Simulation of Signal Strength Based Hyperbolic Localization to Achieve Rogue Attribution

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1. Introduction

1.1 Context/Background

In the last few decades wireless technology has been used preformed an increasing number of tasks; from the advent of cell phones, to the Wi-Fi connections we use everyday. Wireless technology has evolved quickly, requiring the security for that technology to also evolve to meet the ever changing requirements of its users. This makes security in wireless environments an area of increasing importance.

The standard for Wireless Access in Vehicular Environments (WAVE) [1] defines a way in which vehicles can communicate across a network. These mobile communications need to be secured in order to protect not only the information they contain, but also the identity and location of the transmitter. Location tracking has been deemed a critical threat to vehicular networks due to the use of digital signatures in unencrypted messages [2]. Using the digital signature, a person is able to track others over time and space due to the beacon packets that they send.

One measure suggested to protect against location tracking is Secure Anonymous Broadcasting (SAB) [3]. Using SAB, a certificate authority is the only one who can attribute a certificate to the logical identity of a vehicle. This way all vehicles remain anonymous to one another. This presents a problem for certificate revocation of a rogue insider. A rogue insider may have falsified their certificate, so revocation of that certificate is pointless because they may assume a different identity and continue their attack. Since we cannot trust any information gathered from the rogue insider itself, we must gather some reliable information that they have limited control over. One thing that we can use is the received signal strength (RSS) from each of the receivers. Using an estimated Effective Isotropic Radiated Power (EIRP) range for the transmitter, based on the RSS of the receivers, an estimate of the range of distance differences between receiver pairs and the transmitter is formed. Using this estimated range, we construct minimum and maximum hyperbola pairs between receivers in order to create a bounded area where the transmitter is located to some degree of probability. This process of using hyperbolas to bound an area based on RSS values is called Received Signal Strength Based Location Estimation [4]. (RSS/LE)

1.2 Definition of the problem

RSS/LE can be simulated in a static environment. Although static environment simulations are useful for ensuring that the location estimation model works properly, they are inefficient for a large number of test scenarios because each scenario must be tested one at a time. A dynamic simulation creates the opportunity to test many scenarios without having to reset the simulation values for each instance. The problem addressed in this project is the creation of a simulation that demonstrates relative signal strength based location estimation visually through the use of hyperbola pairs.

1.3 Summary of the Results

Using the description of RSS/LE a 3D simulation was created with the Ogre 3D graphics engine. The simulation demonstrates a mobile transmitter and four stationary receivers who emulate Rappaport's log normal shadowing model [5] for values at 5.85 GHz [6]. It also demonstrates the motion of the hyperbola pairs as the receivers' RSS values change with the movement of the transmitter. The hyperbola motion can be viewed from many different camera positions, creating a more detailed view of the simulation.

1.4 Overview of the Report

The background information about the construction of minimum and maximum hyperbola pairs is in Section 2. The results of the project are presented in Section 3. A discussion of the results and an evaluation of the simulation are presented in Section 4. Finally, the conclusion and future work are presented in Section 5.

2. Detailed Background & Setup

2.1 Hyperbolic Localization

In order to give an estimation of the location of a transmitter, a bound based on the received signal strength of each receiver pair must be created. Each receiver produces a set of minimum and maximum hyperbolas, where the minimum hyperbolas are the minimum bounds of the distance difference between itself and the other receivers, and the maximum hyperbolas are the maximum bounds of the distance difference between itself and the other receivers. The hyperbolas are defined by the following formula.

$$\sqrt{(x-a)^2+(y-b)^2}-\sqrt{(x-c)^2+(y-d)^2}=e$$

Where receiver 1 is at point (a, b) and receiver 2 is at point (c, d), and e is the minimum distance difference, or the maximum distance difference, for the minimum and maximum hyperbolas respectively.

After receiver pairs have drawn their respective hyperbola pairs, the area between the minimum and maximum hyperbolas contains the transmitter with a degree of probability. When the minimum hyperbolas of all receivers are viewed together, they form a bounded area which also contains the transmitter with a degree of probability, calculated by combining each hyperbola pair probability. This probability grows with more receivers able to create hyperbola pairs to localize the transmitter. Thus the goal of hyperbolic localization is to use hyperbola pairs generated by a sufficient number of receivers to create a highly probably location estimate of the transmitter.

3. Result

In order to plot the bounding hyperbolas on a Cartesian plane, we must solve the hyperbola equation for either x or y. The equation solved for y is the following formula.

$$
\begin{aligned}
y = {}& (4b^3 - 4db^2 + 4a^2b - 4c^2b - 4d^2b - 8axb + 8cxb - 4e^2b + 4d^3 - 4a^2d + 4c^2d + 8adx - 8cdx \pm \\
& \sqrt{((-4b^3 + 4db^2 - 4a^2b + 4c^2b + 4d^2b + 8axb - 8cxb + 4e^2b - 4d^3 + 4a^2d - 4c^2d - 8adx + 8cdx + 4de^2)^2 -} \\
& \overline{4(4b^2 - 8db + 4d^2 - 4e^2)(a^4 - 4xa^3 + 2b^2a^2 - 2c^2a^2 - 2d^2a^2 + 4x^2a^2 + 4cxa^2 - 2e^2a^2 - 8cx^2a - 4b^2xa +} \\
& \overline{4c^2xa + 4d^2xa + 4e^2xa + b^4 + c^4 + d^4 - 2b^2c^2 - 2b^2d^2 + 2c^2d^2 + 4c^2x^2 - 4e^2x^2 - 4c^3x - 4cd^2x + 4b^2cx +} \\
& \overline{4ec^2x + e^4 - 2b^2e^2 - 2c^2e^2 - 2d^2e^2))} - 4de^2)/(2(4b^2 - 8db + 4d^2 - 4e^2))
\end{aligned}
$$

Using this formula we choose values for x and plot both the positive and negative y values obtained. Once this is completed for all receivers we have minimum and maximum bound hyperbolas that form a boundary which, to some degree of probability, contains the transmitter.

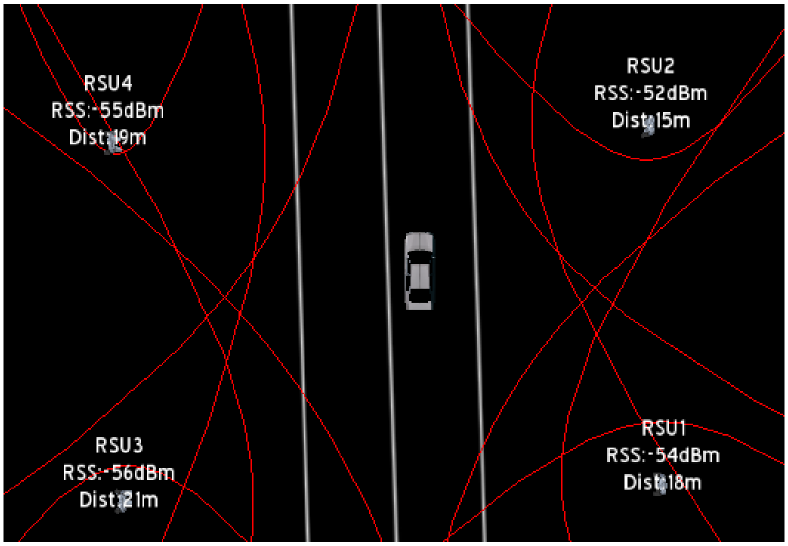

Figure 1. Vehicle in the center of four receivers.

By counting the number of hyperbola pairs the transmitter is contained in at various positions, areas of location estimation accuracy can be found. This is because the location estimation accuracy is measured by the probability that the vehicle is within the hyperbola pairs. The greater number of hyperbola pairs that we are in, the higher the accuracy of the location estimate.

4. Evaluation of the Result

The quality of the result is measured by comparing the simulation results to the static model RSS/LE results. The first comparison is between the drawing and shape of the hyperbolas themselves, it can be seen that the dynamic simulation hyperbolas pairs draw properly given a transmitter position. For instance Figure 4 in the RSS/LE paper [4] and Figure 1 above show the same hyperbola pattern given a transmitter in the center of four receivers. This gives a good indication that the hyperbola equation solved for y gives us correct values.

The second comparison is between the areas of location estimation accuracy. The simulation shows the number of hyperbolas that the transmitter is bounded by at a location, using this we can make a grid of test locations, and compare the results to the probability areas generated in the RSS/LE paper.

3	4	5	6	6	6	6	6	5	4	3
4	5	6	7	8	8	8	7	6	5	4
5	6	7(R)	10	9	10	9	10	7(R)	6	5
6	7	10	10	12	12	12	10	10	7	6
6	8	9	12	12	12	12	12	9	8	6
6	8	10	12	12	12	12	12	10	8	6
6	8	9	12	12	12	12	12	9	8	6
6	7	10	10	12	12	12	10	10	7	6
5	6	7(R)	10	9	10	9	10	7(R)	6	5
4	5	6	7	8	8	8	7	6	5	4
3	4	5	6	6	6	6	6	5	4	3

Table 1. Test locations bounded by the denoted number of hyperbola pairs.
(R) represents the receiver location.

This can be represented graphically as follows.

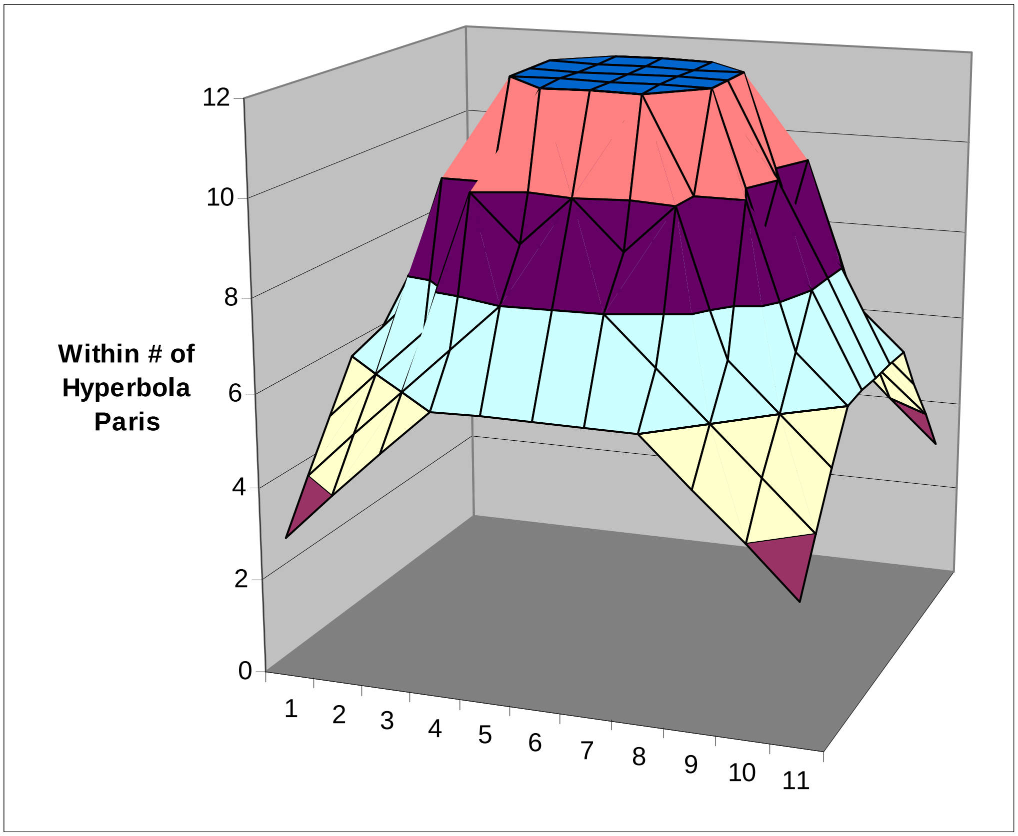

Figure 2. 3D graph of test location results.

When these test location results are compared to results obtained in the RSS/LE paper, it can be seen that both give the best estimate when the transmitter is in the center of the receivers. The worst estimate is when the transmitter is directly behind one of the receivers. The other trends in the data are also consistent with data from the RSS/LE paper.

These comparisons show that the simulation produces very similar results to the work done using static simulation. This is an indicator that the dynamic simulation accurately demonstrates RSS/LE.

5. Conclusion & Future Work

5.1 Conclusion

Using a dynamic 3D simulation to test the RSS/LE model, we are able to evaluate many situations to better understand when the model it works well, and when it doesn't. This graphical tool is useful for providing evidence for the strength of the RSS/LE model. The model itself works well in simulation and relates itself very well to use in vehicular networks. This is because the best estimates for location are between pairs of receivers, and this is the case if receivers are placed along the roadsides. The RSS/LE model provides us with a strong method for rogue attribution by locating the rogue in the real world, so that action can be taken to stop them. The simulation of many scenarios provides information about the models accuracy. Using this information to guide the placement of receivers, we can improve the location estimate and thus improve our ability to find and punish rogue insiders. Locating and revoking these rogues from the network promotes security and integrity.

5.2 Future Work

GUI

- Enable/disable signal based location estimation.
- Enable/disable anomalous position report detection.
- Change frequency and all frequency associated values.
- Camera controls
- Help menu

Signal Based Location Estimation

- Add signal shadowing as a smooth normal random variable.
- Dynamically calculate probable EIRP range.

SAB

- Distinguish between public safety OBUs and normal OBUs.
- Simulate certificate distribution.

Simulator

- Collision detection.
- City landscape model.
- Replace robot models by antenna models (Use free modeling software Blender http://www.blender.org/, with mesh importer http://www.ogre3d.org/wiki/index.php/Tools:_Blender)
- Find/Create different vehicle models.

AI

- Create multiple AI vehicles traveling on the road.
- Calculate signal based location estimation hyperbolas separately as a less reliable boundary.

Appendix: Current Simulation Controls

Button	**Action**
Up or W	Forwards
Down or S	Backwards
Left or A	Turn Left
Right or D	Turn Right
F1	3rd Person Chase Camera
F2	3rd Person Fixed Camera
F3	First Person
F4	3rd Person Top (Mini view becomes 3rd Person Chase Camera)
1	Anomalous position report detection model 1
2	Anomalous position report detection model 2
3	Anomalous position report detection model 3
4	Turn off Anomalous position report detection
5	Toggle Hyperbola labels
+	Increase AI speed
-	Decrease AI speed

References

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[3] C. Laurendeau and M. Barbeau, “Secure Anonymous Broadcasting in Vehicular Networks”, First IEEE LCN Workshop on User Mobility and Vehicular Networks (ON-MOVE), Dublin, Ireland, 2007.

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[6] G. Durgin, T. S.Rappaport and H. Xu, “Measurements and Models for Radio Path Loss and Penetration Loss In and Around Homes and Trees at 5.85 GHz”, IEEE Transactions on Communications, 1998.