Determining the robustness of sensor barriers

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Abstract

Various notions of coverage provided by wireless sensor networks have attracted considerable attention over the past few years. In general, coverage can be expressed geometrically, by relating the positions, and associated coverage regions, of individual sensors to some underlying surveillance domain. The most natural notion is *area coverage*, where the goal is to achieve coverage for *all points* in the surveillance domain by a static arrangement of sensors. A less demanding alternative is *barrier coverage*, where the goal is to ensure merely the absence of undetectable transitions between critical subsets of the surveillance domain (for example, between unsecured entry and exit points).

An arbitrary arrangement $\mathcal{A}$ of sensors is said to form a *barrier* between regions S and T if every path joining a point in S to a point in T must intersect the coverage region associated with at least one sensor in $\mathcal{A}$. Determining if an arrangement of unit disks in the plane (or unit spheres in 3-space) forms a barrier is straightforward; determining the robustness (or redundancy) of such a sensor barrier, however, is considerably more challenging.

Two different notions of width/impermeability have been studied to model the robustness of a sensor barrier. The first, the *thickness* of the barrier, counts the minimum number of sensor region intersections, over all paths from S to T. The second, what is referred to as the *resilience* of the barrier, counts the minimum number of sensors whose removal permits a path from S to T with no sensor region intersections. Of course, a configuration of sensors with resilience k (sometimes referred to as a k-barrier for S and T) has thickness at least k.

Barrier thickness can be computed efficiently, for both unit disks in the plane and unit spheres in 3-space, by finding shortest S,T-paths in the geometric dual of the associated arrangements. For unit disk sensors, we show that any (Euclidean) shortest S,T-path, in the primal arrangement, that avoids a fixed subset of sensors in $\mathcal{A}$, intersects an arbitrary sensor at most three times. It follows that the resilience of $\mathcal{A}$ (with respect to S and T) is at least one-third the thickness of $\mathcal{A}$ (with respect to S and T). (Furthermore, if points in S and T are moderately separated–relative to the radius of individual sensors–then every shortest path intersects any one sensor at most twice, and hence the resilience of $\mathcal{A}$ is at least one-half the thickness of $\mathcal{A}$.) No such relationship holds for unit sphere sensors: the ratio of resilience to thickness can be arbitrarily small.

For unit disk sensors, the 3- (or 2-) approximations of barrier resilience provided by reduction to barrier thickness can be tightened by more careful consideration of the topological properties of simple paths that make double visits to a collection of disks. In particular, we can guarantee a 1.666-approximation when S and T are moderately separated. Determining the complexity of exact, or even improved approximations of, barrier resilience remains open. For unit sphere sensors, determining barrier resilience is APX-hard.

This talk surveys some of these results, emphasizing the ideas (algorithmic, geometric, combinatorial and topological) and their interplay, as well as related open questions. This is based in joint work with Sergey Bereg and Robert Tseng.

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