Poster Abstract: On the Interaction of Network Characteristics and Collaborative Target Tracking in Sensor Networks

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1. INTRODUCTION

Energy is the single most important resource in sensor networks. In the past researchers have studied the issue of energy efficiency either on a node-level or a communication network level. They have focused on how to make the individual node subsystems such as computation (by using dynamic voltage scheduling) or communication (by dynamic modulation scaling) or sensing (by duty-cycling the sensors) energy efficient. Other researchers have proposed several routing or topology management algorithms to efficiently maintain a connected wireless network. However a sensor network is an entire system in which the node subsystems interact with each other via the multi hop wireless network. As a result energy efficient schemes must consider the sensor network as a system.

System-wide energy efficiency is highly application-specific and as a result designing a sensor network algorithm is also performed under specific application constraints such as latency and accuracy. In this poster we consider one sensor network application, namely collaborative target tracking using acoustic sensors. This algorithm is an application of a traditional signal-processing algorithm on a sensor network.

Acoustic target tracking requires multiple range or angle estimates (line of bearing, LOB) for location estimation. For example at least three range measurements or two LOB measurements are needed for a triangulation or a line intersection algorithm to produce the target location. Moreover individual estimates must be combined (fused) on one node to produce the location estimation. In this poster we call the nodes that estimate a target feature (range or angle) as *trackers* and the node that fuses individual measurements as a *fusion node*.

Since the sensing range of acoustic signals is in the order of hundreds of meters the distance between trackers and between a tracker and a fusion node is large compared to the radio range of the wireless network (in the order of a few tens of meters). Therefore individual tracker measurements must traverse multiple wireless hops to reach a fusion node. Moreover tracking a moving target requires continuous feature estimation and continuous transmission of these features from the trackers to the fusion node. Traditional target tracking disregards this underlying wireless network and focuses on the algorithm performance (tracking accuracy) based on parameters such as the number of trackers. In this poster we study the effect of the wireless network impairments on the performance of target tracking algorithm.

There are two major problems for a target tracking algorithm in the context of sensor networks. First of all traditional target tracking algorithms assume that the three range measurements or the two LOB measurements are taken almost at the same time so that the target has not moved a lot. Maintaining measurement simultaneity in a sensor network is a difficult problem since nodes are coarsely time synchronized because of the large scale of the network.

Secondly measurements may be dropped or delayed. Dropped measurements represent lost information for the algorithm and therefore lost accuracy. Lost measurement retransmissions generally help but they introduce delay and energy overheads. In the context of this work we assume that we don't salvage any lost packets. Additionally delayed measurements change the receive order at the fusion node. In some cases the receive order is essential for a state preserving target tracking algorithm such a Bayesian estimation or a Kalman filter algorithm. In these cases the algorithm maintains a target state (location, velocity acceleration, etc) that carries a timestamp. The time-stamped target state helps the algorithm to estimate the target location better since it represents historical data about the target movement. As a result delayed measurements with an earlier timestamp than the state timestamp must either be dropped or incorporated in the algorithm. In this work we consider the out of order measurements as lost information. Later we see how we deal with this problem.

2. APPROACH

In order to overcome the problem of global time synchronization we use a special kind of a Kalman Filter, the SCAAT (Single Constraint At A Time) Kalman filter [1]. This filter maintains a time-stamped target state (location, velocity and acceleration) and updates the state whenever a single range or LOB measurement is received. In this work we only consider tracker nodes that can estimate the range to the target. The filter can be adapted to consider LOB sensors as well. The SCAAT filter requires a specific number of distinct measurements (N) within a specified time ΔT_K so it is remains stable and the estimation error is bounded. That means that the filter requires a specific minimum input rate $N_K = N/\Delta T_K$.

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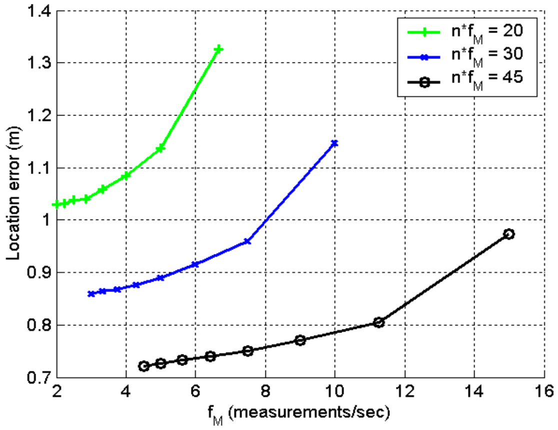

Figure 1. Location error vs f_M for the ideal case

If we assume that n trackers estimate the range with a rate of f_M then the total generation rate of the measurements is $N_G = nf_M$ and it must be greater than N_K at the fusion node. In turn the minimum input rate (N_K) depends on the target dynamics (target velocity, acceleration).

The drawback of using a time-stamped state preserving tracking algorithm is the sensitivity to out of order measurements caused by the jitter in the network. Any out of order measurements will be dropped so the input rate to the filter at the fusion node will not be the same as the generation rate N_G minus the lost measurement rate. We propose to use a de-jitter buffer that buffers the received measurements within a specified time-out. Upon the time-out the buffered measurements are sorted according to their timestamps and passed to the filter for processing. This kind of de-jitter buffer introduces a delay (equal to the time-out) in reporting the target location but results in salvaging a considerable amount of out of order measurements.

For the presented work the trackers can estimate the range to the target with a Gaussian error with zero mean and a standard deviation of 1m. We consider a sensor field 200mx200m where 400 sensor nodes are randomly deployed. For each experiment a number of trackers (n) is randomly selected and the group starts reporting periodically (with a rate of f_M measurements/sec) their range estimate to one fusion node that is in the center of the field. The results show the averages of 1000 runs for each setup. We assume that the trackers estimate the range to the target at different points in time so we don't require global time synchronization. However we assume that the delay of a measurement from a tracker to the fusion node can be accurately estimated using a time synchronization algorithm such as [2]. If the delay of a measurement is correctly estimated then all the measurements can be time-stamped by using the fusion node clock as a reference.

In the poster we first present the ideal case when there is no packet loss or reordering due to the wireless network. We vary the number of trackers and their reporting rate (f_M) so that generation rate is constant. We present the location error plots for three different constant generation rates (Fig. 1). We conclude that we can trade-off the number of trackers for the measurement rate for sustaining a specified location error but we also note that tracker diversity (the number of trackers) contributes more to the location error decrease than the rate f_M. Also when because of practical limitations the tracker nodes cannot estimate a target feature more than f_B measurements/sec then a network designer can find the operating region in the accuracy/n/f_M space for that application.

Next we present some results for more realistic networks where measurements are lost and reordered. We found that the location error (a measure of the accuracy of the algorithm) decreases, as the buffering latency is getting larger and larger which means that the de-jitter buffer salvages the out of order packets. We have seen in some cases that for a specific accuracy (e.g. location error of 1m) we can use 4 trackers with a buffer latency of 40ms (f_M = 15 measurements/sec) instead of 5 trackers with a latency of 15 ms (f_M = 10 measurements/sec). Lower measurement rate will result in lower communication energy and lower number of tracker will result in lower total energy. Here we have assumed that the tracker nodes are always on and their sensing and computational power consumption is almost ten times more than the radio power consumption. In terms of energy we present an energy-accuracy plot (Fig. 2) that shows the consumed communication and total energy for a specific measurement rate and for two buffer latencies (1ms and 60ms). We conclude that with the same energy consumption we can gain more in terms of accuracy by waiting for more time. We also present the plot of a directly measurable quantity at the fusion node (receive rate of in order packets) against the location error. We find that there is an almost linear relationship between those two quantities, which encourages us to propose an adaptive buffering scheme according to the specified level of accuracy.

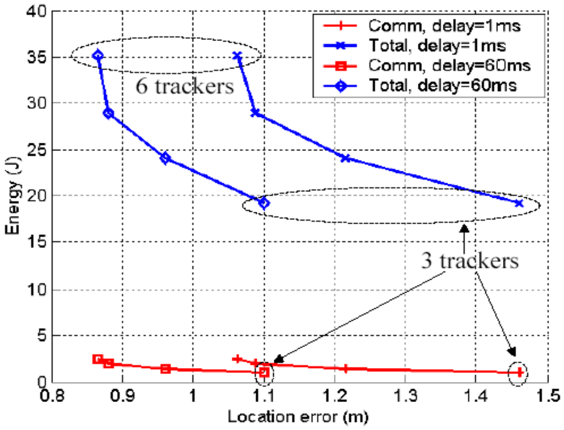

Figure 2. Energy-accuracy plots for different buffer latencies

3. ACKNOWLEDGEMENTS

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4. REFERENCES

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