Assessing the Energy Efficiency of Localization in Wireless Sensor Networks

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Abstract—**We propose an measure to characterize the energy efficiency of algorithms for localization in wireless networks. The measure presented differs from previous approach in that it is bounded and supports objective comparison. Furthermore, it corresponds to the general understanding that a high value should indicate high efficiency. Simulation results for APIT, Centroid Localization and Least Squares Localization estimation are briefly discussed.**

Keywords: wireless, localization, network, energy efficiency

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***Abstract*—We propose a measure to characterize the energy efficiency of algorithms for localization in wireless networks. The measure presented differs from previous approach in that it is bounded and supports objective comparison. Furthermore, it corresponds to the general understanding that a high value should indicate high efficiency. Simulation results for APIT, Centroid Localization and Least Squares Localization estimation are briefly discussed.**

I. Introduction

Sensor networks consist of a large number of electronic devices, called sensor nodes, which are deployed across a geographical area. Each sensor node is capable of sensing environmental parameters, wireless communication and is able to perform simple signal processing. Experimental deployments in the past years have shown that sensor networks can be used in a vast number of applications. The most prominent civil ones are habitat monitoring, environment observation and forecast applications [1][2].

The resource constraint nature of sensor networks make energy-efficiency one of the major design goals [3]. Sensor nodes are usually battery driven. However, breakthroughs in the field of battery capacity are not expected [4]. Consequently, the research community has seen many works on energy-efficient MAC and routing protocols and topology control, for example. Interestingly, not only many of the aforementioned tasks require certain level of spatial awareness, but also an effective interpretation of the sensed data is typically only possible with the knowledge of where the data was sensed. As a consequence, localization of sensor nodes is a central task in sensor networks.

This work proposes a measure to characterize the energy-efficiency of localization algorithms. The measure presented differs from earlier approaches in that it support objective comparison, that it is bounded and is proportional to the general understanding that a high value should denote high energy-efficiency. Furthermore, several well-known approaches to localize nodes in a wireless sensor network are investigated in terms of energy-efficiency. In the following we focus on localization based on Received Signal Strength (RSS) measurements. However, the framework presented is also applicable to other methods of distance estimation.

A. Requirements for a Measure of Energy Efficiency

Also, to enable the absolute comparison of algorithms, the measure has to be upper bounded. Consequently, an algorithm achieving the maximum value of energy efficiency is the most energy efficient of all. This does not neccessarily mean that there is no other algorithm with the same energy efficiency. We refer to this property as *Boundedness*.

To achieve the Boundedness property, the measure needs to be normalized to a general standard. The general standard should consider the varying characteristics of the wireless channel, since all information used to estimate the location will be obtained from or altered by the propagation properties of the wireless communication between sensor nodes.

To support the generell understanding of efficiency, the a high value of the measure should indicate a high efficiency and vice versa. Hence, it should be a monotonically increasing function and strongly related to the abstract definition of efficiency. We refer to this property as *Proportionality*.

II. Related Work

Feng et al. investigate localization based on distances estimated from RSS [5]. They use the *Utility* defined as the ration of energy consumption and decrease of the Cramer-Rao-Bound (CRB) on localization error to characterize the impact of a specific node on the overall energy efficiency. Specifically, an anchor node is more energy efficient the smaller its Utility is. Although Utility is lower bounded and based on the CRB and therefore uses a reliable reference, it lacks objectivity since the energy consumption is not normalized and has unit W/m^2. In addition, the proportionality criterea is not met since low Utility denotes high efficiency.

Reichenbach et al. compare several algorithms for localization in terms of energy-efficiency regarding the *Power-Error-Product* (PEP) [6]. The PEP is the product of location error and energy spend for localization. Therefore, a small PEP denotes high energy efficiency. However, the significance of the PEP is limited since it is not bounded, does not use a fixed reference and is antiproportional to the general understanding of efficiency.

In many other works, efficiency is only used as a term and not defined explicitly. This work aims at contributing an objective mean to characterize the energy efficiency of localization. The distinctive features of the measure are: It is objective since

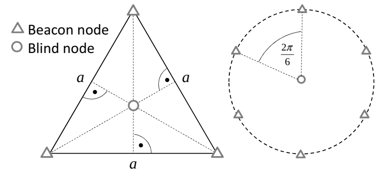

Figure 1. Geometry leading to the smallest CRB.

it is based on the best achievable accuracy (CRB) and the bits transmitted to denote the energy consumption. It is bounded and corresponds to the general understanding that a high value denotes a high efficiency.

III. Energy Efficiency of Localization

In general, efficiency is the ratio between benefit and effort whereby a high value indicates high efficiency and vice versa. In terms of localization in resource constrained sensor networks, the smaller the Mean Square Error (MSE), the larger the benefit and the smaller the energy consumption, the smaller the effort. Consequently, relating the MSE to the energy $\Delta\mathcal{E}_i$ spend to localize a node i should characterize effectively the energy efficiency η_i of an algorithm.

$$\tilde{\eta}_i = \frac{e_i^{-1}}{\Delta\mathcal{E}_i} \tag{1}$$

However, since the MSE and the energy consumption depend on specific hardware and environment, we find it useful to normalize the MSE. The CRB is suituable for this task and can be computed in closed form [7]. However, this requires a lower bound on the CRB which is difficult to derive in the case of RSS because of its dependence on the distance between beacon nodes and blind node. Therefore, we use the average best CRB as a reference. Best indicates that we assume ideal geometry of the blind node and its adjacent beacon nodes, as illustrated in figure 1. Thus, the average best CRB $\overline{CRB^*}$ is given by the expectation

$$\overline{CRB^*} = 2\pi \int_0^{r_{\text{tx}}} CRB^*(r)\, p(CRB(r) = CRB^*) dr \tag{2}$$

Similarly, $\Delta\mathcal{E}_i$ is normalized to the energy $\Delta\mathcal{E}^*$ spend to retrieve the distance information needed for trilateration. It is assumed that nodes always transmit with full power regardless of the true distance to the communication partner. With the normalized MSE $\tilde{e}_i = e_i/\overline{CRB^*}$ and the normalized energy consumption $\tilde{\Delta\mathcal{E}}_i = \Delta\mathcal{E}_i/\Delta\mathcal{E}^*$ of node i, the efficiency can be written as $\breve{\eta}_i = \tilde{e}_i^{-1}/\tilde{\Delta\mathcal{E}}_i$. Taking into account the possible range of $\breve{\eta}_i$, it seems feasible to use the log scale which is often used in communication engineering when a signal should be observed and compared over a large range of values.

$$\eta_i = 10 \log_{10}\left(\frac{\tilde{e}_i^{-1}}{\tilde{\Delta\mathcal{E}}_i}\right) \tag{3}$$

Thus, (3) enables objective comparison of different localization algorithms whereas the upper bound on energy efficiency is connected with the best possible accuracy given by the CRB.

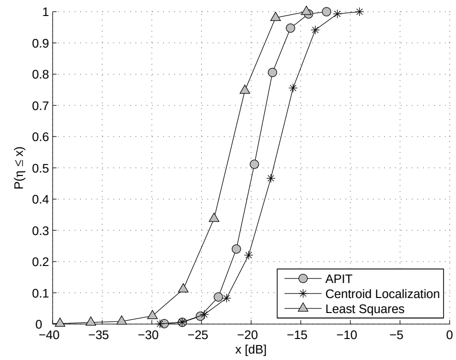

Figure 2. eCDF of $\eta$for some well-known localization algorithms. Spatial decorrelation distance of wireless channel: 20 m, variance of lognormal fading 3.91 dB, pathloss exponent 2.3.

An increase of η_i by 3 dB consitutes doubling the unitless energy efficiency $\breve{\eta}_i$.

IV. Results

We assume a wireless channel with lognormal fading which is a reasonable approximation of the wireless transmission in a static network. In addition, radio signals are attenuated according to free-space-pathloss model. Figure 2 depicts the empirical Cumulative Density Function (eCDF) of η, i.e. the percentage of nodes that have equal or less the energy efficiency as shown on the horizontal axis.

V. Conclusion

We propose an measure of energy efficiency of localization in wireless networks that is bounded and facilitates the comparison of localization algorithms using simulations regarding their energy efficiency.

Acknowledgment

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