UNCERTAINTY IN TRILATERATION

Is RSSI-based Range Estimation Accurate Enough for Animal Tracking?

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Abstract: Animal tracking is important to farmers. It is mainly performed using GPS receivers. Equipping only some of the animals with GPS receivers and have the others use them as beacons for RSSI-based trilateration could be beneficial. This article tests whether such a solution is possible from an uncertainty point of view. First a range of RSSI measurements were performed. These measurements were used to create a formula for RSSI as a function of distance. The RSSI standard deviation measured in the tests gave an indication of the error, or uncertainty, related to using RSSI to calculate distance. The distance function and standard deviation were then used as a basis for simulations that calculated the uncertainty of RSSI-based range estimation. The simulations showed that the localization error related to distance estimation by RSSI was too high for it to be an efficient solution, even with a device twice as accurate as the test device.

1 INTRODUCTION

Animal tracking is a concept which has been of scientific and commercial interest for a long time. Different studies have for instance tried to figure out where birds stay during the winter and how far a pack of wolves roam. New technologies, such as GPS and satellites, have revolutionized animal tracking.

Livestock tracking is of great interest to agriculture. By using new technology it is possible for a farmer to keep track of his livestock without leaving the office. Livestock tracking has proven to be especially effective in sheep farming. Sheep farmers traditionally send their animals to graze in the mountains during the summer. In autumn they then need to recover their sheep. This is a tedious and time consuming process. It is not easy to search for the sheep in large mountainous areas without roads. The fact that the sheep tend to walk in small flocks rather than one large group does not help either. Thanks to commercial solutions such as Telespor, built on the Electronic Shepherd research project (Thorstensen et al., 2004) , sheep farmers can now remotely track their sheep.

These systems typically rely on GPS for localization. There are a couple of weaknesses with this approach. First GPS consumes a lot of energy. This means that one either have to reduce update frequency or equip the nodes with big batteries that can last an entire season. Secondly, GPS satellites produce a weak signal. Therefore it can be hard to locate sheep in dense forests and other areas with a relatively low GPS signal strength.

An alternative way to locate sheep or other animals could alleviate these problems. Since there are several sheep in a flock, it could be possible to use RSSI (Received Signal Strength Indicator) to measure the range between sheep. Some of the sheep would find their position using GPS. The others could find their own position by trilateration using the range measurements from the GPS sheep.

The main topic of this paper is whether such a method gives an acceptable uncertainty, or localization error, or if RSSI simply is unsuitable as a range measurement tool in this context. Acceptable uncertainty means it should be possible to retrieve the sheep in a reasonable amount of time.

The paper is organized as follows: Chapter 2 presents related work. Chapter 3 gives an overview of trilateration and uncertainty. Chapter 4 contains the results of both our RSSI and range measurements as well as our simulation results. Chapter 5 concludes the paper.

2 RELATED WORK

RSSI and localization in wireless sensor networks have been the topic of many research projects, such

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as: (Awad et al., 2007); (Sichitiu et al., 2003); (Barsocchi et al., 2009); (Paul and Wan, 2009) and (Hyo-Sung and Wonpil, 2009). Many of these algorithms focus on indoor localization (Awad et al., 2007); (Barsocchi et al., 2009); (Paul and Wan, 2009) and (Hyo-Sung and Wonpil, 2009), even if RSSI is not particularly suitable for indoor range estimation due to walls and other obstacles that affects the signal propagation (Akyildiz et al., 2002). In a room it can be effective however, and also a good alternative since GPS is not available. In (Awad et al., 2007) they used a neural network to estimate the distances based on RSSI. This worked well, however the distances in their experiment were below 5 m, making it inapplicable to animal tracking. They used an exponential function to predict distance from RSSI. Using regression, they found it to be a suitable function.

In (Sichitiu et al., 2003) the researchers performed RSSI measurements using IEEE 802.11b network cards. These measurements show a good correlation between RSSI and distance. The measurements were performed at relatively short distances, the longest being 40 meters. This makes the topology and terrain less of a factor. They also simulated the accuracy of their RSSI-based localization algorithm. They were able to get a low uncertainty. The main problem with applying their simulation to long range applications is that their ± 25 m RSSI accuracy is too optimistic. The experiments in this paper show that ±100 m is closer to the truth.

Researchers have also tried using RSSI to locate cattle in grazing fields. In (Huircán et al., 2010) they were able to locate animals by having a high beacon density, with only 80 m between beacons. This makes their solution expensive for animals that reside in a large area. To cover an area of 5000 x 5000 m, which is not unusual for sheep grazing in the mountains, would require approximately 3900 beacons.

3 TRILATERATION AND UNCERTAINTY

Trilateration is a well-known method for localization. A good introduction to the topic can be found in (Yang and Liu, 2010). To be able to unambiguously locate an object in two dimensions using trilateration, the following information is necessary:

1. The position of at least three other objects.
2. The distances between the object being located and each of the other objects.

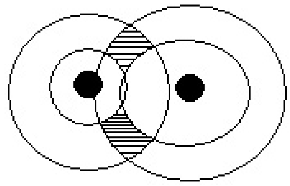

Figure 1: Trilateration with two beacons. The object could be located in both shaded areas.

If these are known, one can solve a set of equations to find out the position of the last object. Although the position of three other objects is enough to locate an object, the accuracy improves with every extra distance and location combination that is known.

Applying RSSI-based trilateration to livestock tracking is not trivial. There are especially two problems that arise from relying on trilateration based on other animals' positions. The first problem is that one needs the position of at least three other animals. This means that at least four animals must be fairly close to each other and three of them must find their positions via different means. To achieve this, the flock must be dense compared to the maximum range of the transceivers used to send messages between the animals. Some of the sheep must also have a different localization method. Localization is possible with fewer than three other known positions, but it will lead to reduced accuracy due to separate uncertainty areas, as illustrated in figure 1.

The second problem is the uncertainty of the final position estimate. The uncertainty comes from two sources, the position of the other objects and the distance to those objects. If the other objects were localized via GPS their position should be fairly certain. GPS receivers typically have an accuracy of 10 meters under normal conditions. The distance uncertainty depends on the accuracy of the distance measurement tool.

RSSI is generally reduced with increasing distance and easy to obtain if both animals carry transceivers. Therefore it is a good candidate as a distance measurement tool. Distance is however not the only thing affecting RSSI. Terrain, obstacles, vegetation, antenna orientation and weather also plays a role. With that in mind the objective of this paper is to determine if RSSI is a suitable tool for livestock tracking. That means to test if it can provide acceptable uncertainty in a realistic terrain.

4 TEST SETUP AND RESULTS

To test whether RSSI can be used as a range estimator for tracking of sheep and other animals, several RSSI measurements were performed. The results from these measurements were then used in a set of simulations designed to test the accuracy of RSSI-based trilateration.

4.1 RSSI Measurements

The RSSI measurements were performed outdoors in varying environments similar to those where sheep typically graze. Hills, forests and flat open ground, were all present in the areas where the measurements were carried out. The radio equipment used in the tests was Waspmotes, wireless sensor network motes from Libelium. They are equipped with an 868 MHz XBee transceiver connected to an antenna capable of transmitting a 315 mW signal. During the tests they were never able to transmit a signal over more than 2 km. The average achieved range during testing was 505 m with a standard deviation of 170 m. The RSSI measurements were carried out separately from the range tests.

Table 1: RSSI measurements.

Distance	Avg. RSSI	Std. Dev.	# tests
50	71.4	6.8	25
100	89.7	11.0	25
200	100.3	8.5	25
300	104.8	9.1	20
400	97.6	1.8	5
500	115.0	1.4	5
600	124.0	1.4	2

The RSSI tests were performed in the following manner: A beacon node was first setup. This beacon node would reply to any request received from the mobile node carried by the person performing the test. The tester could then read the RSSI at the mobile node. For each test location, 5 RSSI readings would be done at a distance of approximately 50 m. The tester would then perform 5 readings at 100 m, 200 m, 300 m and so forth, until no signal was received. Table 1 summarizes the results of these measurements. The RSSI in the Waspmote range from 61 db, when the antennas are placed next to each other, to 130 db, when there is almost no signal. As predicted, table 1 shows significant variations in the RSSI at equal distances due to geographical differences. The small variation at the three longest distances is due to the fact that there was only one of the five beacon placements that were able to transmit a signal that far.

4.2 Simulation Setup

The simulations ran in a Java simulator written specifically for these tests. The simulator would first uniformly distribute the sheep flock over an area of 5 x 5 km. This size was chosen because it represents a typical grazing area for a flock of sheep. The simulator equipped all the sheep with transceivers that had the same range (505 m) and standard deviation (170 m) measured during the range tests. Some of the sheep would also be equipped with GPS receivers. These receivers have an accuracy radius of 10 m in the simulations. All of the animals knew which sheep were within their radio range, and the exact position of those sheep. The sheep without GPS receivers calculated the uncertainty of their own position estimate based on the position of sheep with GPS within radio range. This uncertainty was calculated in the following manner: For each neighbor with GPS, the known distance to that neighbor would be used to calculate a minimum and maximum RSSI value. The function used for converting distance to minimum (-) and maximum (+) RSSI was:

$$RSSI\,(dist) = 9.431 + 17.2 * ln(dist) \pm 2\sigma \qquad (1)$$

where $\sigma = 6.7823$ when dist < 100 m
and $\sigma = 9.5448$ otherwise.

This function was based on the results from the RSSI measurements. With increasing distance there was more variation, therefore a higher standard deviation was used for distances over 100 m. These two values would then be translated to a minimum and maximum distance representing the uncertainty of the distance estimate using an inverse function:

$$dist(RSSI) = 5.211 * e^{(0.03592*RSSI)} \qquad (2)$$

The uncertainty area corresponding to each GPS neighbor is therefore doughnut shaped. The total uncertainty area is decreased with every additional GPS neighbor. Every simulation scenario was repeated 100 times and the results are an average of the values in those runs.

Table 2: Average uncertainty area among non-GPS nodes [m^2].

GPS %	50 sheep	100 sheep	150 sheep	200 sheep	250 sheep
20	1889539	1714458	1555184	1376825	1260480
40	1726486	1390939	1119644	879674	701482
60	1530232	1104071	773226	563953	421873
80	1382559	904196	584406	409051	285684

4.3 Simulation Results

Two metrics have been chosen as the main success criteria, average uncertainty area and average extremity distance. The uncertainty area is defined as the area a node can be in given it knows the location and an approximate distance to a set of other nodes. A smaller uncertainty area means less area has to be searched and the animals can therefore be retrieved faster. The second criterion is the extremity distance. It is defined as the length of the longest straight line possible to draw within a bounding box surrounding the uncertainty area. This metric is important since one of the main purposes of animal tracking is to be able to find the animal quickly when searching for it in the real world. The problem with just looking at the uncertainty area is that the area can be quite small and still have a large extremity distance. An example of such an area would be a very thin rectangular shape. This would result in a lot of time spent walking from one end of the area to the other. The simulations have been performed with different flock sizes and different GPS/non-GPS ratios (20-80% GPS). The average uncertainty and extremity distance will decrease with a denser flock. Therefore it is interesting to test at which flock size these reach acceptable levels and also if what can be considered normal flock sizes (between 50-250 animals) have an acceptable uncertainty. In the tests the ratio of animals having an acceptable uncertainty and extremity distance were also measured. The limits for these two metrics were set to 40000 m^2 and 300 m, respectively. These limits have been set so that animals within those limits can be found in less than an hour.

Table 3: Average percentage without GPS neighbours.

GPS %	50 sheep	100 sheep	150 sheep	200 sheep	250 sheep
20	72.1	51.7	38.1	27.8	20.5
40	51.4	27.7	14.6	7.7	4.7
60	37.0	15.8	6.8	2.6	1.1
80	28.3	9.2	2.7	1.0	0.5

Table 3 displays the average percentage of non-GPS animals that did not have any GPS neighbors.

Their uncertainty and extremity distances will not be counted towards the averages reported in table 2 and 4. Scenarios that have over 20 % without GPS neighbors are not suitable for RSSI trilateration. The animals are too sparsely deployed in these scenarios.

Table 2 show the average uncertainty area in the different simulation scenarios. It generally improves with more GPS nodes. All scenarios have too much uncertainty, even with 80 % of the nodes having GPS. This is because RSSI as a range estimator is not accurate enough.

Table 4 displays the average extremity distance. The situation here is the same as with the uncertainty area. Even the best scenario has, on average, over twice the extremity distance considered adequate.

Table 5 show the percentage of sheep that got an acceptable uncertainty and an acceptable extremity distance. This increased with a higher beacon density, but even with 200 GPS beacons only 2.2 % of the non-GPS sheep where able to get below the acceptable uncertainty limits.

The RSSI measurements were performed with only one type of wireless device. To test the effect of having more accurate RSSI measurements and consistent antenna range, simulations were run with half the measured standard deviation. The extremity distance of these simulations are shown in table 6. The distances are slightly more than half of those measured in table 4. It is still not a good enough solution, since on average only 59.5 % of the non-GPS nodes have an acceptable uncertainty even when 80 % of 250 sheep are equipped with GPS.

Table 4: Average extremity distance among non-GPS nodes [m].

GPS %	50 sheep	100 sheep	150 sheep	200 sheep	250 sheep
20	2060	1952	1850	1736	1656
40	1959	1745	1558	1389	1244
60	1837	1556	1301	1132	1001
80	1747	1410	1146	980	850

Table 5: Average percentage of non-GPS nodes having an acceptable uncertainty area and extremity distance.

GPS %	50 sheep	100 sheep	150 sheep	200 sheep	250 sheep
20	0.1	0.2	0.4	0.5	0.5
40	0.3	0.4	0.6	0.8	1.1
60	0.3	0.7	1.2	1.1	1.6
80	0.2	0.9	1.3	1.8	2.2

Table 6: Average extremity distance among non-GPS nodes [m] with only half of the measured standard deviance.

GPS %	50 sheep	100 sheep	150 sheep	200 sheep	250 sheep
20	1232	1133	1046	989	918
40	1137	981	845	727	625
60	1076	856	689	560	447
80	934	726	542	422	354

5 CONCLUSIONS

RSSI-based trilateration using GPS beacons is not suitable for animal tracking. The uncertainty is too high, even with RSSI measurements twice as accurate as those obtained during tests. In those tests factors like placement of the node relative to the animal's body, weather conditions and antenna orientation were not considered. These factors could increase the RSSI variability significantly, making it even harder to locate the animals. The variability in RSSI measured in the tests comes from the impact the terrain and other non-distance related factors have on the signal propagation. Topography becomes more important over long distances, making animal tracking a particularly poor application for RSSI-based distance estimation. A system that does not need to rely on RSSI for localization would therefore be preferable. Such a system could make use of the fact that most animals travel in groups. Therefore if one knows the location of a group and the group's members, it is possible to locate all members. The group's location could be established using GPS and the members could be determined by detecting the recipients of a wireless broadcast of a membership message. This approach could save energy and increase robustness compared to a GPS-only approach.

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