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Energy-efficient Localization for Virtual Fencing

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1. OVERVIEW

This poster addresses the tradeoff between energy consumption and localization performance in a mobile sensor network application. It focuses on combining GPS location with more energy-efficient location sensors to bound position estimate uncertainty in order to prolong node lifetime. The focus is on an outdoor location monitoring application for tracking cattle using smart collars that contain wireless sensor nodes and GPS modules [1]. We use empirically-derived models to explore duty cycling strategies for maintaining position uncertainty within specified bounds. Specifically we explore the benefits of using short-range radio contact logging alongside GPS as an energy-inexpensive means of lowering uncertainty while the GPS is off. Results show that GPS combined with radio-contact logging is effective in extending node lifetime while meeting application-specific positioning criteria.

2. ENERGY-EFFICIENT LOCALIZATION

The cattle monitoring collars incorporate a Fleck node, a GPS module, and an audio board for generating audio cues to indicate to animals that they are crossing a virtual fence line. The Fleck node itself comprises an Atmel-1281 MCU and NRF905 radio. Four D-Cell batteries in series provide power to all the collar components via several switch-mode regulators.

The active mode power consumption of the GPS board is by far the largest of all components at 165mW, compared to 50mW for the radio and 18mW for the MCU. Figure 2 compares the collar node energy consumption for an always on GPS module (Figure 1(a)) against a

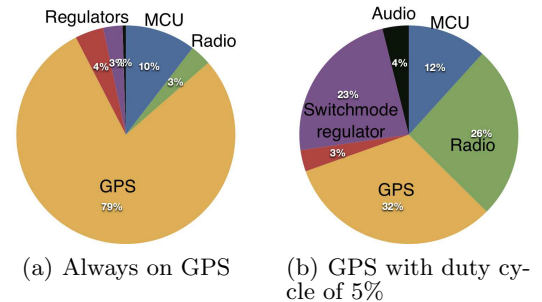


Figure 1: Impact of GPS duty cycling

5% duty cycled GPS module. Both configurations use a 10% radio duty cycle (using low-power listening). The always-on GPS module accounts for 88% of the power consumption of 209 mW and limits the nodes' lifetime to 19 days, while 5% duty cycle GPS accounts for about a third of the overall node power consumption of 25mW, which extends the nodes' lifetime by a factor of 7.5. This confirms the importance of duty cycling the GPS on the mobile nodes. In both scenarios, the MCU remains on only as required to service the GPS or radio, which couples its duty cycle to these components' duty cycles.

2.1 GPS Duty Cycling

While GPS provides the most reliable absolute location estimate outdoors, its high power consumption demands duty cycling in order to achieve the target lifetime.

Whenever the GPS is powered off at time t_k , and until it next acquires lock, the position uncertainty grows progressively according to

$$U(t) = \bar{s}(t - t_k) + U_0, t \geq t_k$$

where \bar{s} is the assumed speed and U_0 is the initial uncertainty. We require U to remain with an absolute acceptable uncertainty (AAU), $U < \text{AAU}$. Because the GPS has a finite lock time, t_L , we need to start the lock process after at most T_{max} seconds, where

$$T_{max} = \frac{\text{AAU} - U_0}{\bar{s}} - t_L \quad (1)$$

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is the GPS off time. The lock time, t_L , has a weak dependence on the length of time that the GPS has been off and on the deployment environment. The assumed speed is a critical parameter that controls the uncertainty/energy tradeoff. Offline analysis of a dataset that contains GPS data from 35 collar nodes collected continuously (once per second) over 2 days indicates an average speed of only 0.4 m/sec, and 95% of the time the cows move at 1m/sec or less, with an absolute maximum of 3.5m/sec. Speed can also be set dynamically according to the latest observed speed for each node.

2.2 Coupling GPS and contact logging

Mobile nodes can use non-GPS relative localization signals to reduce position uncertainty while the GPS module is powered off [2]. In our application, we exploit the fact that the mobile nodes (cows) tend to cluster together making short range RF contact logging feasible. Consider that node A has powered off its GPS and is growing its estimated uncertainty as a function of time. Receiving a beacon from node B implies that node A is within the contact radius R .

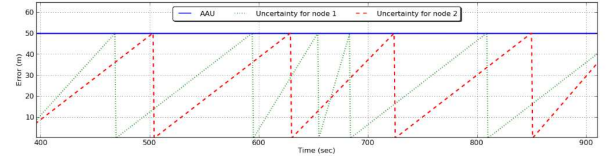
However the beacon could also include node B's last measured position x_k^B and its current uncertainty estimate U^B . If $U^B + R < U^A$ then node B is nearby and has a lower uncertainty than node A. In this case node A lowers its uncertainty estimate to $U^A := U^B + R$

Lowering the estimated uncertainty enables node A to keep its GPS off for longer, which reduces its energy consumption. If a node's estimated uncertainty approaches AAU, it turns its GPS on.

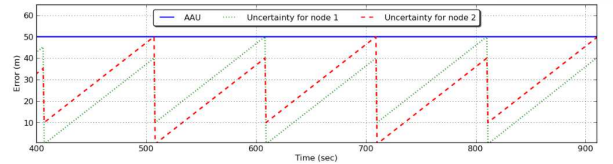
If all nodes run this algorithm, the expensive GPS position fix is shared across the nodes. The fairness of the algorithm stems from the fact that when node A relies on node B for its position estimate, $U^A > U^B$, and if the two nodes use the same assumed speed to grow their uncertainty, then node A will decide to turn on its GPS before node B, which allows B to rely on A for its position estimate in the next cycle.

2.3 Results

To evaluate the impact of our algorithms, we have implemented the duty cycling strategy in a Python-based simulator using the large dataset of actual cow position. Figure 2 illustrates the impact of contact logging on GPS duty cycling for two nodes with dynamically set speeds. Without contact logging, Figure 2(a), each node independently tracks its uncertainty estimate and acquires a GPS position fix whenever its uncertainty approaches AAU of 50m, resulting in 5 fixes for node 1 and 4 fixes for node 2. Using contact logging, the nodes can reduce their GPS fixes to 3 and 2 respectively in the same time window. Figure 3 summarizes the impact of contact radius on GPS duty cycle and er-



(a) Error behaviour for GPS duty cycling



(b) Error behaviour for GPS duty cycling coupled with contact logging

Figure 2: Impact of contact logging on GPS duty cycles

ror rate over the entire dataset. The optimal contact radius is at 10m, with a 25-33% reduction in duty cycle over GPS duty cycling ($R=0$). Extending the contact radius further appears to have a detrimental effect on duty cycle. Contact logging improves the error rate in all cases, particularly the dynamic speed model.

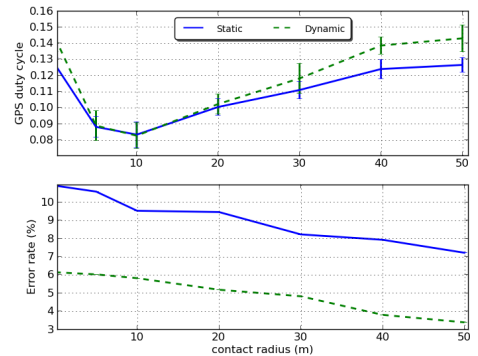


Figure 3: Effect of contact radius

3. CONCLUSION

Coupling GPS duty cycling with short-range radio contact logging can both extend the lifetime and reduce positioning errors in a multi-agent tracking application.

4. REFERENCES

- [1] T. Wark et al. The design and evaluation of a mobile sensor/actuator network for autonomous animal control. In *IPSN '07*, 2007.
- [2] L. Chan et al. Collaborative localization: Enhancing wifi-based position estimation with neighborhood links in clusters. In *Pervasive*, 2006.