Can a multi-hop solution improve GSM coverage for tracking networks?

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Abstract

The areas where sheep graze typically have low GSM coverage. This paper outlines a method for extending that coverage by utilizing a multi-hop network. It is part of an ongoing project in sheep tracking that aims to provide farmers with the location of their sheep. Various sheep grazing scenarios are simulated and results are compared against the current industry-leading solution. For dense flocks the system provides better GSM coverage than the existing solution.

Keywords: Sheep tracking, multi-hop, wireless sensor networks, localization, wireless network coverage.

1 Introduction

Sheep farming is a traditional livestock production that struggles to compete with more industrial productions such as pigs. The low meat prices has lead to small margins for sheep farmers and therefore everything that can help improve those margins is of utmost importance. During the summer and autumn it is common to send the sheep into the mountains to graze on the nutritious grass that can be found there. Much money is wasted because some of the sheep get lost in the mountains.

There are four main reasons for sheep loss: Predators, disease, accidents or simply that the farmer does not find the sheep when retrieving them.

If the location of the sheep were monitored, the number of sheep lost for the last reason would be almost non-existent. It would also be possible to help some of the sheep that die from accidents, particularly the ones where the sheep die because it gets stuck on a ledge or in a hole. Knowing their location would make the job of
locating sheep lost to predators or disease easier as well. It would improve the accuracy of public statistics and compensations, as well as remove the uncertain feeling the farmer gets when his sheep are lost. And most importantly a sheep tracking system would save the farmer a lot of time that he would otherwise have to spend on finding the sheep when retrieving them in autumn.

There is an obvious need for a sheep tracking system, but there are also many challenges related to its design. The main challenges are energy consumption, cost, robust hardware, localization and data retrieval. Low energy consumption is needed since it will be difficult to change the batteries when the sheep are in the mountains. The farmer should not have to change the battery during the season, which typically lasts 3-4 months. Low cost is essential to make it an attractive solution to the low income sheep farmers. A unit should preferably cost no more than $ 250-300. The hardware must at the same time be able to be attached to a sheep for a few months without being destroyed. This involves tolerating adverse weather conditions and the sheep scratching themselves against trees. Finding the location of the sheep is another central issue. A GPS receiver can be used, but it is somewhat expensive, $ 65 per unit for the Waspmote GPS module [18] used in this project, and it does not always have coverage. A GPS unit also consumes a lot of energy and therefore considerably shortens battery life. The final issue is how to return the sheep locations to the farmer. This has proven to be one of the toughest challenges because of poor GSM coverage in the desolate mountains. An illustration of the GSM coverage in a typical sheep grazing area can be found online [5].

The sheep tracking problem can be split into two main parts: locating the sheep and sending the locations of the sheep back to the farmer. To keep costs at a minimum locating the sheep using RSSI trilateration was tested. This proved to be too inaccurate [19] and therefore GPS is used for positioning. To solve the problem of data retrieval in areas with low GSM coverage, a multi-hop data retrieval network was developed. This article focuses on that network and tests the feasibility of a multi-hop solution to the GSM coverage problem.

It is easy to think of other uses than locating sheep for a multi-hop GSM and GPS-based tracking system. It is obviously possible to track other animals as long as their anatomy allows it, i.e. that they are big enough to carry the weight of the equipment. Another use would be as an emergency system for people walking in the mountains. Most people rely only on their mobile phone, regardless of the GSM coverage in the area. There exist commercial emergency satellite devices that can broadcast the transceiver’s position to an external receiver. Using a variant of the sheep tracking system it would also be possible to alert people in the vicinity. This could potentially lead to a much quicker rescue. In general, this study is relevant for all geographical sensor networks where only some of the nodes have
access to a communication resource and the ones that have access can change over time.

The main topic of this paper is the extension of GSM coverage. The paper is organized as follows: Chapter 2 contains related work with a special emphasis on the market leading Telespor system [1]. Chapter 3 contains information on the multi-hop data delivery technique we have used. The benefit of this technique is shown through different simulations in Chapter 4. Chapter 5 concludes the paper and describes where we see this project heading in the future.

2 Related work

There are some related work both in data retrieval and GSM in sensor networks. However the most closely related work is the existing sheep tracking solution from Telespor. Telespor is a commercially available sheep tracking solution based on the Electronic Shepherd research project[1]. In the Telespor system the sheep are equipped with GPS receivers and GSM transceivers. On regular intervals they report their GPS position to a central server directly via the GSM network. That is all there is to it, simple but working. The farmers can see where their sheep are and change network settings such as update frequency via a web interface. Telespor has become popular among sheep farmers in Norway with more than 20 000 sheep fitted with this equipment. A research project [2] has shown that it eases the life of farmers and helps in locating both alive and dead sheep. However a lot of the farmers involved in that project reported problems in areas with poor GSM coverage. Sometimes it could go weeks between successive updates from a sheep, as it was outside the GSM coverage area. Another issue that was mentioned was the cost of the system (approximately 300$ per node), therefore keeping costs at a minimum is an important success criteria for such solutions. The current cost of the system requires farmers to receive subsidies to afford installing it on entire flocks. Our system has one very important difference when compared with Telespor. The nodes are equipped with long range transceivers which makes node to node communication possible. This is what enables multi-hop data retrieval and therefore makes it possible to retrieve data from sheep that are outside the GSM coverage area.

Data retrieval in locations without a GSM network has been studied before [3, 7, 8-11]. In Zebranet [3] the researchers were trying to track zebras in Kenya. They equipped the zebras with GPS collars. The collars would store the locations of the zebra. When two zebras met they would exchange location data. This way if the researcher found one zebra they could collect data from several zebras. This is different from our sheep tracking application since we need the ability to remotely track the sheep. In our application it is assumed that there is some GSM coverage in the area. Therefore we chose to use a multi-hop scheme instead. We have
however implemented a function where the farmer can collect data from nearby sheep if he walks around with a transceiver node. This is a useful function to find sheep that are far from GSM coverage and to get fresh data when retrieving the sheep. Koala is a data retrieval system for applications with long sleep intervals [7]. Koala does not require synchronized nodes since it use a system with preamble packets instead. We have not implemented a similar system since synchronization is easy in our system via GPS or by setting the clocks before deploying the motes.

Many sensor network projects rely on GSM/GPRS for data transfer [12-16]. This is not without challenges. In [12] they experienced many short disconnections from the GSM network. Some were due to hardware issues, while others were caused by bad weather conditions. We also experienced how bad weather influenced the range of our equipment. To have complete coverage in foggy condition requires a much denser network. SensorScope [14] use a GPRS-enabled gateway node to transfer glacier data. In that project all the nodes were assumed to be stationary, making it easy to place the gateway where it has weather proof GSM coverage. The other nodes can also be placed so that they have a route to the sink. This approach is not applicable to a scenario with moving sheep carrying the nodes. Tambling et. al [17] tried to locate lion kill sites using GPS-collars with GSM transceivers on female lions. If the lion stayed in one place for more than an hour they would investigate the site to see if they could find a carcass. They felt they could have located more sites if they always had access to fresh data, but this was not possible due to the low GSM coverage in the area. If they had used a multi-hop scheme for data retrieval this problem could have been reduced.

3 Multi-hop data delivery

Transferring data from the sheep nodes to the Internet-connected central server is not a trivial task since we are talking about remote areas with very little existing infrastructure. It could perhaps be possible to use a satellite modem. The cheapest and most lightweight option however is to use the existing GSM network for data transfer. The only problem is that the mountain areas where the sheep typically are sent for the summer have only partial GSM coverage.

To solve the coverage problem we decided to create a multi-hop data delivery scheme. An overview of the sheep tracking system can be found online [5]. In order for this scheme to work the nodes need to be synchronized, since a sleep-awake duty cycle is used. The synchronization can either be done prior to deploying the sheep network, or while the sheep are in the mountains via accurate GPS clocks. In this project the synchronization was done prior to deployment because of simplicity. The sheep are in the mountains approximately 100 days. During this period the Waspmote’s internal clock should have no more than ±30
seconds drift [18]. Our algorithm can tolerate this without any nodes falling out of synch with the rest of the network.

Algorithm 1: Multi-hop data delivery

Figure 1 illustrates the execution cycle of the sheep nodes. We assume all working nodes have been synchronized and therefore enter the data delivery phase at
approximately the same time. The multi-hop scheme then follows algorithm 1. This is a standard flooding algorithm. The nodes relay everything they receive immediately. They store the relayed updates to avoid endless forwarding loops. The algorithm finishes when the send or end timer expires. These timers should be set so that they do not expire before the algorithm has completed the expected maximum number of hops in a network. Each hop takes around 20 seconds on the equipment we used, in addition to the initial $X = 60$ second synchronization delay. Flooding algorithms are not very efficient in terms of energy consumption [6], but they are well suited for networks that have a topology that change frequently. Also sheep tend to walk together in smaller groups and therefore the number of messages received by each sheep will be manageable. Our focus was not to create the most efficient algorithm, but to create a simple algorithm, Algorithm 1, that could be used to test if our ideas of GSM coverage extension would work in a real world deployment. A more energy-efficient algorithm could be created if the sheep knew where the GSM antennas were placed. With this information it would be possible to have only sheep that were closer to a GSM antenna than the source sheep forward positions. The nodes do not remember which sheep had GSM coverage between update intervals. This assumption was made based on an update interval of 24 hours. This is a fair estimate considering battery life, energy consumption and the time the sheep are in the mountains. Using these settings, a Waspmote equipped with a 2300 mAh battery should be able to operate for approximately 180 days. With such a 24 hour update interval the likelihood that the same set of sheep will have GSM coverage is drastically reduced. Therefore it makes no sense for the other sheep to remember them or the network routes to them.

4 Results

We were not able to deploy the finished system on sheep last summer. Therefore we chose to test our principles in a different way. To test if the multi-hop scheme can provide significantly better GSM coverage than the Telespor solution, simulations were performed with both systems. These simulations were based on results we got from range measurements performed with the equipment we have implemented the system on.

4.1 Range Measurements

The effectiveness of the multi-hop scheme relies on the range of the transceivers that send data between the sheep nodes. Therefore it is important to have real-world range measurements to use as a basis for the simulations. The equipment we used to make our range measurements were Waspmotes [18], wireless sensor network motes from Libelium. The main advantage of Waspmote compared to other sensor motes is long range and modularity. They are both important when
implementing a sheep tracking network. The Waspmote supports GPS and GPRS which are vital to our application. Modularity can be used to save costs by only equipping some of the sheep with GPRS modules. The long range is essential to the multi-hop scheme since it would otherwise require a very dense sheep network. The Waspmotes we used were equipped with an 868 MHz XBee transceiver connected to an antenna capable of transmitting a 315 mW signal, well within the European 500 mW legal limit for the 868 MHz band [18]. On their website Libelium claims that the Xbee 868 MHz transceivers have a maximum range of 12 km with the same 4.5 dBi antennas we used and 315 mW transmit power [4]. This result was achieved under ideal conditions with both transceivers placed on mountain tops with a clear view between them. To get more realistic results of the range that could be expected when the equipment was mounted on the sheep, we performed several range measurements. These measurements were performed in areas where the sheep typically stay during the summer months. These areas were not accessible by car and include mountains, forests, hills and plains. The weather during the tests was mostly cloudy. At one point there was dense fog and this reduced the range of the transceivers to less than half their normal range. To make the tests similar they were performed using the same procedure every time. A Garmin 305 GPS watch was used to measure the distances. This watch has an horizontal accuracy of less than 10 meters (50 % of the measurements) under normal conditions [20]. A transceiver was placed on the ground and the person performing the test would then start to walk away from the transceiver. After 500 meters, the first signal test was performed. If a signal was received the tester would walk further away while testing every 100 meters. If the signal was lost, the tester would walk back while testing until there was a signal again. This position would be marked on the GPS and the straight line distance from the starting point would be used as a range estimate. A total of 27 measurements were performed with an average range of 505 meters. The shortest range that was measured was 114 meters, while the longest was 1000 meters. The shortest measurement was in foggy conditions while the longest was over a lake. The complete results of the range measurements are available online [5].

4.2 Simulation setup

A Java-based simulator was created to simulate a flock of sheep in an area with one GSM antenna present. In each simulator run the sheep would be randomly spread in a pre-defined area. A GSM antenna would also be randomly placed in the same area. Some of the sheep would carry GSM transceivers while the others would have to rely on the multi-hop scheme to send back their positions. The nodes that were outside GSM coverage would try to use the multi-hop scheme as well. The XBee and GSM transceivers were both assumed to have a circular range. This is a simplification as factors such as terrain and antenna orientation influence the range of these transceivers. This simplification is possible since these
simulations are intended as a rough test of the benefit of the multi-hop scheme and therefore very accurate simulations are not needed. Each simulation setup would be run 1000 times. To simulate Telespor it is assumed that all sheep are equipped with GSM transceivers and none of them use the multi-hop scheme even if they are outside GSM coverage. The simulation area was fixed at 5000 x 5000 m.

**Table 1: Scenario parameters.**

<table>
<thead>
<tr>
<th>Scenario</th>
<th>GSM range [m]</th>
<th>Number of sheep</th>
<th>Number of sheep with GSM antennas</th>
<th>XBee transceiver range [m]</th>
<th>Number of clusters</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>3000</td>
<td>30</td>
<td>9, 15, 30</td>
<td>400</td>
<td>n/a</td>
</tr>
<tr>
<td>2</td>
<td>3000</td>
<td>150</td>
<td>45, 75, 150</td>
<td>400</td>
<td>n/a</td>
</tr>
<tr>
<td>3</td>
<td>1000</td>
<td>150</td>
<td>45, 75, 150</td>
<td>600</td>
<td>n/a</td>
</tr>
<tr>
<td>4</td>
<td>1000</td>
<td>30</td>
<td>9, 15, 30</td>
<td>600</td>
<td>n/a</td>
</tr>
</tbody>
</table>
| 5        | 1000           | 150             | 45, 75, 150                       | μ = 505 \ 
σ = 174                  | n/a                |
| 6        | 1000           | 150             | 45, 75, 150                       | μ = 505 \ 
σ = 174                  | 5                   |
| 7        | 1000           | 150             | 45, 75, 150                       | μ = 505 \ 
σ = 174                  | 30                  |
| 8        | 1000           | 150             | 45, 75, 150                       | μ = 505 \ 
σ = 174                  | n/a                |

**4.3 Simulation results**

The Telespor system is used as a comparison or baseline in the different scenarios that were simulated. Coverage ratio is used as a measure of success. Coverage ratio is the number of sheep which can report back positions divided by the total number of sheep. It was also important to test if the percentage of sheep with GSM antennas made a big impact on coverage ratio. If a satisfying coverage ratio can be reached with a low percentage of GSM sheep, it is possible to save money by not outfitting every sheep with GSM equipment. 15 different scenarios have been simulated. All scenarios were tested with 30, 50 and 100% of the sheep carrying GSM antennas. In this Chapter, 8 of the most interesting simulation results are covered. These 8 scenarios were chosen based on which we thought were most realistic. The results of the other 7 scenarios we simulated are available online [5].

As the results in Figure 2 show, the multi-hop scheme was not very effective in scenario 1. The main problem is that the small flock is too thinly spread, leading to each sheep being connected to few others.

In scenario 2 the GSM coverage was kept at the same level, therefore Telespor has the same result as in the previous scenario. This is a better scenario for the multi-
hop scheme as it gives a 13 percentage points increase in coverage ratio with a 100 % GSM ratio.

The GSM coverage is reduced in scenario 3. Figure 2 shows the potential of the multi-hop scheme. Telespor has a low coverage ratio of 10.52 % while the multi-hop scheme has a coverage ratio of 92.69 % with only 30 % of the sheep having GSM equipment. It also shows that for the multi-hop scheme having many neighbors is more important than the GSM coverage.

The only change from scenario 3 to 4 is the reduced flock size. This has a devastating effect on the coverage ratio of the multi-hop scheme. A multi-hop scheme is pointless when there are no neighbors to send the data to.

Scenario 5 uses the measured average range of the XBee transceiver. However unlike the other terrain types the range of each sheep’s XBee transceiver is not fixed. Instead the connectivity of each pair of nodes is evaluated as true or false using the following formula:

A pair of nodes a and b is connected if and only if distance(a, b) < x, where x is a random number which follows a Gaussian distribution with the same mean and standard deviation as we measured in our tests.

The result in scenario 5 is quite similar to scenario 3. The reduced range is compensated by the fact that the XBee range varies instead of being fixed. This is beneficial for the multi-hop scheme since with varying range there is always the possibility that one of the sheep hits the “range jackpot” and can therefore act as a connection to a remotely located sheep. In reality this is quite possible, for instance if two sheep have a clear view of each other while the others are on a different side of a hill.

Sheep have a tendency to move in small flocks or clusters. It is therefore interesting to see if placing the sheep in clusters will affect the coverage ratio. To test this, a fixed number of clusters were each given a random position in scenario 6. Each sheep were then randomly placed into one of the clusters. Otherwise the simulations were performed in the same way as scenario 5. Scenario 6 placed the sheep in relatively large clusters by just having 5 clusters which gives an average cluster size of 30 sheep. In this scenario the relatively few clusters caused the distance between each cluster to become too long to benefit much from the multi-hop scheme. Another interesting observation is that changing the percentage of sheep which had GSM antennas made no impact on the coverage ratio. This is because as long as each cluster almost certainly contains one sheep with a GSM antenna, there is no need to add more.
Scenario 7 uses the same parameters as scenario 6, only with 30 clusters. This leads to an improved coverage ratio with the multi-hop scheme and a small difference between equipping 30, 50 and 100% of the sheep with GSM antennas.

Scenario 8 is identical to scenario 5 with the addition of an extra GSM base station randomly placed in the area. As expected the Telespor coverage almost doubled (some overlap between the two stations prevented double coverage), but not much happened with the multi-hop coverage ratio. This is mainly because the coverage was already at such a high level in scenario 5 that there was not much room for improvement.

![Graph of Coverage Ratio](image)

**Figure 2: Coverage ratio for the different scenarios.**

### 5 Conclusion

The multi-hop scheme will never have worse GSM coverage than Telespor. Given the right conditions a multi-hop data delivery scheme solves the problem of sheep tracking in areas with little GSM-coverage. It is important that the sheep flock is dense enough so that the data packets can find their way to the few sheep that are inside the coverage area. If this condition is satisfied the number of sheep carrying GSM antennas only slightly affects the coverage ratio. To increase the coverage ratio for sheep that have strayed from the rest of the flock, it would be possible to set up permanent nodes that provide coverage in areas that would otherwise be without it. This would be efficient if it is just small areas where the sheep are grazing that are without coverage. This could also help to create a bridge to remote areas without GSM coverage.
In future work, the sheep tracking system needs to be tested under real conditions. Considering the simulation results, seeing how the network performs with many nodes in an area with low GSM coverage would be especially interesting. It will also be important to study the effect of placing permanent nodes in the terrain, to see if it is a viable solution. Also our simulations showed that a small change in the simulator can cause a big change in the result. Going from a fixed antenna range to one that is Gaussian distributed lead to a significantly different coverage ratio. Therefore it could be interesting to improve the simulator by developing a more realistic sheep mobility model than a simple random placement. In this model we can take into account things like flock behavior, drop-off point and the presence of water to determine how the sheep will move in the wild. This will lead to more realistic simulation results.

References