Opportunistic Localization: Modeling and Analysis

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Outline

Introduction

Localization is a very useful task in many fields, from environmental monitoring to tracking

The most accurate results are performed relying on distance estimates between nodes (range-based algorithms) $\Rightarrow$ Localization performance strongly depends on ranging technique

Usually good ranging estimates means dedicated and expensive hardware (acoustic devices, high frequency oscillators, ...)

On the contrary the very common and cheap RSSI circuit gives quite poor ranging estimates, especially when distance is high.

Main Idea

In our approach we rely on some assumptions:

- Heterogeneous scenario ⇒ Nodes have different localization accuracy
- Mobility ⇒ Network topology changes frequently and randomly (*opportunistic scenario*)
- Cooperative network ⇒ When nodes meet they cooperate to improve both own and other nodes localization accuracy

We divide and model the problem in two main aspects:

- Meeting model ⇒ How do nodes meet in a mobile and oportunistic scenario?
- Opportunistic enhancement model ⇒ How do nodes exploit the localization information exchanged? How much is the improvement?

Meeting Model - Main Idea - I

We suppose radio interface has a opportunistic phase duty–cycle
$\Rightarrow$ Two nodes have a meeting only if both are in the scan phase

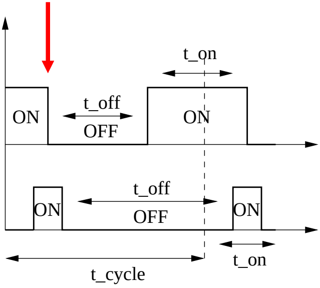

Figure: Opportunistic communication can occur

Distribution of meeting time, given duty–cycle (case $\delta_A + \delta_B \leq 1$)

$$f_{\tau_o}(\tau) = \begin{cases} \delta_A \delta_B & \tau = 0 \\ (\delta_A + \delta_B)/T & 0 < \tau \leq T(1 - \delta_B) \\ 2(T - \tau)/T^2 & T(1 - \delta_B) < \tau \leq T \end{cases}$$

Meeting Model - Main Idea - II

During a meeting, we can consider a node still and the other moving with constant speed and direction

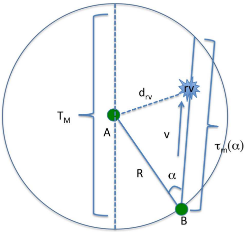

Figure: Meeting model

- τ: time since the beginning of the fly-by event;
- $s(\tau) = v\tau$: distance covered by B at time τ;
- $d(\tau, \alpha) = \sqrt{R^2 + s(\tau)^2 - 2Rs(\tau)\cos(\alpha)}$ Euclidean distance between A and B at time τ;
- $\tau_m(\alpha) = 2R\cos(\alpha)/v$: overall fly-by duration;
- $T_M = 2R/v = \tau_m(0)$: maximum fly-by duration.

Meeting Model - Interesting parameters

Given this model we can obtain:

- Hit probability $\Rightarrow$ Probability that the meeting time occurs in range
- Distribution of hit distance

Hit probability

Distribution of hit probability given α, v and R

$$P_H(\alpha) \quad = F_{\tau_o}(\tau_m(\alpha))$$

For the total hit probability, we average the angle from previous distribution, obtaining

$$P_H = \int_{-\pi/2}^{\pi/2} P_H(\theta) f_\alpha(\theta) d\theta$$

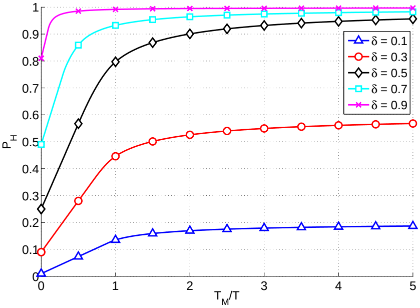

Figure: Hit probability P_H when varying the duty–cycle $\delta_A = \delta_B = \delta$

Distribution of hit distance

Given previous distributions and geometry, we can obtain the hit distance distribution as

$$F_d(x) = \frac{1}{\pi}\int_{-\pi/2}^{\pi/2} F_{t_{rv}}(t_2(x,\alpha)) - F_{t_{rv}}(t_1(x,\alpha))d\alpha$$

where

$$t_{1,2}(x,\theta) = \left(\frac{R\cos(\alpha) \mp \sqrt{x^2 - R^2\sin^2(\alpha)}}{v}\right)$$

$$F_{t_{rv}}(t,\alpha) = \begin{cases} F_{\tau_o}(t,\alpha) & 0 \le t < \tau_m(\alpha) \\ F_{\tau_o}(\tau_m(\alpha),\alpha) & t > \tau_m(\alpha) \end{cases}$$

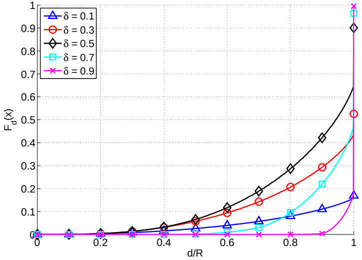

Figure: CDF of the hit-distance d when varying the duty-cycle δ

Opportunistic localization enhancement

We assume that each node can perform self-localization and that the error on the position is a 2D-Gaussian Random Variable with zero mean and a certain variance σ^2, known by the node.

In case of rendezvous the two nodes perform the following steps:

1. exchange packets containing their current position estimate and the theoretical accuracy of such an estimate
2. perform a range estimation (for instance, by using RSSI measures)
3. update their current position estimate by using the Maximum Likelihood algorithm

Maximum Likelihood algorithm

The new position estimation is chosen according to the following equation

$$\begin{aligned}\tilde{\mathbf{s}}_{A,B} &= \arg\max_{\mathbf{s}_A,\mathbf{s}_B} \Pr\left[\hat{d}, \hat{\mathbf{s}}_A, \hat{\mathbf{s}}_B \middle| \mathbf{s}_A, \mathbf{s}_B\right] \\ &= \arg\max_{\mathbf{s}_A,\mathbf{s}_B} \Big\{ f_{\epsilon_A}\left(\|\hat{\mathbf{s}}_A - \mathbf{s}_A\|\right) \cdot \\ &\qquad \cdot f_{\epsilon_B}\left(\|\hat{\mathbf{s}}_B - \mathbf{s}_B\|\right) f_r\left(\hat{d}\|\mathbf{s}_A - \mathbf{s}_B\|\right) \Big\}\end{aligned}$$

Opportunistic Localization Performance - I

To study the impact of the proposed scheme on localization accuracy, we define the *opportunistic gain* metric Δ_i, $i = A, B$[1], as

$$\Delta_i = \frac{\sigma_i \sqrt{\pi/2} - \tilde{\epsilon}}{\sigma_i \sqrt{\pi/2}}$$

where $\tilde{\epsilon}$ is the mean localization error after the opportunistic localization, whereas $\sigma_i \sqrt{\pi/2}$ is the mean localization error of the node obtained by using the native localization scheme.

[1] In the following slides, we will call A the node with a better self-localization system

Opportunistic Localization Performance - II

We evaluate the performance of the opportunistic scheme for different localization accuracies and for different distances between the two nodes, assuming to perform ranging with RSSI

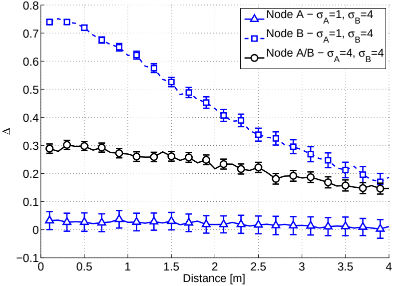

Figure: Relative localization error gain after an opportunistic update varying the hit distance

Results - I

Merging the meeting model and the localization update model we get the opportunistic localization performance in a real scenario.

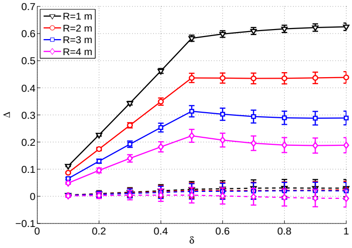

Figure: $\sigma_A = 1$, $\sigma_B = 4$, $\sigma_\psi = 5$

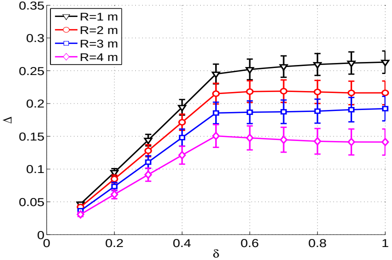

Figure: $\sigma_A = 4$, $\sigma_B = 4$, $\sigma_\psi = 5$

Results - II

- Considering the first scenario, where node A is very accurate, node B can improve his localization up to 20% with $R = 4$ and up to 70% with $R = 1$
- Increasing the duty cycle, performance increases until $\delta = 0.5$, then performance are quite stable, because we consider only the first meeting between nodes and with high duty cycle this occurs far from the node.
- Even if nodes have the same bad accuracy, nonetheless our scheme obtains an improvement up to 15-25%

Conclusion

- Theoretical analysis gives us the possiblity to investigate the impact of some parameters such as duty–cycle, coverage range, cycle–time and speed, on opportunistic localization.
- Improvement on localization estimate is fairly good, even in very hostile scenario
- Coverage range has a great impact on performance due to the dependance on the distance of the accuracy of RSSI ranging

Future Work

- Explore other techniques to manage the opportunistic enhancement, with a less computational effort than ML
- Implement this opportunistic protocol over a real sensor network in our testbed (T-Mote Sky sensor nodes)

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