles. We use the same construction in Figure 1 (b) where the uncertainty region is again the ring defined by the two blue circles. It is evident that the situation is better in Figure 1 (a): the uncertainty region is not only much smaller, but it is located in places where one has interest in querying the location of the mobile users (in very far places, such a query might be irrelevant and filtered by other means).

Figures 1(c) and (d) still represent a square room, but instead of one access point, we place two (note that we represent the same room in both subfigures–Figure 1 (d)) is a zoom-out view of the room). We arbitrarily place the access points in the same locations in both figures, but use different models in each. Figure 1 (c) shows the result using the cooperative model: for a specific reading of both access points, we draw the corresponding rings and fill the intersection areas of the rings, which represent the possible locations for the individual. Thus, in this specific example, we are guaranteed that the individual is inside the room. It is also easy to see that the uncertainty

[1]Figures 1 (b) and (d) do not show some of the rings completely as we want to focus on the room neighborhood.

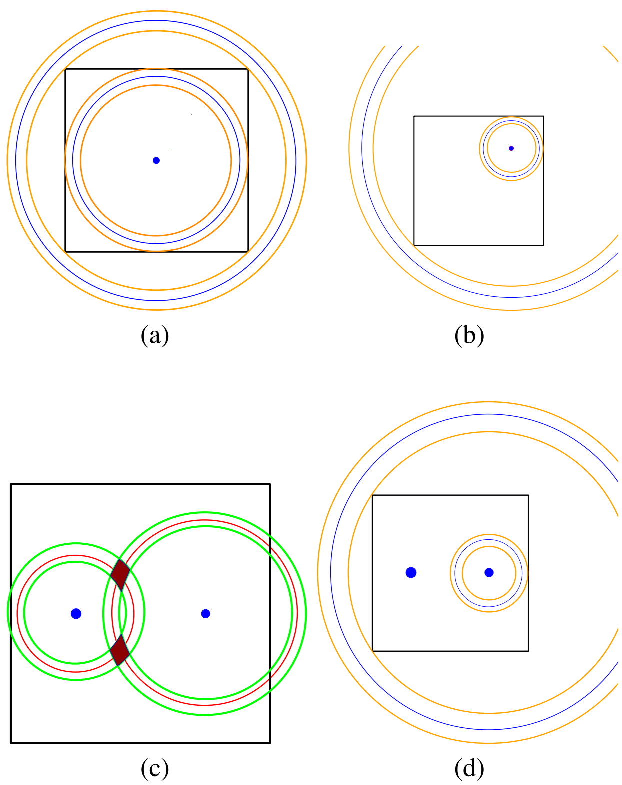


Fig. 1. Simple examples of access points placement

regions will lie near the boundary of the room, and that using two access points greatly decreases the uncertainty regions. In Figure 1(d), which represents the independent model, we drew the rings and the uncertainty region for one of the access points. The rings for the other one are symmetric. The intersection of the uncertainty regions of both access points (each is a ring) is the uncertainty region for both independent access points. It is evident that it is much bigger than the uncertainty region in Figure 1 (c). It is not surprising that the vicinity of the boundary is always categorized as uncertain.

## III. Directions for Further Work

The following is a list of possible directions.

- Is the problem in NP?
- Is the problem hard?
- How does the uncertainty region look in the cooperative model?
- It is natural to prefer placing access points in the vicinity of boundary edges. Can a greedy heuristic give good results?