Security against Sybil Attack in Wireless Sensor Network through Location Verification

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Abstract. A new functional for planar triangulation called Inner Core has been proposed in [4] for a location verification based defense against Sybil attack for sensor network, and also has been shown that the legitimacy of a new node inside the Inner Core of a triangle obtained by the triangulation of the set of sensor nodes can be established. In [4] it has been conjectured that Inner Core of a triangulation of a set of planar points achieves its maximum for Delaunay triangulation. In this paper, we present a formal proof of the conjecture. In order for the protocol proposed in [4] to work, what is required is an empty triangle formed out of three existing sensor nodes in whose Inner Core new node claims its presence. We present here an algorithm to find out such an empty triangle, so that it can be used for checking the legitimacy of the new node.

1 Introduction

Sensor networks are now being widely deployed in planned or ad hoc basis to monitor and protect different targeted infrastructures including life-critical applications such as wildlife monitoring, military target tracking, home security monitoring and scientific exploration in hazardous environments. The criticality of a large subset of applications triggers the need for providing adequate security support for them. Unlike in general data networks, the nodes of sensor networks may be physically captured by an adversary and thus can induce different modes of harmful attacks in addition to active and passive eavesdropping.

Douceur first introduced the notion of Sybil attack [2] in sensor networks, where a single entity illegitimately presents multiple identities. Physically captured nodes claiming superfluous misbehaving identities could control a substantial fraction of the system leading to malfunction of basic operational protocols including routing, resource allocation and misbehavior detection. Newsome et al. in [3] have pointed out that location verification can be a valid defense mechanism against Sybil attack. Following that line, a new functional for planar triangulation called Inner Core has been proposed in [4]. Also it has been shown that the legitimacy of a new node inside the Inner Core of a triangle can obtained by triangulation of the set of sensor nodes. But no algorithm has been provided to find out such a triangulation, where there is a triangle inside whose inner core the new node is present. It has also been conjectured in [4] that the functional Inner Core of a triangulation of a set of planar points achieves its maximum if and only if the triangulation is Delaunay triangulation [1].

This paper presents an extension of the work presented in [4]. We present here a formal proof of the conjecture. We also have carried out simulation on several set of randomly scattered points and have found that Inner Cores of all the triangles obtained by Delaunay triangulation covers on an average 30-50% area of the convex hull of the planar points. Again, a new node's legitimacy cannot be checked if it is not inside the Inner Core of a triangle. So this reduces the applicability of the protocol proposed in [4] for defending Sybil attack. The protocol in [4] can work seamlessly if an empty triangle can be found out in whose inner core the query point lies. A triangle formed by three sensor nodes is called empty if it does not contain any other sensor nodes except the new one. Through simulation we have found that Inner Core of all the empty triangles covers on an average 75-95% area of the convex hull of the planar points and thereby increasing the applicability of the protocol.

2 Inner Core and Its maximality for Delaunay Triangulation

The definition of Inner Core of a triangle as given in [4] is as follows.

Definition 1 ***Inner Core of a triangle*** *(Figure 1) T with A, B and C as vertices is defined as,*

$$IC(T) = Disk(V_A, l_A) \cap Disk(V_B, l_B) \cap Disk(V_C, l_C) \cap T,$$

where $l_A = min$ *{Length of the sides of the triangle T incident on* V_A*}, and* $Disk(V_A, l_A)$ *is the circular region with* V_A *as its center and* l_A *as its radius.*

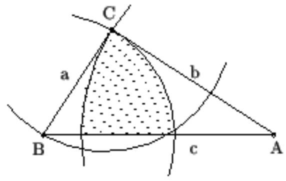

Fig. 1. Inner Core of Triangle T

Definition 2 ***Inner Core of triangulation*** *Δ of a set $S \subset R^2$ of planar points is defined as the union of the Inner Cores of its constituent triangles, i.e.,*

$$IC(\Delta) = \bigcup_{T \in \Delta} IC(T).$$

For a set S of planar points, the set $\mathcal{F}$ of all triangulations becomes exponential in size with the number of planar points. So, a natural and obvious question is to find out the triangulation for which Inner Core gets maximized, i.e., to find out $\Delta \in \mathcal{F}$ for which the area of $ConvH(S) - IC(\Delta)$ is minimized, where $ConvH(S)$ denotes the convex hull of the set of planar points S.

Delaunay triangulation D of a set of points $S \subset R^2$ forming a regular triangular lattice coincides with the lattice itself and hence $ConvH(S) - IC(D) = \phi$ and thus maximizes Inner Core. From this observation it was conjectured in [4] that Inner Core is maximized for Delaunay triangulation among all the triangulations. Here we present a formal proof for the conjecture.

Let us first compute the area of the IC of the triangle $T = (\triangle ABC)$. Without loss of generality we assume that $\angle A \leq \angle B \leq \angle C$.

$IC(T) = \frac{1}{2}$ [The common area of intersection between two circles (one with radius $= a$ and another with radius $= b$), where the centers of the circles are distance c ($\geq a, b$) apart]

$$= \int_{\frac{a^2-b^2+c^2}{2c}}^{a} \sqrt{a^2 - b^2}\ dx$$

$$= \frac{\pi a^2}{4} - \{(\tfrac{a^2-b^2+c^2}{4c})(\tfrac{\sqrt{(a+c+b)(a+c-b)(b+c-a)(b-c+a)}}{2c}) + \tfrac{a^2}{2} sin^{-1}(cosB)\}$$

$$\frac{IC(T)}{Area(T)} = \frac{\frac{\pi a^2}{4} - \{(\frac{a^2-b^2+c^2}{4c})(\frac{4\triangle}{2c}) + \frac{a^2}{2} sin^{-1}(cosB)\}}{\triangle}$$

$$\texttt{where, } Area(T) = \frac{1}{4}\sqrt{(a+b+c)(b+c-a)(a+c-b)(a+b-c)}$$

$$\frac{IC(T)}{Area(T)} = \frac{sinA}{sin(A+B)}[\frac{B}{sinB} - cosB]$$

It can be easily proved that for any B in $[0, \frac{\pi}{2}]$, $\frac{IC(T)}{Area(T)}$ increases monotonically with the increasing values of A (where $A \in [0, \frac{\pi}{3}]$). So we have now proved the following lemma:

Lemma 1. $\frac{IC(T)}{Area(T)}$ of a triangle increases monotonically with the increase in the minimum angle of a triangle.

In the process of obtaining the Delaunay triangulation we start with any triangulation and then successively replaces the illegal diagonals with the legal diagonals. In a quadrilateral, if we replace an illegal diagonal with a legal diagonal then that increases the minimum angle of the corresponding triangles, and hence following the lemma $\frac{IC(T)}{Area(T)}$ increases for the triangles. Hence we obtain the following result:

Theorem 1 *The functional $IC(\Delta)$ of a set of planar points S achieves its maximum if and only if Δ is the Delaunay triangulation of S.*

3 Modification of Location Verification Based Security Protocol [4]

In [4], it has been suggested to work with Delaunay triangulation if the triangulation in whose Inner Core the new node is located cannot be found out. In the Delaunay triangulation, the triangle inside which the new node is placed is found out, and it is checked whether the new node is present inside the Inner Core of the triangle. If it is inside the Inner Core of the triangle then the agent can check the legitimacy of the new node, otherwise legitimacy of the new node cannot be checked. We simulated random sensor network in a 400×400 plane to find out what percentage of area of the convex hull formed by the sensor nodes is covered by the Inner Cores of all the triangles obtained by Delaunay triangulation of the node points. The simulation result has been presented in Figure 2. It is evident from Figure 2 that Inner Core of Delaunay triangulation covers 30-50% of the area of the convex hull. It implies that in more than 50% cases the agent has to communicate with the setup server to check the legitimacy of the new node, which is not desired.

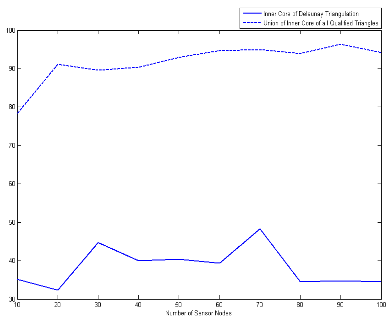

Fig. 2. Percentage area of Convex Hull covered by Inner Core of the Delaunay triangulation of the Convex Hull and union of Inner Core of all possible qualified triangles formed by any three sensor nodes for different number of nodes

To make the protocol applicable for any randomly deployed sensor network, we modify the protocol proposed in [4] as follows. Previously, agent is required to start the protocol by finding a triangulation of the set of planar points S

such that the new node is inside the Inner Core of a triangle. In absence of the knowledge of such a triangle, the agent works with Delaunay triangulation as it maximizes the area of the convex hull covered by inner core of the triangles.

The modified version of the protocol arises from the observation that we require an empty triangle for the central portion of the protocol to be workable. But, we start by finding Delaunay triangulation of the set of nodes, for it ensures maximum coverage of the convex hull of the set of nodes by Inner Core and also each triangle in it is empty. This is obviously a step towards limiting our search for an empty triangle in whose Inner Core the query point is located. The problem thus can be solved if the agent can find out an empty triangle formed out of the existing nodes, inside whose Inner Core the new node is placed.We call such a triangle a *qualified triangle*. Now instead of finding a triangulation, we directly seek for a qualified triangle. We simulated random sensor network in a 400×400 plane to find out what percentage of area of the convex hull formed by the sensor nodes is covered by the Inner Cores of all the possible triangles formed by any three sensor node points. Simulation result shows that Inner Core of all the qualified triangles covers on an average 75-95% area of the convex hull of the planar points and thereby increasing the applicability of the protocol(Figure 2).

4 Algorithm to Find out a Qualified Triangle

We present here an algorithm to find out a qualified triangle and it is the task of the agent to run this algorithm. The algorithm takes a set of points S and another point p (the point corresponding to the new node), which is inside the convex hull of the set of points S. The algorithm returns a qualified triangle, if such triangle exists, otherwise it reports that no such triangle exists.

There may be at most nC^3 triangles formed by n nodes. The objective of this algorithm is to get rid of searching these $O(n^3)$ number of triangles. The agent starts the algorithm by triangulating the set of points representing N sensor nodes based on Delaunay's triangulation. Finding out Delaunay triangulation of a planar set of n points can be done in $O(nlogn)$ time [1]. Then the agent finds out the triangle inside which the new node is placed in $O(n)$ time [1]. This step of the algorithm essentially helps find out a triangle inside which the new node is placed in $O(nlogn)$ time. The objective of starting with Delaunay triangulation is to maximize the area of the Inner Core of the triangle with which the search process starts.

After finding the triangle inside which the new node is placed, the agent checks if the triangle is a qualified one. If it is so the algorithm terminates reporting the triangle to the agent. Otherwise the search process to find out a qualified triangle continues in breadth first manner. Let us illustrate the algorithm through an example. The example has been shown in Figure 3. Suppose the new node is inside triangle (1, 2, 3). The agent finds out whether the new node lies in the Inner Core of this triangle. If the node does not lie in the Inner Core then consider the triangles formed with sides (1,2) (2,3) (3,1). For side (1, 2) the following triangles are obtained: (1,2,7), (1,2,6), (1,2,4) and (1, 2, 5). The

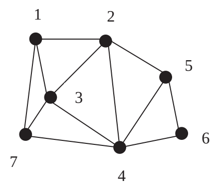

Fig. 3. An example of a network

agent verifies the appropriate triangles in the same procedure as done for triangle (1, 2, 3). The process is continued until all the triangles are covered before concluding that there is no qualified triangle. The algorithm stops at any time if agent finds a qualified triangle.

For every triangle the agent checks if the new node is inside the triangle and the triangle has not been already considered. To prevent repeated search two Boolean arrays are maintained. One of them keeps track of the triangles searched, and the other keeps track of the sides explored. Both of them are initialized to false for every element. When a triangle or a side is explored the corresponding entry in the array is set to true. The algorithm terminates when all the entries of the triangle array become true, or a qualified triangle is found.

5 Conclusion

In a sensor network, Inner Core based security against Sybil attack is possible if the new node is inside the Inner Core of an empty triangle formed by the existing sensor nodes. Given a set of points on a plane how to find out such a triangle efficiently was an open question. Though Delaunay triangulation maximizes the sum of the areas of the Inner Cores of the triangles, it cannot cover more than half of the area of the convex hull of the set of randomly generated planar points. Here we suggest to work with an empty triangle in whose Inner Core the query point lies, and that indeed enhances the applicability of the protocol.

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